Procurement Auctions with Renegotiation and Wealth Constraints

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Abstract

Renegotiation is a common practice in procurement auctions which allows for post-auction price adjustments and is nominally intended to deal with the problem that sellers might underestimate the eventual costs of a project during the auction. Using a combination of theory and experiments, we examine the effectiveness of renegotiation at solving this problem. Our findings demonstrate that renegotiation is rarely successful at solving the problem of sellers misestimating costs. The primary effect of allowing renegotiation is that it advantages sellers who possess a credible commitment of default should they have underbid the project. Renegotiation allows these weaker types of sellers to win more often and it also allows them to leverage their commitment of default into higher prices in renegotiation from a buyer.

JEL Codes: C91, D44, D82

Key Words: Procurement auctions, renegotiation, bankruptcy, default, experiments

1 Introduction

A common problem in procurement auctions is that a seller will not know the true cost of completing the project at issue when placing a bid. Projects that require a longer time frame to complete could experience substantial labor and materials cost shifts over the course of the project that may not be foreseeable prior to the auction. Also, unexpected difficulties

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may emerge requiring additional design work, or different production technologies that were unanticipated during the bidding phase. Despite these difficulties, these costs must be estimated prior to an auction in order for a seller to be able to construct a bid they expect to be profitable. Due to the cost uncertainty it is likely that some sellers will overestimate the final cost while others will underestimate it. If the procurement auction takes the form of a standard low-price auction in which the lowest bid wins and the winning seller is paid their bid, then it is likely to be the case that the winning seller will be the one that underestimated the cost of the project by more than any of his competitors. If unaccounted for in the bidding behavior, this adverse selection is what leads to the well-known Winner's Curse phenomenon and can lead to substantial losses for the sellers.

The existence and prevalence of the Winner's Curse has been well documented in both the lab and the field (see for example Kagel and Levin (1986a); Charness and Levin (2009); Bajari and Hortacsu (2003)). What this literature demonstrates is that bidders find it quite difficult to learn to correct their bidding behavior for the fact that conditional upon winning they learn that they had the lowest estimate of the cost.

In a procurement context, the exceptionally low bids that a buyer receives should be a concern to both parties in the transaction. Of course, the seller should be concerned that they will potentially lose money, but the buyer should also be concerned due to the possibility that the seller may default on the project before it is completed. This problem is clearly a major issue for those who engage in procurement as a number of different mechanisms have been developed to combat it. One common practice involves an auctioneer removing bids from consideration that are deemed too low.[1] Harstad and Rothkopf (1995) examine a similar option in a standard common value auction where winning bidders can withdraw bids. Chen, Xu, and Whinston (2010) suggests that the way to deal with the problem involves contingent contracting though their aim is to solve a slightly different, though related problem where a seller is under-delivering quality. Calveras, Ganuza, and Hauk (2004) propose a solution to the problem of sellers going bankrupt midway through a project which consists of a surety bond that the winning seller must pay for that will compensate the buyer in the event that the seller fails to complete the project. Chang, Chen, and Salmon (2012) and Decarolis (2011) examine the use of an average bid auction in which the winning bidder is the one who bids closest to the average.

One of the more commonly used mechanisms to deal with the possibility that a seller has underbid, and the focus of this study, is renegotiating the terms of a contract after it is awarded. Two well-known examples of post-award renegotiation would be the North South metro line in Amsterdam and the Big Dig in Boston. Contractors working for the City of Amsterdam began construction of a new North-South line of their metro to go through the central part of the city in 2002. The initial budget was set at €1.46 billion but after multiple rounds of renegotiating, it had risen to €3.1 billion by 2009. It was originally intended to be completed by 2011, but latest estimates now suggest it might be completed

[1] For example, the US Office of Defense for Acquisition, Technology, and Logistics, which is responsible for supervising acquisition for the Department of Defense, has the following policy for unreasonable low bids (FAR 14.407- 3(g)): If the evidence does not reasonably support the existence of a mistake and the contracting officer has determined that the bid price is unreasonable, the contracting officer must reject the bid as unreasonable.

Retrieved from: http://www.acq.osd.mil/dpap/cpf/docs/contract_pricing_finance_guide/vol1_ch8.pdf by 2017. The Big Dig in Boston has suffered similar problems leading to over $1 billion in renegotiated payments to the construction firms involved.[2] While these are highly visible examples of renegotiation following a competitive bidding process, the phenomenon occurs in a wide range of situations. Decarolis (2012) examines a data set of procurement auctions in Italy and finds that much of the price reduction achieved by using auctions for the procurement process are lost through renegotiation. Bajari, Houghton, and Tadelis (2011) provide estimates of what they call adaptation costs in highway paving contracts which amount to an 8-14% increase in the final price over the initial price set by auction. Gil and Oudot (2009) argue that due to the potential need for renegotiation, complex procurement projects should not even be allocated using auctions.

