Private Provision of a Stochastic Common Property Resource

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2012 AAEA Annual Meeting, Seattle, Washington, August 12-14, 2012.

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I. Introduction

This study addresses the problem of pricing a common property resource when the supply is stochastic and requires collective action to finance a system for delivering the resource to users. It is motivated by the situation water users south of the Sacramento-San Joaquin Delta in central California face with the ultimate demise of the current system for transporting water through the Delta to them. It is widely agreed that part of the solution of the current impasse between environmental water uses and urban and agricultural demands will be some form of isolated conveyance facility such as a tunnel that conveys water under the Sacramento River Delta. The cost of this infrastructure will likely range from $7.5 - $12.5 billion (Sunding 2011). Given the current financial climate in California, it is fair to assume that the majority of funding for such a project will come directly or indirectly from private sources. The public good nature of the shared infrastructure suggests that private entities may find it difficult to finance such an undertaking given the strong incentives to free ride. Further, a public agent would find it difficult recover the cost of such a project by charging average cost per unit delivered because the declining marginal cost of building infrastructure implies some with very low willingness to pay are not able to pay given average cost exceeds willingness to pay.

In California the current water allocation system, and thus the benefits derived from its use, is implemented reactively by a long-standing central agency protocol. The rigid nature of allocations does not necessarily reflect the value placed on the marginal unit of water. Compounding this effect is the uncertain nature of the supply of water from one year to the next. The requirement that any water diverted by the facility must comply with environmental flow

[1] This project was made possible by a grant from the UCDavis Center for Watershed Sciences.

requirements which vary from year to year means that the ability to divert water is stochastic and the reliability of water supplies is directly linked to the planned capacity of the system. To protect themselves from input supply risk, some users with very high willingness to pay for reliable supplies may be willing to pay a premium to ensure a greater reliability in receiving water rather than relying on a fixed administrative procedure. As such there is a potential to exploit the heterogeneity in willingness to pay among users to increase the efficiency in allocating the cost of financing such an infrastructure project. This incentive also coincidently reduces incentives to free ride by those with a high willingness to pay, since they can increase their expected benefits from delivery of the input by increasing the reliability of delivery.

While reliability pricing has been used widely in energy systems, its use in financing large fixed infrastructure investments has not been widespread. The traditional infrastructure approach is to size the system based on engineering criteria, and subsequently attempt to recover the fixed costs by differential charges based on delivery capacity. However, the public good nature of soliciting contributions to cover the cost of infrastructure investment invariably creates a free-rider problem. One way to reduce free riding as noted above is through reliability pricing while another may be to have the size of the project be determined endogenously. If the size of the infrastructure were determined by the sum of the contributions rather than by engineering criteria, then the incentive to free ride might be reduced. It is likely to depend on how the reduction is determined. If those with contributions below costs are excluded then free riding is expected to decline since this risk of deriving no benefits creates an incentive for subjects with low willingness to pay values (i.e., those below the cost of building the project) to offer at least that much. If, however, the size is reduced but the relative share of the scarce input is not changed then then it is likely that the free-riding will increase since now everyone is given an incentive to undervalue their willingness to pay since very low contributions still return positive earnings. If everyone perceives everyone else is undervaluing their contribution the incentive grows stronger and we can expect the greatest free riding when sizing is done this way.

We use laboratory experiments to evaluate the performance of reliability pricing in soliciting contributions to finance the provision of a stochastic input with and without endogenous sizing to test for both price formation efficiency and reduction in free riding relative to historical allocation of the input. Real-world data are not available to conduct such analysis, nor would it necessarily be preferred if it were, given the difficulty of controlling for confounding factors when assessing treatment effects. Additionally, individuals may not fully understand the nature of the game or how to succeed in playing, making their decisions may appear less than optimal. They may also select a criteria other than profit maximizing given the complexity of the decision making required that they select a less than optimal contribution. As such, outcomes derived in theory need not apply in practice. These experiments provide a setting for us to evaluate the productivity of these mechanisms that could not otherwise be tested with data collected from a real world experiemnt.

In the experiment we use a 2 x 2 within-group experimental design to isolate the effects of reliability pricing and self-sizing while controlling for idiosyncratic differences among subjects (Camerer 2003, Levin 1999). The potential for subjects to know little about the computer game they play in the laboratory leads us to test for order effects given some subjects may take time to learn how to play the decision based computer game. The within-group design involves sessions where subjects play two separate decision games - each a different treatment. We reverse the order to allow all treatments to be run first and second.[2]We also use iterative

[2] Later in the paper we refer to data from Part 1 and Part 2 to mean data gathered when a treatment is run first or second, respectively.

periods within sequential rounds to allow subjects to learn about others' behavior and how to play to game. This method allows us to discern if observed differences among treatments arise because of confusion, learning, or the treatment itself. If order effects matter we would expect different outcomes between part 1 and part 2. If subjects learn slowly then we expect to see order effects with Part 2 effects providing meaningful results. The analysis conducted on the experimental data suggests strong order effects with those from Part 2 of a session illustrating clear treatment effects. Table 1 lists the treatments evaluated in the experiment. We repeat each game multiple times within a session to allow subjects time to learn how to play. The setting is similar to a threshold public good game with proportionate rebates for contributions in excess of the cost threshold. To capture the reliability pricing in this setting we adopt a ranking mechanism which we divide into three reliability rate classes – high, medium, and low. The ranking allows those at the top to receive their input (e.g., water) at a higher rate of reliability than those further down.

Past laboratory experiments have shown that a repeated play of the game can reduce free riding (Pecorino 1999). Some suggest, however, this is a result of conditional cooperation (i.e., when subjects contributions do not necessarily reflect willingness to pay but rather are an attempt to help others in their group (Matani and Flores 2009, among others)). In the problem that motivates this research, the stakeholders are familiar with one another and for some time. Any sense of community or rivalry is surely to affect attempts to collectively act. We also expect that any solicitation would take several periods to allow participants to tacitly negotiation across contributions to maximum overall welfare. We capture this interaction by adopting an iterative updating approach, which creates a repeated type game within a single period since each time subjects are updated about the elicitation they are in a sense starting a new game. We do not attempt to examine the effect of the iterative game relative to alternatives here.