While renegotiations clearly occur, there is a question as to whether the mechanism actually solves the problem it is intended to or whether it instead creates unintended incentive effects, thereby causing other problems in the procurement process. Wang (2000) provides a theoretical argument for how allowing for post-auction renegotiation could help a buyer obtain lower prices but this is in a private value environment in which there is no Winner's Curse problem to deal with. In a common or affiliated values environment, the theoretical argument for how renegotiation could resolve the problem is less clear. The goal for a buyer would be to use renegotiation to help sellers who accidentally bid too low avoid default, and by doing so the buyer hopes to avoid additional recontracting costs associated with finding another seller to complete the project. While this does mean the buyer expects to pay higher prices through renegotiation, the buyer may well be satisfied with that trade-off if recontracting costs are too high.

The purpose of this study is to determine if there is a theoretical argument for why/how renegotiation might solve this problem and to provide experimental evidence on whether it can succeed empirically. We begin with a theoretical analysis of how renegotiation affects bidding behavior in the auction and the procurement process overall. One issue that becomes immediately apparent is that in order for renegotiation to have any impact on the process, from a theoretical perspective, the winning seller must have a credible commitment to abandon the project after learning his true costs. If a seller lacks such a credible commitment, then the buyer will have no incentive to renegotiate a higher price and a seller clearly never has the incentive to renegotiate a lower price. To account for this we examine situations in which sellers have varied degrees of credible commitment to default. The commitment to default will be modeled on the premise that firms differ according to their size and borrowing/loss constraints. One can well imagine large firms with deep pockets who have the ability to sustain losses on individual projects choosing to absorb those losses rather than abandon the project. This is because such firms might face substantial costs from defaulting on one bad deal due to the possibility that such an action could have adverse consequences on multiple other projects in which the firm is engaged. On the other hand, smaller firms may be unable to complete projects whose price is lower than the costs due to liquidity constraints. For ease of analysis, we restrict our theoretical environment to two types of sellers: strong sellers who can (and will) accommodate any losses without choosing to default and weak sellers who cannot absorb any losses and so default under any loss.[3]

[2] The Boston Globe maintains a repository of information on the history of the Big Dig at http://www.boston.com/news/specials/big_dig_problems/

[3] The starkness of these assumptions are not necessary for the main comparative statics in the theory.

We find little reason to believe that renegotiation will help alleviate losses associated with the Winner's Curse problem in procurement auctions. Our theoretical analysis shows that when all sellers are strong, renegotiation should never be expected to occur as buyers will reject all offers knowing strong sellers can absorb losses. However, when wealth constrained bidders are added to the population of sellers, we find that renegotiation can substantially change the incentives of the auction stage. In theory, with a mix of weak and strong sellers, the expectation is that weak sellers should win all projects at very low prices and then use their credibility to default as leverage to negotiate a final price much more favorable to the seller. While this may decrease seller losses, it does so at substantial expense to the buyer and due to the asymmetric advantage of the weak seller it also leads to negative efficiency consequences. We then perform an experimental test to determine if these predictions hold as people may behave differently than theory predicts. We find that the theory performs quite well in predicting the comparative statics of how people behave and it is also useful in predicting the relative nature of auction outcomes. This leads to our finding in the experiments that renegotiation is not an effective means of solving the Winner's Curse problems in this environment.

There are prior studies which examine aspects of this problem but none deal directly with the issue of whether renegotiation does or does not help to correct for losses associated with the Winner's Curse in procurement auctions. Waehrer (1995), Roelofs (2002), and Parlane (2003) all examine auctions with default options used by bidders to examine the impact of limited liability on auction outcomes. Waehrer (1995) and Parlane (2003) provide theoretical examinations of how limited liability affects bidding behavior in an environment assuming private values with uncertainty. Waehrer (1995) does allow for renegotiation but since the environment does not allow for a Winner's Curse the results do not speak to the issues we are concerned with. Shachat and Tan (2013) also investigate procurement auctions with renegotiation when sellers have independent private costs (no Winner's Curse). Renegotiation in their environment involves buyers initiating the process to lower the purchase price while our environment is the reverse with winning sellers initiating renegotiation in an attempt to raise the selling price. Roelofs (2002) also examines a case closer to ours as he provides both a theoretical and experimental examination of how limited liability among bidders in a common value setting can alter bidding behavior. This limited liability treatment is somewhat similar to how we implement wealth constrained sellers, but it does not include renegotiation. Wealth constrained bidders in the procurement context have also been examined empirically by Krasnokutskaya and Seim (2011), but their focus is on the use of preferential treatment policies within an auction mechanism to help overcome costs of entry for weak bidders.

In the next section we will explain the theoretical environment and the predictions for bidding and renegotiation behavior. Section 3 will describe the design of the experiment. Section 4 will present the results and we conclude in section 5 with a discussion of what the results from this study suggest regarding the use of renegotiations following procurement auctions.

We discuss in more detail later how relaxing this strong assumption will affect our results.

2 Theory

We analyze a procurement auction with n sellers bidding for a project offered by one buyer. The model is constructed around experimental treatments which investigate the effects of post-auction renegotiation between the winning seller and buyer, and bidders with wealth asymmetry. The environment we use is based on the private plus common value structure introduced in Goeree and Offerman (2003) and Goeree and Offerman (2002). Translated into the procurement setting, this structure assumes that the total cost facing a seller, c_i, is composed of both private and common costs. We assume that the private portion of a seller's cost, t_i, is drawn independently for each of the n bidders from a common distribution. Each bidder is also assumed to receive a signal, τ_i, which is independently drawn from another common distribution related to the common cost element. A bidder's total cost is equal to their private cost plus the common cost, τ, which is equal to the average of all of individual signals. This can be represented as

$$c_i = t_i + \sum_j \frac{\tau_j}{n} \tag{1}$$

For the experiments we assume $n = 4$, while t_i is drawn from a uniform distribution over the range $[0, 50]$ and τ_i is drawn from a uniform distribution on the range $[0, 100]$. We further assume that the value of the buyer is high enough such that they would be willing to buy under any cost realization, or $v_b = 150$.

The auction structure we investigate is the standard low price procurement auction in which sellers simultaneously submit a bid, b_i, and the lowest bid wins and sets the auction price, $p^* = \min_j\{b_j\}$. The earnings of the winner are equal to the auction price less the true cost or $p^* - c_i$, and the buyer earns $v_b - p^*$. In some treatments we will add a renegotiation stage which follows the auction. In the renegotiation stage we allow the winning seller to observe the true common cost, $\sum_j \frac{\tau_j}{n}$, and then make a take it or leave it offer of a new transaction price, f, to the buyer. If the buyer accepts the offer then that offer becomes the new transaction price and the buyer will earn $v_b - f$ while the winning seller receives earnings of $f - c_i$. If the buyer rejects, then the transaction price remains the price which resulted from the auction. When making his decision, the buyer will not be able to observe the total cost of the seller, but he will know the distribution of possible costs.

We will assume the existence of two types of bidders - strong and weak. Strong bidders are assumed to be able to absorb losses and so any losses they make are simply represented as negative earnings. In contrast, weak bidders will be assumed to default upon suffering a loss of any size. This default will result in a penalty to the seller, k, and recontracting costs, r, to the buyer. For the experiment we assume that the default penalty suffered by the seller is $k = 50$ and the recontracting cost for the buyer is $r = 25$. During the auction, the number of weak and strong sellers is common knowledge and in the event of a renegotiation phase, a buyer knows whether or not they face a strong or weak winning seller.

In order to understand the effects of allowing renegotiation we must analyze this model under conditions where renegotiation is and is not allowed. Similarly, in order to understand how the asymmetric liability of sellers affects outcomes we also need to analyze the model in the presence and absence of the weak sellers. This leads to 4 different scenarios which we address in turn to provide a characterization of the bidding behavior in each case.