Table 1. Treatments.

	Historically-Determined Allocation (H)	Reliability Pricing Allocation (R)
Fixed Project Size (F)	FH	FR
Endogenous Project Size (E)	EH	ER

The experiment is calibrating using data for the water supply problem in California. Four water users are characterized in the experiment – two urban centers, high-valued agriculture, and low-valued agriculture. The number of units they are entitled to differ as does the valuation on these units. The cost function over the feasible range of sizes exhibits decreasing marginal cost.[3]

To our knowledge this is the first study to consider a problem of supplying a common property resource when the supply is stochastic and requires collective action to finance a system for delivering the resource to users. This research also contributes to the literature by considering a reliability pricing mechanism for coordinating delivery among stakeholders in tandem with a threshold public good elicitation mechanism to improve the efficiency of project provision and the likelihood reduction in free-riding. In this effort we also extend the literature on endogenous group size within a public good setting. The limited literature on endogenous group size has primarily looked at alternative exit and entry rules within a public good setting (Ahn, Isaac, and Salmon 2008, 2009). We instead examine how an endogenous group size may improve the efficiency of providing a public good under alternative distributions mechanisms for the stochastically supplied good.

[3] This is a plausible assumption given the cost function for infrastructure projects often exhibit diminishing marginal cost. However, future research could focus on alternative cost functions.

Analysis includes a comparison of treatment for measures of size, price-formation efficiency, and free riding. We use graphical analysis to illustrate the data. The Wilcoxon matched-pairs signed-ranks test to determine if treatment means are derived from different distributions given the data from one period to the next are neither independent nor likely to be normal distributed. We also take advantage of the panel nature of the data and, in line with past experimental economic research, estimate a treatment model using the asymptotic convergence technique. We then evaluate the treatment effects in pairwise comparisons.

Results from a preliminary analysis of the data show that a solicitation using reliability pricing and self-sizing outperforms other designs in reducing free riding through improved price formation efficiency. Reliability pricing results in more projects and projects closer to the optimal sized project relative to historical deliveries. In addition, a self-sizing historical allocation mechanism that has the lowest probability of no delivery results in the greatest free riding as expected.

The next section of this paper provides a review of the related literature on elicitation mechanisms, priority rights, and endogenous group size. This is followed by a description of the experimental design. Next, we present the results from the analysis. These results provide a cursory illustration of the individual outcomes from the experiment. We note measures of individual demand revelation, we determine efficiency, and report distributional effects across treatments. This section also reports the results from a rigorous econometric analysis of the unique panel data generated from the experiment. Lastly, we concluded with some insights from the analysis and suggestions for future research.

II. Related Literature

Elicitation mechanisms have been used to raise resources to fund restoration efforts, support public radio, political campaigns, and a host of other collective actions. These mechanisms used for generating private funds to build, construct, and support the provision of a public good have been studied extensively in the literature as well. Bagnoli and McKee (1991) provide one of the earliest laboratory experiments that focus specifically on the private provision of a threshold public good when a provisional point mechanism is used. They find strong support for the theoretical results found in Bagnoli and Lipman (1989), in which an efficient equilibrium is shown to exist when the elicitation occurs simultaneously and a full refund is offered when the provisional point is not reached and rebates when exceeded.

At the same time Erev and Rapoport (1990) show sequential bidding is more efficient than simultaneous bidding when there are no refunds. Sequential contributions, when earlier contributions are made public, have been used for such actions as fund drives and political campaign financing. More recently, Coats, Gronberg, and Grosskopf (2009) compare sequential and simultaneous contributions with and without a refund rule. They find sequential contribution mechanisms provide the public good more often and more efficiently than a simultaneous mechanism. We might expect elicitations for a large infrastructure project would not be done in a single simultaneous elicitation but rather be of sufficient length to generate resources to finance the construct of a project. In our experiment we consider an iterative contribution mechanism that incorporates a sequential feature where individual contributions are made at any time throughout an elicitation of sufficient length. We do this to replicate the situation in California where we might expect an elicitation to build a conveyance facility will not be done overnight but occur over a longer period of time so all affected parties may be able to participate and a project is undertaken if it is Pareto-improving. We leave for future research the problem of comparing an elicitation with a sequential contribution feature and one with sequential and updating features.

Other research on elicitation related to our study is the work on rebate rules. Marks and Croson (1998) first investigate differences in contributions across alternative rebate rules. Cadsby and Maynes (1999) follow with an analysis of rebates that allowed subjects to contribute any portion of their entitlement toward the provision of the public good. Spence at el. (2009) found experimentally that the proportional rebate rule achieves aggregate and individual demand revelation. We adopt a simple proportional rebate rule in our experiment. If contributions exceed total cost, then those who contribute receive a rebate proportionate to their share of total contributions. More details on the rebate rule are provided in the experimental design section.

Furthermore, the elicitation proposed in our study provides complete information on total contributions. The treatments where subjects can select reliability rate classes requires additional information about the last contribution in each class as it establishes the contribution value needed to enter that reliability rate class. We do not expect this information will affect our results given Marks and Croson (1999) found that information has little effect on the ability of a provisional point mechanism to reveal demand in the aggregate.

Priority Rights and Reliability Pricing

The supply problem that motivates this research is similar to other public good problems when congestion restricts the ability of users to efficiently allocate limited space, capacity, or resources. Examples include cruising for parking spots and roadway traffic, railways, airport terminals, national parks, among others. Many of the solutions sought for these problems involve market-based mechanisms that allow the price to dictate the scarcity of the resource. Vickery (1971) proposed a responsive price to capture the greater scarcity in the available resource. The problem the water situation presents does not allow such real-time price changes proposed by Vickery since financing is done in advance of any deliveries. Nonetheless, users may be able to prioritize delivery in advance so those who derive greater benefits may be able to receive their entitlement prior to another user. If a shortage does occur those with less reliable delivery go without.