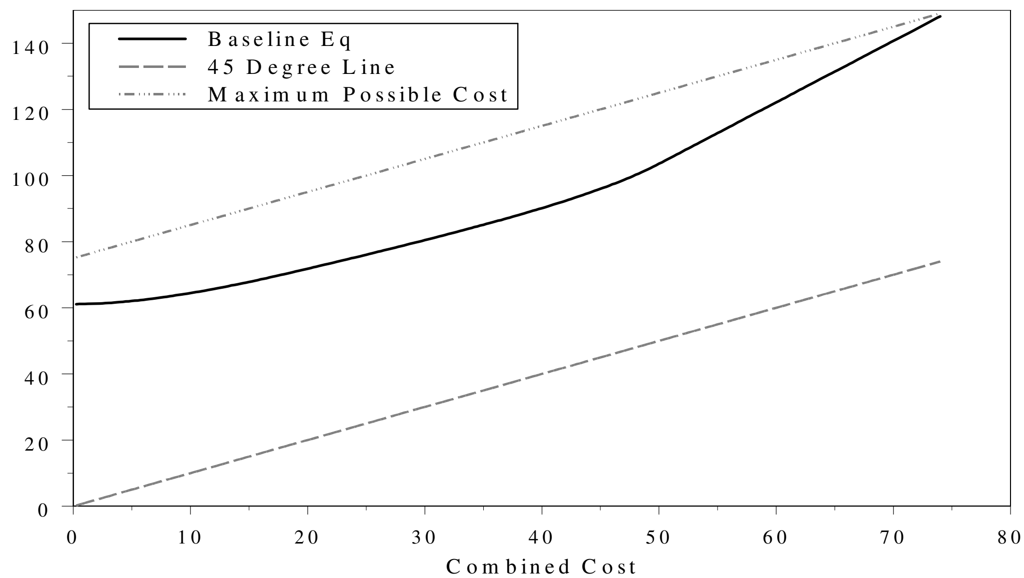

Figure 1: Equilibrium bid function for Baseline and Renegotiation treatments.

2.1 Baseline

The baseline condition refers to the case in which only strong sellers are included in the auction and renegotiation is not allowed. The bidding behavior in this environment can be derived in a straightforward manner based on Goeree and Offerman (2003) and we will mimic the notation used in Milgrom and Weber (1982). We first construct a combined cost signal of $x_i = t_i + \tau_i/4$ which represents the information available to seller i about his final cost when placing his bid. As all bidders are symmetric strong bidders, in this environment we will focus on bidder 1 who has a combined cost signal $x_1 = t_1 + \tau_1/4$. If we let X_1 be equal to the expected minimum combined signal out of n draws and Y_1 be equal to the expected minimum combined signal out of $n-1$ draws that are above X_1, then the equilibrium bid function can be expressed as

$$b(x_i) = E(\tau + t_i | x_1 = x_i, X_1 = x_i) + E(Y_1 - X_1 | x_1 = x_i, X_1 = x_i). \tag{2}$$

The first component is an estimate of the cost to bidder i, assuming his signal is the lowest, while the second represents an estimate of the difference between the expected lowest and second lowest combined signals given that bidder i has the lowest signal.

Figure 1 graphically illustrates the baseline bid function, given the distributional assumptions used in the experiment.[4]

2.2 Renegotiation

We now add the possibility of renegotiation after the auction between the winning seller and buyer. We maintain the assumption of the baseline that all sellers are strong types

[4] The full derivation of the baseline bid function with the distributional assumptions can be found in the appendix.

who can absorb losses. As this is a two stage game with imperfect information, we use backward induction to solve for a weak perfect Bayesian Nash equilibrium. In the second stage, we can assume that the auction has concluded yielding some price, p^*. While the buyer does not observe the seller's cost, he knows that all sellers are strong which implies that the probability of default for any winning seller is 0. Thus, any belief structure over costs yields equivalent decisions by the buyer. If the seller offers any price $f > p^*$, then the buyer can accept and pay a price of f or reject and pay the lower price of p^*. It is clearly a best response to reject any offer of $f > p^*$. A seller could in principle offer some $f < p^*$, which the buyer would accept, but this is clearly dominated behavior for the seller. The result of this analysis is that we observe there to be a multiplicity of equilibria involving the sellers making any offer $f \geq p^*$ and the buyer rejecting any of those offers. In all cases the final transaction price stays at the auction price, p^*.

Since the final transaction price will always stay at the level set by the auction, there is no change in the incentives during the auction stage. The equilibrium bidding behavior is therefore the same between the baseline and renegotiation cases. This is an important result because it demonstrates that the only way renegotiation can affect the auction outcome is when the winning seller may possibly default on the project.

2.3 Wealth

Our third case removes the option of renegotiation and introduces asymmetric bidders. Half of the bidders are strong sellers who can absorb all losses, and the remaining half are weak sellers who will default if they make losses in the auction stage. Defaulting forces the weak seller to accept a penalty of k and imposes recontracting costs, r, on the buyer. We assume that k is larger than the loss from the auction, so defaulting does not serve as a form of limited liability.[5] In this case, default by the weak seller substantially increases the potential damage from underestimating the cost of the project as any bid, even slightly under the true cost, will lead to a substantial loss. In contrast, strong sellers do not face the threat of additional costs when the true cost is misjudged. This asymmetry in liability constraints leads to a change in the incentives underlying bidding behavior. Weak sellers essentially bid as if they possess a loss averse utility function, as they must bid to avoid any losses, while strong sellers do not.