Priority auctions have been considered elsewhere when congestion has limited use of common infrastructure. Brewer and Plott (1996) and Nilsson (1999), for example, consider the use of priority rights for allocating congestible track capacity. Brewer and Plott (1996) show a proof of concept when evaluating the ability of a decentralized market to allocate this congested resource. Nilsson (1999) considers a second price auction rather than the first price Vickery auction used in Brewer and Plott (1996) and found it too provides highly efficient allocation of scarce railways. Cook and Plott (2006) consider a similar mechanism for allocating congestion in canal locks to inland waterways. These locks have limit capacity and when too many boats seek passage some method is necessary to allocate the limited capacity. The priority rights allow individuals to move up or down a queue through mutually-beneficial trade. In these settings the use of priority rights provides greater efficiency over centrally-planned allocation of shortages. We exploit this concept when designing a reliability pricing mechanism so that those with delivery in the highest rate class receive their input first as if they are at the front of a queue. Those with delivery in the next highest rate class receive their input next, and so on. As suggested by this prior research, we can expect this type of pricing to provide greater price formation efficiency.

Endogenous Size

Research on endogenous project size in threshold public good problems has received sparse attention even though the size of the project is a crucial part of the initial planning and decision process and is likely to affect contributions as well. We investigate if allowing users to self-size the project results in greater efficiency, given the greater flexibility that an endogenous size offers. In all but a few studies, the size of the project is fixed. Among those exceptions, Ahn, Isaac, and Salmon (2008, 2009) test alternative entry and exit rules when group size is endogenous.

Also related, Pecorino (1999) uses a repeated game to measure the effect of group size on the provision of a public good and found that group size does not necessary reduce the ability of the group to provide the public good. This suggests a small number of users will not hinder the ability of the elicitation to generate sufficient contributions to provide for the public good. Pecorino and Temini (2009) consider group size as well but again only relative to other group size and does not allow the elicitation to determine an optimal size. When the public good is not divisible it follows that the group size is not easily determined through an elicitation and only affects contributions given a group size. When the resource is divisible, however, an elicitation where contributions are made based on a delivery queue (i.e., reliability pricing) and the size of the project is determined endogenously is possible. We test such a mechanism below.

III. Experimental Design

Students were recruited from introductory economics course at California State University Sacramento to serve as subjects in the experiment. Experimental sessions were conducted using the software program z-Tree (Fischbacher 2007). Each session lasted approximately one hour and all students were paid cash at the conclusion of the experiment corresponding to their earnings in the experiment and a set fee for showing up on time. No student was permitted to participate in more than one session. Each session consisted of two parts to allow for the within group design. The order of the treatments was reversed in subsequent sessions to control for any order effects (Mitani and Flores 2009). A total of 40 two-part sessions were held. Table 2 shows the number of groups for each treatment by its order in a session. Equal number of groups were scheduled but were not run because some subjects who signed up to participate did not show up and thus the number of concurrent groups was reduced accordingly.

Table 2. Groups within each treatment by parts

	EH	FH	ER	FR
Part 1	8	9	15	8
Part 2	9	9	7	15
Total	17	18	22	23

Each part was divided into 4 rounds with 3 contribution and reporting periods in each round. The first two periods of a round were non-binding and allowed subjects insight into how to play the game and the group's collective behavior. The last period in each round was binding, determining the status of the delivery system and how the benefits and costs were distributed. The 4 rounds in each part provided subjects additional opportunity to learn how to play the game and the group's behavior. Each period was 30 seconds long followed by a 30 second reporting period, during which subjects were informed on their decisions and the group outcomes.

At the beginning of a session subjects were told they shared the use of a generic good with three other individuals in the laboratory. Each subject was randomly assigned to a group and the identity of the other members of their group was not revealed. They were informed no delivery system currently existed to deliver their good to them. They were then asked to finance the construction of a delivery system that would deliver the good to their group, allowing them to receive benefits from the use of their share of the good. They were told they could make any non-negative contribution but if they wanted to contribute zero they needed to enter that amount so the computer would recognize that value as their contribution.[4] Subj ects were informed of their benefits but not the benefits for others while the cost of the delivery system was known to everyone. Subjects were made aware that the benefits they received from the use of the good differed from others' in their group. Subjects were randomly assigned to play as one of four types within their group. Table 3 shows the four different types and the corresponding water user.

Table 3. Subject Type and Water User Description

Type	Description
1	High-valued Agriculture
2	Low-valued Agriculture
3	Medium-sized Urban Center
4	Large-sized Urban Center

Fixed Size, Historical Allocation Treatment

In the fixed size historical allocation treatment each subject was given a single value for the benefit they would receive from using a generic input if the delivery system were built. This value was based on a long run, annual average projection of benefits over 100 years following the construction of a delivery system. This simplification in benefits was necessary to avoid excessive time required to train subjects on probabilities of outcomes and discounting as well as the added confusion this would most likely infuse into the experimental setting. Nonetheless,

[4] This instruction indirectly informed everyone that is was possible for anyone in their group to receive their benefits even if they contributed nothing to finance the delivery system.

such a simplification is not likely to change how subjects respond given some rule is necessary for decisions to be made today given the uncertainty of future outcomes. Long run averaging is one such rule. Additionally, the cost of building and maintaining the delivery system were presented on an annual basis as well in which the costs are annualized using the capital recovery method with a discount rate of 5 percent.

In the fixed size treatment subjects were asked to contribute a single amount toward financing the delivery system. If the contributions from all four members of a group exceed the cost then the system was built for that group and each member of the group received their benefits from using the generic input. If contributions exceed cost, then those who contribute receive a proportionate rebate. After each period they were informed whether the system would be built or not, their benefits if it is built, their contribution, their rebate, and their earnings for that period. We expect contributions in this treatment to be at or below the cost of building the project given the rebate rule discourages anyone from contributing more since the rebate ensure less than a dollar return on overinvestment as long as one other contributor exists. Those with willingness to pay below the cost of the infrastructure project (i.e., the agricultural users) may offer to pay more than their willingness to pay but only because the rebate rule provides them some assurance that they can make positive earnings..