Solving for closed form bid functions for both strong and weak sellers is not tractable for this case. We have chosen instead to construct the bid functions using a computational method. This approach involves calculating the expected utility to a seller from following a specified function for their type using a simulations method assuming that the other three sellers are using the proposed bid functions for their type. We then determine whether there are profitable deviations from the proposed function for a seller of either type by calculating the best response bid function for both types. If profitable deviation for either type is possible, a new function can be proposed and tested using the same criteria.[6] This

[5] The default penalty, k, can be interpreted as the closure of the firm, or the present value of reputation loss in future transactions as a firm who defaulted.

[6] Bid functions were approximated using splines over the point estimate of the best response that resulted from the simulation process. While the spline process was relatively flexible, we did impose shape primitives on the process which are based on the theoretical assumptions for these bid functions. Specifically, we estimated a monotonically increasing polynomial where the bid for the maximum combined cost signal is

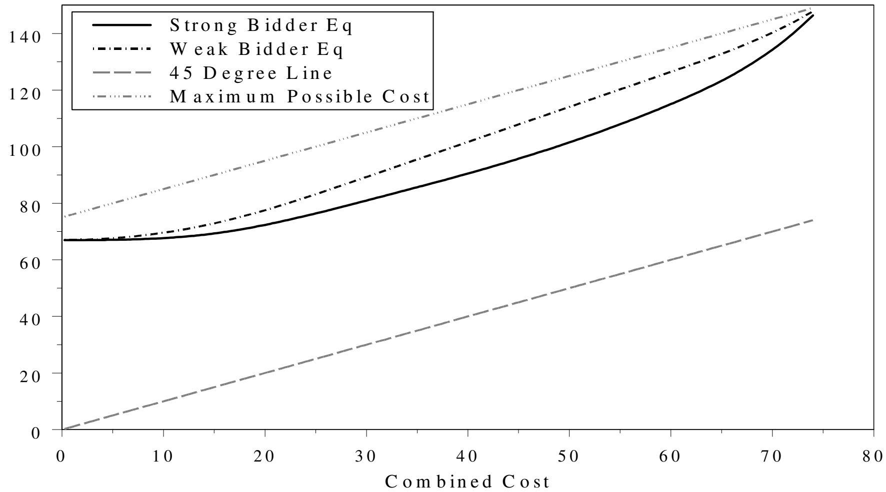

Figure 2: Equilibrium bid functions for strong and weak bidders in Wealth treatment.

process iterates until we find a fixed point for both functions, i.e. a set of functions for that are best responses to themselves. Due to the computational nature of the approximations, finding a precise fixed point is impractical so we ended the computational search process using a tolerance level defined by a measure equal to the sum of the square of the distance between the initial and best response bid functions at every value of x_i.[7] We have verified this approximation procedure by using it to reproduce the analytical bid function derived in the baseline case and we have checked the robustness of the solution by verifying that we obtain the same function starting from multiple initial proposals, including flat bid functions.

Figure 2 graphically displays the bid functions for this case. The qualitative nature of these bid functions is quite intuitive. The weak sellers bid less aggressively than the strong sellers to avoid the possibility of even small losses. The strong sellers are able to bid more aggressively as they do not suffer from the same serious consequences related to small losses. The effect of this difference is that at equivalent cost draws strong sellers will be advantaged over weak, allowing them to win more often.

2.4 Wealth and Renegotiation

The final environment combines both renegotiation and asymmetric bidders. The presence of weak sellers changes the outcome from what is observed under renegotiation without asymmetry due to the fact that the weak bidders have a fully credible commitment to default if they end up losing money at the conclusion of all final transactions. The equilibrium concept necessary for this environment is a weak perfect Bayesian Nash equilibrium as we must specify the beliefs held by the buyer regarding the probability with which the seller

equal to 150, the highest possible cost, $b(\overline{x}) = \overline{c}$. A detailed algorithm is available from the authors upon request.

[7] The iterative process continued until the tolerance level of both weak and strong estimated bids fell below 0.001.

they are facing will default at the transaction price from the auction.[8] Let $h \in \{w, s\}$ define the type of the seller and let $\rho(p^*, f, h)$ be the belief on the part of the buyer regarding the probability with which the seller they are facing will go bankrupt if the final price is the winning bid observed in the auction, p^*, given the price requested in renegotiation, f, and the type of the seller, h. The set of equilibrium strategies for the bidders can be characterized by:

$$b_w^*(x_i) = 0 \quad (3)$$

$$f_w^*(c_i, b_i) = 175 \quad (4)$$

$$b_s^*(x_i) > 0 \quad (5)$$

$$f_s^*(c_i, b_i) \geq b_i \quad (6)$$

Note that the offers made by the sellers in the renegotiation stage can be conditioned on their true cost, c_i, rather than just their combined cost signal, x_i, due to the fact that the sellers learn their true cost at the conclusion of the auction and prior to making the renegotiation offer. The choice for the buyers in the renegotiation stage, $D \in \{Accept, Reject\}$, must be accompanied by an appropriate set of beliefs regarding the probability with which they believe a seller will default after a rejection. Both can be characterized as follows:

$$D(p^*, f, h) = \begin{cases} Reject & if \quad h = s \ \& \ f > p^* \\ Accept & if \quad h = s \ \& \ f \leq p^* \\ Accept & if \quad h = w \ \& \ p^* = 0 \ \& \ f \leq 175 \\ Reject & if \quad h = w \ \& \ p^* > 0 \ \& \ f > 0 \end{cases} \quad (7)$$

$$\rho(p^*, f, h) = \begin{cases} 0 & if \quad h = s \\ 1 & if \quad h = w \ \& \ p^* = 0 \\ 0 & if \quad h = w \ \& \ p^* > 0 \end{cases} \quad (8)$$

The justification for this set of strategies and beliefs being an equilibrium is straightforward. In equilibrium, all weak sellers should bid 0 to maximize their chances of winning in the auction stage regardless of their observed combined signal. In the renegotiation stage, the buyer will expect that a weak seller who has bid 0 will default with probability 1 if the offer is rejected.[9] Recall that in the event a seller defaults, the recontracting cost for the buyer is $r = 25$ and the value of the completed project to the buyer is $v_b = 150$. Consequently a buyer will expect to receive utility of -25 for rejecting an offer of the weak seller or $150 - f$ for accepting. A rational buyer accepts so long as $150 - f \geq -25$ or $f \leq 175$. A weak seller therefore maximizes his earnings by setting $f = 175$.

Technically we must define beliefs and actions for the buyer off the equilibrium path,

[8] Technically the beliefs should be over the type or cost of that seller with those beliefs about type determining the beliefs about the probability of default. It is notationally more convenient to make the beliefs directly about the default probability and so we have chosen to represent them that way. Since the beliefs about type and default probability have a direct relationship between them, this choice has no important consequences.

[9] It is technically possible, given the discrete distributions used in the experiment, for a subject to have a true cost equal to 0 and therefore not default at that price. This involves receiving $t_i = 0$ and then $\tau_j = 0$ for all j. The probability of that event is equal to $\frac{1}{51} * \frac{1}{101}^4 = 1.88 \times 10^{-10}$. We feel justified in the choice to round this to 0 for convenience.

i.e. for when a weak seller is observed to bid a positive amount. Since it is impossible for a weak seller to ever do better than a price of 175 it matters little what these off equilibrium path beliefs and actions are so we will assume that the buyer assumes the bid was perfectly revealing of true cost and that the seller will never go bankrupt leading to a reaction of always rejecting. Any alternative belief structure works as well, including one in which the buyer accepts any offer less than or equal to 175, regardless of the auction price.

Given that weak sellers will bid 0, a strong seller can never bid in such a way so as to profitably win the auction. The best response by the strong seller is to bid anything greater than 0 to ensure losing. In the off-equilibrium case that the strong seller wins, again any renegotiation offer they request will be rejected by the buyer if it is above the auction price as the buyer knows with certainty that the strong seller will not default. Of course the buyer will happily accept an offer below the auction price though the seller should never offer that. Consequently the strong seller can request anything greater than or equal to the auction price and it will be rejected by the buyer.

While there are multiple equilibria corresponding to different ways of specifying the strategy of the strong sellers and the off-equilibrium path beliefs/actions of the buyer, all of these equilibria have the same outcome. Every auction results in a tie between the weak sellers and that tie is broken randomly. The winning weak seller then makes a renegotiation request of 175, which the buyer accepts.

While the environment we have set up with weak sellers that default on any loss is an extreme case, the general nature of the equilibrium structure will hold constant for different ways of specifying the default threshold. So long as a weak seller can demonstrate a credible commitment to default with a very low winning bid, he will have leverage in post-auction renegotiations. This is something that should be possible for most alternative specifications of weak sellers since realistic cost distributions should be bounded away from zero. In the conclusion we will return to a discussion of these issues including discussing the degree to which practices like excluding abnormally low bids can eliminate this possibility. Yet, before determining if such practices might work we must first determine if a problem exists in their absence and so we specify and test this more extreme environment.

3 Experimental Design

The experimental design consists of four treatments which correspond to each of the theoretical environments described above: Baseline (B), Renegotiation (R), Wealth (W), and Wealth & Renegotiation (W&R). Each session of the experiment consisted of a single treatment. At the beginning of a session the subjects were randomly assigned to either the role of buyer or seller and that role assignment remained constant over the entire experiment.