Endogenous Size, Historical Allocation Treatment

In the endogenous size historical allocation treatment subjects were given 13 different benefits values each corresponding to 13 different-sized delivery system. A 13 unit system was deemed large enough to delivery everyone their maximum share of the good and thus they would receive the same benefits as seen in the fixed size historical allocation treatment when a 13 unit system was built. They were also given the cost of building delivery systems of different sizes. Each subject was again asked to contribute a single amount. They were told that if total contributions equaled or exceeded the cost of a 13 unit delivery system then a 13 unit system would be built and any excess contributions returned to the contributors as a rebate proportionate to the relative contribution. If total contributions were less than the cost of building a 13 unit system, then a 12 unit system would be considered, and so on. The size of the delivery system selected is the largest possible system for which total contributions equaled or exceeded total cost. Benefits were reduced proportionately (by 1/13th) as the size of the system decreased. As in the fixed size treatment, when total contributions exceeded total cost for the endogenously-selected size, then a proportionate rebate was made to each contributor. Again, we would not expect contributions to exceed the cost of the facility. Additionally, this treatment is expected to have the greatest degree of free-riding given subjects are assured benefits regardless of their contribution as long as a delivery system is built. This is similar to the participation game studied by Heijnen (2009) who found that the probability of a breakdown (i.e., when everyone contributes nothing) is non-negligible in such a setting.

Fixed Size Reliability Pricing Treatment

In this treatment subjects were again asked to contribute toward financing a delivery system of an exogenously-determined size (i.e., 13 units large). However, now they were given different endowments based on historical entitlements, and asked to make a contribution for each of their units. Table 4 shows the endowment of units each subject received. For each unit they were given a declining benefit value based on where in the ranking of contributions their units reside similar to the benefits as shown in Table 5. Also notice in Table 5 that each additional unit in a class receives lesser value since we assume diminishing marginal benefit from the delivery of the generic input. If the contribution is one of the top four it is in the top class and receives the maximum possible benefit for that unit. The fifth and sixth ranked contributions were in Class 2, and the remaining contributions were located in Class 3. Subjects did not know *a priori* which class their units would be located given the class depended on where in the ranking each unit was located. Once everyone in a group made its contributions, the computer would rank the contributions and apportion ex post.

Table 4. Endowment of Units by Type

Type	Units
1	3
2	5
3	2
4	3

Table 5. Representative Benefit Table

Unit	Class 1	Class 2	Class 3
1	10440	7830	5220
2	6120	4590	3060
3	1800	1350	900

Subjects were also informed during the reporting periods what the lowest contribution was in each class. This, presumably, would allow subject to evaluate whether to increase their contribution for a particular unit and thus increase the chances that their unit moves up to a more reliable rate class or lower their contributions while hoping to remain in a rate class such that their earnings increase. The presence of reliability pricing leads us to expect to see contributions in excess of the cost of the project since there is likely a premium associated with receiving delivery with greater reliability.

Endogenous Size Reliability Pricing Treatment

This treatment is identical to the fixed-size reliability pricing treatment except the size of the delivery system is determined endogenously. The size, however, is determined in a different manner than in the endogenous-size historical allocation treatment. In this treatment, the size is based on the total contributions as before but now when the contributions do not exceed the cost the lowest ranked contributions, and thus units, are removed from the system until the remaining contributions are enough to cover the cost of a smaller delivery system. In other words, if the total contributions do not exceed the cost of building a 13 unit system, then the lowest ranked contribution is discarded and a 12 unit system is considered. If the remaining 12 contributions do not cover the cost of a 12 unit delivery system then the lowest contribution among the remaining 12 is discarded and an 11 unit system is considered, and so on. If a contribution is discarded, then the unit associated with that contribution is not delivered and no benefits are received for that unit. As before, if contributions exceed the cost of building the endogenously determined size delivery system, then a rebate is shared proportionately by those who have delivered units and who made contributions.

This treatment is expected to have the lowest degree of free-riding given subjects with high willingness to pay are given an incentive to contribute more to increase the probability of receiving the greatest value for their contribution and also provides an incentive for those with a low willingness to pay to contribute more than they would otherwise to increase the probability that their units are included in the delivery system such that they receive some, instead of none, of their benefits.

IV. Data Analysis

Data from the experiments were analyzed to determine if differences arose across treatment with respect to free riding, price-formation efficiency, and the success of the solicitation to finance a delivery system, and in the case of the endogenous sized delivery system one that meets theoretical predictions. Fortunately, data on contributions relative to willingness to pay allows us to look at both free-riding and price formation efficiency simultaneously. To examine size we cannot directly compare fixed sized treatments against endogenous sized treatments but can look at each separately to see if reliability pricing brings about greater success in achieving an optimal outcome.

Data on subjects were collected at the end of the experiment using a survey questionnaire. In Figures 1 and 2 we show survey results with respect to subjects' year in school and their distribution across the colleges of the university. The majority of the subjects were in their first or second year of college and many reported a major other than economics, reflecting the diverse population in the general education courses where subjects were recruited. The average number of economics course the subjects took was 1.44, and just under half of the subjects were female. A comparison of these statistics across sessions revealed no systematic differences across the sessions. Where we found meaningful differences was with their understanding of the game they were playing. The majority of the subjects believed they understood it by Part 2. This observation suggests that when we draw conclusions about the experimental result we are likely to see an order effect. Fortunately, the lack of other differences across subjects across sessions suggests that the results using data from Part 2 treatments are likely to be more meaningful when deriving inferences about the treatments. For this reason we focus the following discussion on the result using data from Part 2.

Figure 1. Histogram of Subjects by Class

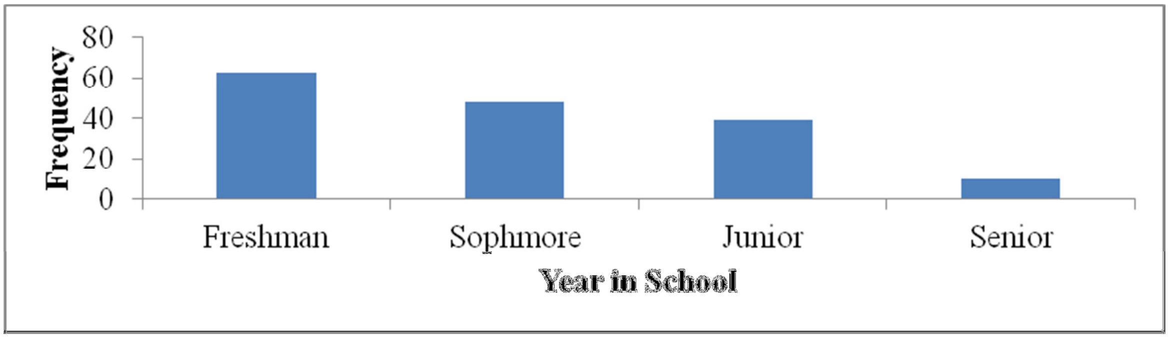
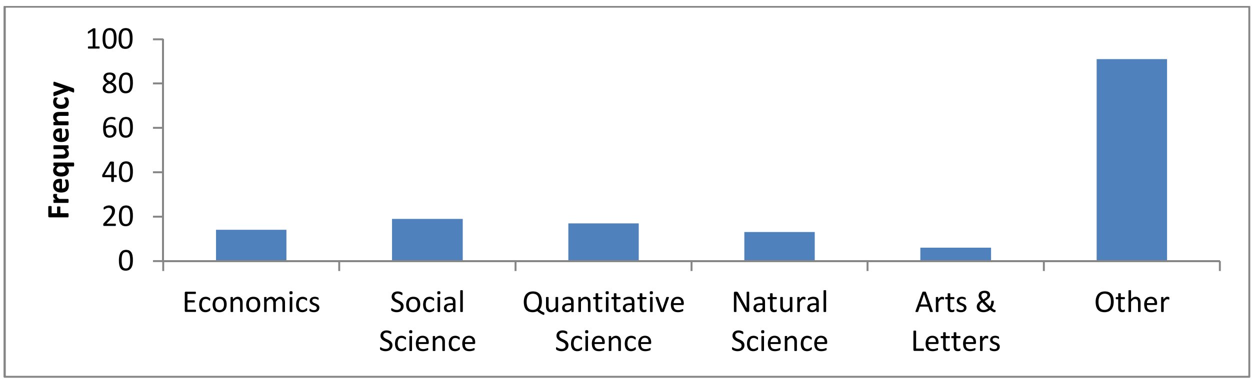


Figure 2. Histogram of Subjects by Declared Major



Figures 3 and 4 illustrate Part 2 data on success of building a fixed sized system for the two fixed-size treatment and the endogenously-determined size for endogenous-size treatments, respectively. Note that periods 3, 6, 9, and 12 are binding. It is apparent from this comparison of means over the 12 periods that the reliability pricing treatments are more successful at financing a delivery system. A comparison of means using the Wilcoxon matched-pairs signed-ranks test (Wilcoxon 1945), given the data from one period to the next are not independent nor likely to be normal distributed, show that we can reject the data are from the same distribution for the fixed sized treatments (at significance level $\alpha = 0.05$). We can also reject the null hypothesis of the Wilcoxon matched-pairs signed-ranks test that both sets of endogenous sized delivery systems are from the same distribution (α = 0.05). These results do not change in a meaningful way when we account for binding and non-binding periods. They do however differ from the Part 1 results where we see no discernible difference between treatments. We believe this is primarily due to subject lack of understanding about the game until Part 2.

Figure 3. Frequency of Success for Fixed Size Treatments

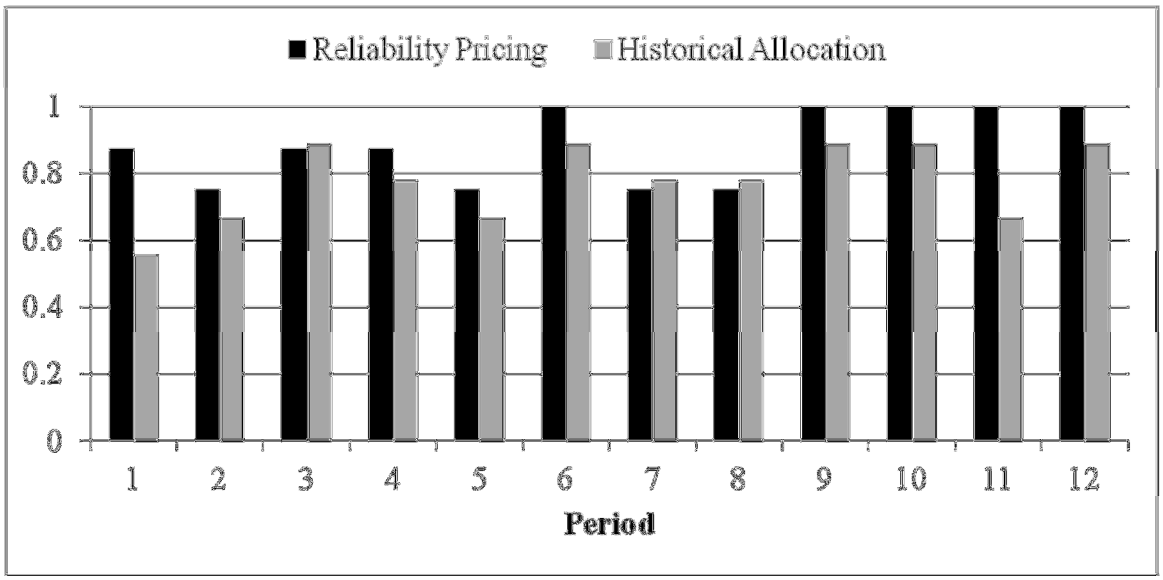
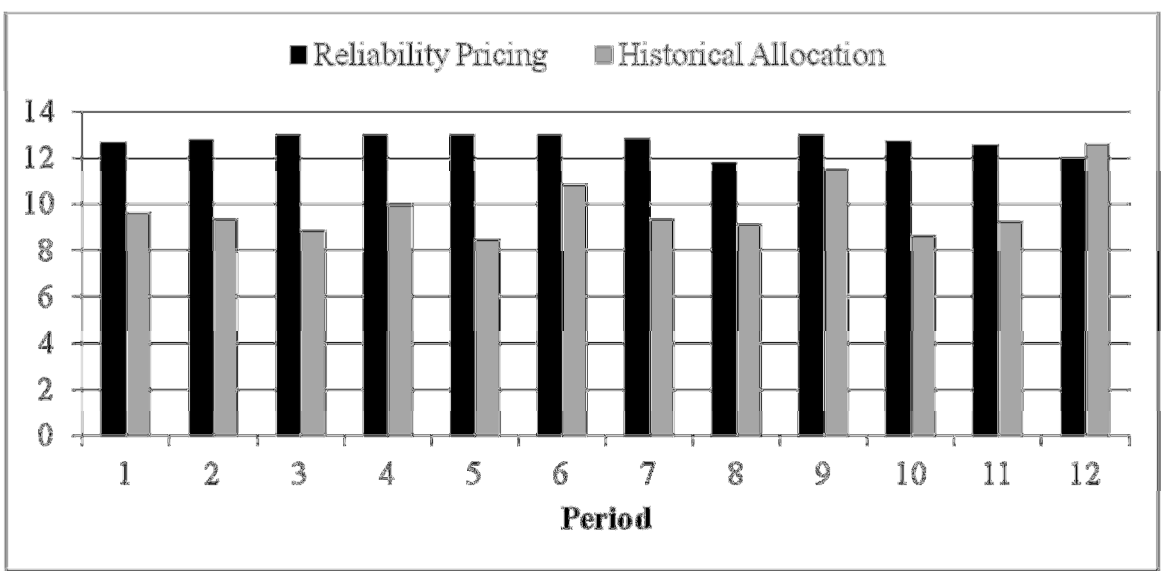