As already noted, the cost environment used a direct translation of the private plus common value structure of Goeree and Offerman (2003) to the procurement setting. All costs and values in the experiment were denominated in experimental currency units (ECUs). The private cost element, t_i, was drawn from a uniform distribution on the range $[0, 50]$ and the common cost element, τ_i, was drawn from a uniform distribution on the range $[0, 100]$. There were four bidders in each auction, and the total cost to any bidder i was equal to $c_i = t_i + \sum_{j=1}^{4} \frac{\tau_j}{4}$. The value of the project to the buyer in each round of the auction was always 150, which is equivalent to the maximum possible cost.

	B	R	W	W&R
Buyer		\$52.35		\$38.53
Seller	\$23.07	\$23.45	\$22.33	\$27.11

Table 1: Average earnings by treatments.

In all treatments, each period began with a standard low price procurement auction in which the subjects in the role of seller would be told of their draws of t_i and τ_i and then asked to place a bid. The winning bid was the lowest submitted and that bid determined the auction price. In the treatments without renegotiation, the auction determined the final outcome. In the treatments with renegotiation the winning seller from the auction stage was informed of the true cost and then allowed to submit a take it or leave it offer to the buyer if they chose to. If that offer was accepted it became the final transaction price while if it was rejected, the auction price remained the final transaction price. In the Baseline and Renegotiation treatments all auctions had four strong sellers, none of whom could default on a project. In the Wealth and Wealth & Renegotiation treatments there were two weak sellers and two strong sellers per auction. In contrast to the strong sellers, the weak sellers defaulted if they experienced any loss. In the event of default, a subject in the role of a weak seller was charged a 50 ECU default penalty while the buyer faced a 25 ECU cost. Subjects in the role of buyer were informed of the closing auction price, the price requested in renegotiation, and whether the winning seller was strong or weak. The buyer did not know the seller's exact cost, only the distribution of possible costs.

We conducted 3 sessions for each treatment yielding a total of 12 sessions. Each session consisted of 30 rounds. To ensure the least amount of changes between sessions, we used the exact same signal draws across all treatments. In the sessions without renegotiation we had 16 subjects in the role of sellers with no humans in the role of the (completely passive) buyers. In the sessions with renegotiation we had 16 sellers and 4 buyers.[10] Sellers and buyers were randomly matched into groups each period.

As subjects could and are expected to make losses in these experiments, we endowed subjects with initial balances to hopefully ensure that they would not have negative cumulative earnings at any point in time. We set the seller endowment at 375 ECUs while the buyer endowment was set at 150 ECUs. As it was still possible, even with those endowments, for individuals to achieve a negative overall balance, we employed some standard rules for dealing with the bankruptcy prospect. The rules allowed for subjects who go bankrupt a single time to be re-initialized with a new endowment. Any subject who went bankrupt a second time was removed from the session and received only their participation fee. In the end, eight subjects went bankrupt once and one subject went bankrupt twice.

Due to the fact that buyers were expected to earn substantially more ECUs than sellers, we used different conversion rates for converting ECUs into USD for the two roles. For those in the role of sellers, 1 ECU=\$0.04 and for those in the role of buyers, 1 ECU=\$0.015. This lead to overall earnings of \$45.73 for the buyers and \$23.93 for the sellers which includes the \$10 participation fee. Table 1 shows the earnings broken down by type and treatment.

[10] One session in the Renegotiation treatment had only 3 buyers and 12 sellers due to a smaller than expected number of subjects showing up that day.

3.1 Hypotheses

The preceding theoretical analysis in conjunction with the experimental design sets up a series of hypotheses that can be empirically tested. In this section, we briefly state our primary hypotheses of interest to guide the data analysis in the results section.

Hypothesis 1 *There will be no observed difference in bidding behavior or auction outcomes between the B and R treatments.*

This first hypothesis proceeds from the fact that all renegotiation requests from strong sellers are expected to be rejected and whether renegotiation is allowed or not should be irrelevant if subjects act as theory suggests. It is certainly possible though that a different behavioral norm could emerge. Many prior studies (Güth, Schmittberger, and Schwarze (1982); Kahneman, Knetsch, and Thaler (1986); Rabin (1993); Fehr and Schmidt (1999)) indicate that individuals often have a concern for fairness, or more generally, the welfare of other people. Other prior studies also suggest that some individuals have a bias towards honesty in their behavior (Charness and Dufwenberg (2006); López-Pérez and Spiegelman (2013); Fischbacher and Föllmi-Heusi (2013)). If both sorts of behavior transfer into this environment, then it is possible that a norm develops in which sellers bid in good faith during the R treatment (i.e. they bid no differently from the B treatment) and then only request renegotiation when they find out that they are losing money. The buyers might then decide, since they value the welfare of the other, to accept the renegotiation offer if they deem it a reasonable split of the potential surplus. The development of such norms seems unlikely but behavior along these lines is what would be necessary for renegotiation to help mitigate losses for the winning seller – in particular losses sustained by winners suffering from the Winner's Curse.