Figure 4. Size of Delivery System for Endogenous Size Treatments



Figures 5, 6, 7, and 8 show the average deviation between maximum willingness to pay and individual contributions for the four different player types as described above. We might conclude from these figures that the reliability pricing treatments result in much less divergence between these two values with lower values appearing for the endogenous-sized reliability pricing treatment (ER). This suggests that reliability pricing creates an incentive for those with the highest willingness to pay values (types 3 and 4) to offer contributions that are closest to their willingness to pay and in excess of the cost of building the infrastructure project ($4,452.50). There is a negligible difference between the historical allocation treatments. Also, noteworthy is that, on average, player types 1 and 2 consistently contributed more than their maximum willingness to pay. Presumably they did so because of a fear of being "left out" of the system or because they misperceived their chance of having the input in a higher reliability rate class and thought their willingness to pay was higher given higher expected payoff from having input delivered with greater reliability. In any event, it appears that the reliability pricing treatments result in a ranking of contributions such that type 1 and type 2s have their units ranked lower than those for type 3 and type 4, suggesting that reliability pricing improves price-formation efficiency. Also, when reliability pricing is combined with endogenous sizing (the ER treatment), an incentive is created for all subjects to contribute more than they would otherwise do in the other treatments.

Figure 5. Difference between Maximum WTP and Contribution for Type 1 Players

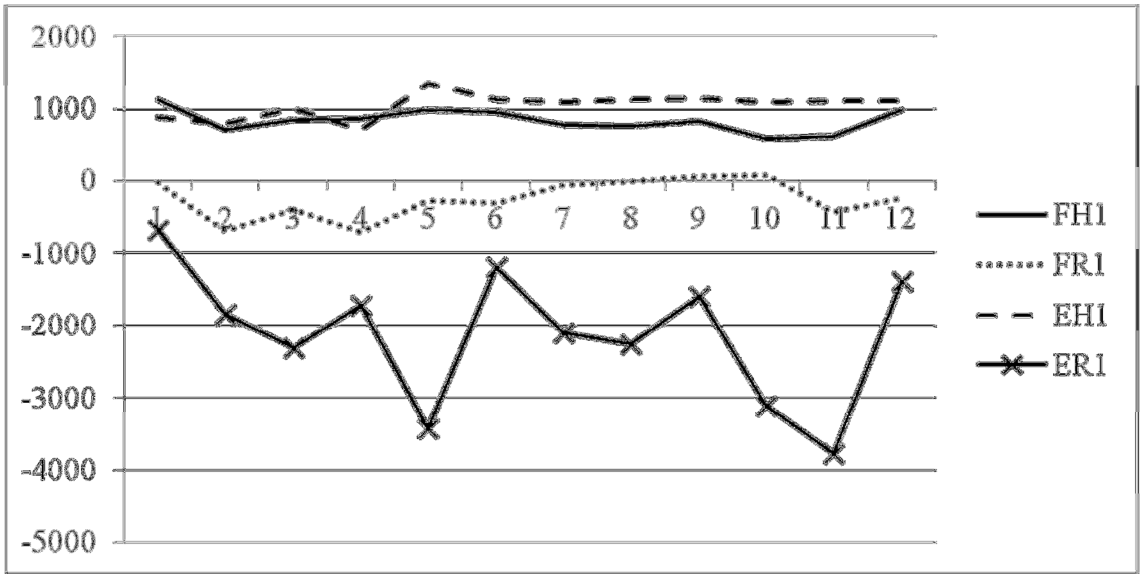


Figure 6. Difference between Maximum WTP and Contribution for Type 2 Players

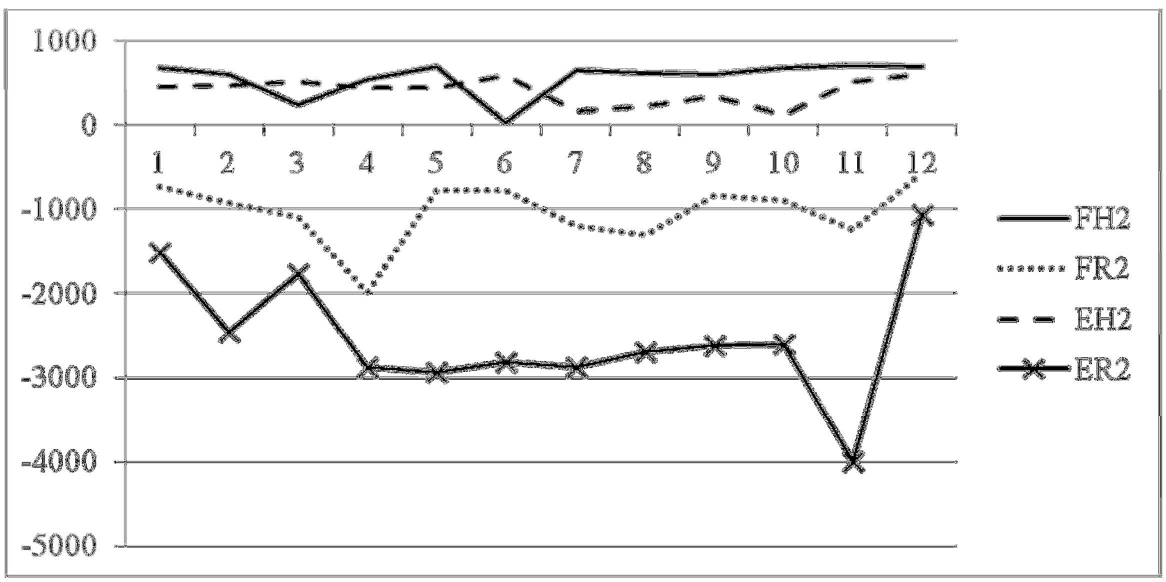


Figure 7. Difference between Maximum WTP and Contribution for Type 3 Players

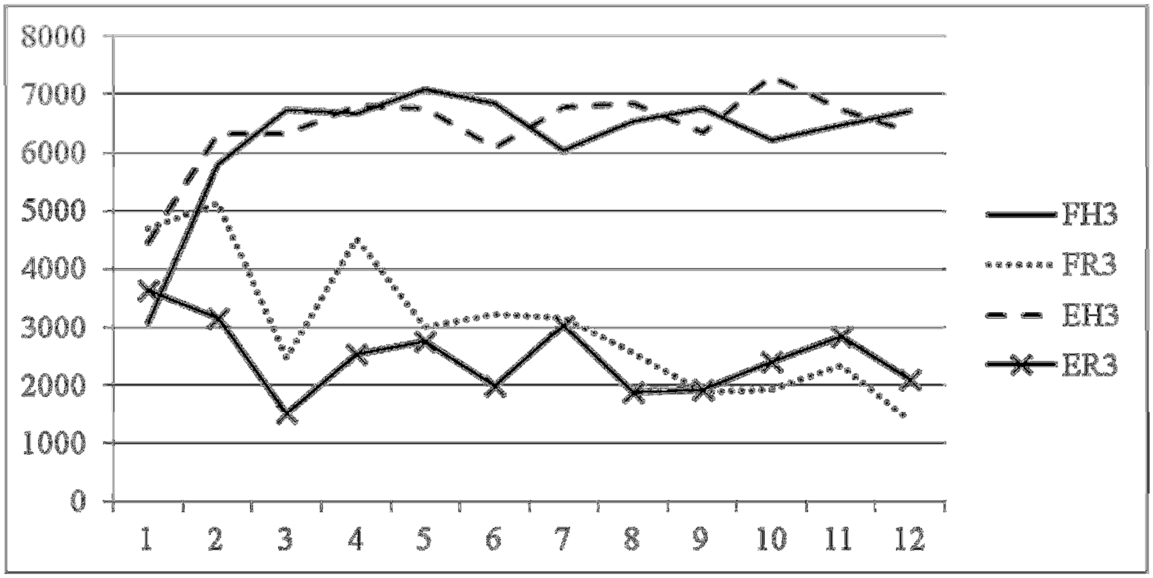
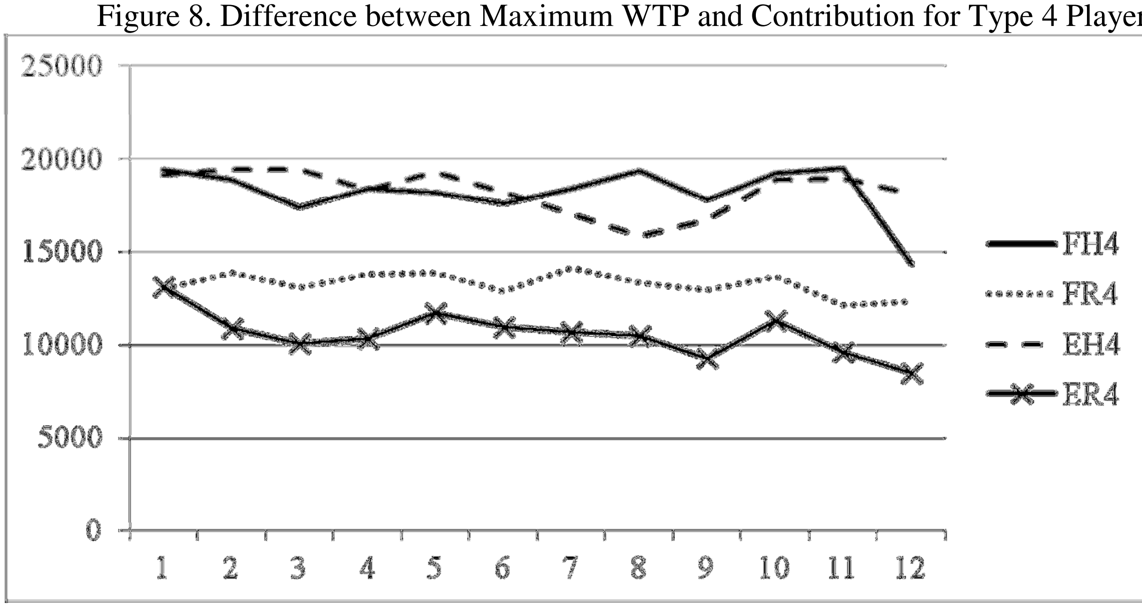


Figure 8. Difference between Maximum WTP and Contribution for Type 4 Players



We next perform a more rigorous statistical comparison between treatments. In line with past experimental economics research, we estimate the treatment model using the asymptotic convergence technique first introduced by Ashenfelter et al. (1992) and subsequently adapted by Noussair et al. (1995), which accounts for subject learning throughout the experimental session (other examples from the literature using this technique include Muller et al. 2002; Godby 1999; Phillips et al. 2001; Menkhaus et al. 2003; and Ruffle 2005). Contribution activity in the early periods are more likely to reflect subject learning than profit-maximizing behavior. As such early responses to the treatments may not reflect differences attributable to the treatments but rather differences in learning how to play the game across treatments. The asymptotic convergence technique allows differences in early periods to be explained by idiosyncratic differences between sessions and differences in later periods to be explained by differences in treatment effects. It does so by weighting session effects more heavily at the beginning of the session and then weighting treatment effects more heavily at the end.

In the equations that follow, the dependent variable y_{mt} is the variable of interest observed within session *m* at time *t*: divergence between maximum willingness to pay and contributions, probability of a fixed sized system is built, or the size of a delivery system when the size is determined endogenously. The convergence equation is:

$$y_{mt} = \beta_1 D_1 \left(\frac{1}{t}\right) + \cdots + \beta_m D_m \left(\frac{1}{t}\right) + \cdots + \beta_M D_M \left(\frac{1}{t}\right) + \beta_{FH} FH_m \left(\frac{t-1}{t}\right) + \beta_{EH} EH_m \left(\frac{t-1}{t}\right)$$

$$+\beta_{FR} FR_m \left(\frac{t-1}{t}\right) + \beta_{ER} ER_m \left(\frac{t-1}{t}\right) + u_{mt}. \qquad (1)$$

The variable β_m is the estimated coefficient on the *m*th session indicator variable (D_m). The variable D_m is then weighted by *1/t* so that session effects in later periods receive less weight in the determination of the dependent variable of interest. The variables β_{FH}, β_{EH}, β_{FR}, and β_{ER} are the estimated coefficients for the fixed-size, historical allocation, endogenous-size, historical allocation, fixed-sized reliability pricing, and endogenous-size, reliability pricing treatments, respectively. Each treatment effect is weighted by $\left(\frac{t-1}{t}\right)$ so that treatment effects in later periods receive greater weight in the determination of the dependent variable of interest. Similar to Shanley and Grossman (2007), we estimate all four treatment effects explicitly so we can conduct pair-wise comparisons across treatments while accounting for learning. The estimated asymptotic coefficients from this convergence process reported in Table 6 are corrected for heteroskedasticity and autocorrelation using the Prais-Winsten transformation.[5] We also estimated models accounting for binding and non-binding periods and found no statistical significance and thus report results for the base model depicted in equation 1.

The asymptotic convergence technique results for the probability of success in building a delivery system of fixed size as seen in Figure 3 suggest the probability is statistically higher for the reliability pricing treatment relative to the historical allocation treatmentat at a 10% significance level (i.e., p-value =0.053). Further, under endogenous sizing shown in Figure 4 the size of the delivery system is statistically higher for the reliability pricing treatment relative to the historical allocation treatment (EH vs ER) at the 1% significance level (p-value = 0.001).

The asymptotic convergence results for free-riding costs shown in tables 6 and 7 further suggest that reliability pricing does a better job of reducing free-riding and when coupled with an endogenous size mechanism has the lowest free rider cost. The F-test shown in table 7 imply that the ER treatment out performs the others in terms of reduction in free riding relative to the FH, EH, and FR treatments. We also see that without reliability pricing an endogenous sizing mechanism has the highest free riding cost as expected given this treatment assures everyone

[5] We also estimated more conventional time fixed-effects and quadratic time trend models in addition to the convergence models presented in the paper to evaluate the robustness of our results under alternative assumptions about subject learning. We also estimated a random effects model to allow for group-level effects at the session level. Little qualitative or statistical difference appeared across the different specifications. Regression results for these alternative specifications are available on request.

receives some benefits regardless of contribution unless no system is built.[6] There is very little risk of being left without any benefits.

Table 6. Asymptotic Convergence Results on the Cost of Free-Riding

Variable	Est. Coefficient	Standard Error	p-value
FH	6355.776	1256.394	0.000
FR	3601.534	891.3973	0.000
EH	6786.722	977.6648	0.000
ER	1570.391	915.8051	0.087

Table 7. Pairwise Tests of Market Institutions

F-test	F-Statistic	p-value
FH = EH	0.05	0.8279
FR = ER	2.53	0.1122
FH = FR	3.20	0.0740
EH = ER	15.16	0.0001

V. Conclusions

This paper considers the problem of supplying a common property resource when the supply is stochastic and collective action is required to finance a system for delivering the resource to users. This research also contributes to the literature by considering two alternative mechanisms, a reliability pricing mechanism and a self-sizing one, for coordinating delivery among stakeholders, in tandem with a threshold public good elicitation mechanism. The experimental results suggest that financing an infrastructure project when the delivery is allocated based on reliability pricing rather than historical allocation results in significantly greater price formation efficiency and less free riding whether the project is of a fixed size determined by external policy makers or determined endogenously by the sum of private contributions. It also turns out that

[6] We also found that when this latter treatment is used we see the greatest number of zero contributions among all treatments. This result is statistically significant at the 1% significance level.

when reliability pricing and self-sizing (endogenous) mechanism are used in combination that free-riding is reduce the greatest among the treatments tested. Also noteworthy, self-sizing when combined with historical allocations results in the worst level of free-riding.

Lastly, the results from the analysis suggested that the rebate rule may have encouraged those with willingness to pay values less than the cost of the project to feel confident when contributing more than their willingness to pay and to do so when they faced the endogenous-sized reliability pricing solicitation since a rebate would likely return them positive earnings. In subsequent research we would like to explore the role of the rebate rule in the effectiveness of reliability pricing and self-sizing in increasing price-formation efficiency and reduce free riding.

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