Hypothesis 2 *Strong sellers will bid more aggressively than Weak sellers in the W treatment and this will be reversed in the W&R treatment.*

Hypothesis 3 *Strong sellers will win more often than weak sellers in the W treatment while weak sellers will win more often in the W&R treatment.*

The support for both of these hypotheses falls directly out of the predictions of bidding behavior in the two treatments. In the W treatment, the weak sellers must bid conservatively to avoid losses which trigger a considerable default penalty, while the strong sellers can bid more aggressively as they simply absorb losses rather than default. This means the strong sellers will be advantaged in the W treatment. For the weak sellers, the opportunity to engage in renegotiation with the credible threat of default will have a substantial impact on their bidding behavior, allowing them to bid much more aggressively when renegotiation is an option. This shift in bidding behavior will have the consequence that weak sellers will now be able to win more often than strong in the W&R treatment.

Hypothesis 4 *All renegotiation offers by Strong sellers will be rejected in both R and W&R treatments. Renegotiation offers by Weak sellers will be more likely to be accepted at lower auction closing prices.*

According to the equilibrium structure, all renegotiation requests by strong sellers should be rejected while all weak sellers should bid 0, request a renegotiated price of 175, which should then be accepted by the buyer. In regard to the offers by strong sellers, there is no self-interested rationale for why buyers would ever do anything else. However, the case is not as clear with weak sellers. Therefore, in our hypothesis we have accounted for how buyers may respond if weak sellers do not make bids/offers in exact accordance with the theoretical prediction. If the winning weak seller wins the auction at a price above zero, self-interested buyers may not always want to accept renegotiation offers. As there are an infinite number of ways to specify off equilibrium path behaviors for the buyers, we do not see a reason to specify a single one for testing purposes. We argue though that any plausible model for how buyers should respond to a weak seller's renegotiation attempt would be that a buyer is more likely to accept an offer if the auction price is lower since the probability that the winning seller is expected to default at that price is higher. On the other hand, if an auction closes at a relatively high price then a reasonable expectation is that the default risk is lower and so a buyer might take the chance and reject that offer.

Hypothesis 5 *Final transaction prices will be rank ordered such that $P_{W\&R} > P_W$ and $P_B = P_R$. Seller losses should be ordered in the reverse.*

Of ultimate importance to those involved in these types of auctions is this last hypothesis which ranks the final transaction prices paid by buyers and the expected losses to sellers. According to the equilibria derived above, the W&R treatment clearly delivers the highest price and the B and R treatments are clearly expected to be equivalent. According to the equilibria, there should be no losses in expectation among the sellers. Of course, from many prior experiments with common/affiliated values environments (e.g. Kagel and Levin (1986b); Kagel and Richard (2001)) we know that individuals are highly unlikely to bid exactly as theory predicts and that losses are likely. If the price ranking remains robust to the new bidding behavior and if there are losses, they should be inversely related to the final prices.

4 Results

4.1 Summary Statistics

We begin by displaying summary statistics of the data from the experiments. The hypotheses stated above will be formally tested in the next sections but prior to seeing the regression analysis, it is informative to examine the simple statistics which emerge from the data.

Table 2 contains summary statistics on revenue, efficiency, and buyer surplus. We include average auction prices in addition to average final prices for the R and W&R treatments to demonstrate how much of the change in observed revenue is due to renegotiation. Auction price, final price, and buyer surplus data are the same for the B and W sessions since renegotiation is not possible.[11]

[11] In the case of default, the final price is recorded as the last price from the auction if there was no renegotiation, or if renegotiation was refused.

By hypothesis 5, auction prices are equivalent between the B and R treatments because renegotiation should never be successful. The average auction price in R (59.38) is approximately equivalent to B (61.35). Auction prices in the W&R treatment are theoretically predicted to equal 0, and while we do not observe prices at the zero level, we do find that auction prices in this treatment are substantially lower than the W treatment and all other treatments.

Comparing auction prices to final prices for the treatments with renegotiation, there appears to be little difference between the auction price and the final price for the R treatment. For the W&R treatment we see a large difference between the average auction price (27.95) and the average final price (79.10) and that average final price is higher than the average final price in all other treatments, even though it is still lower than the theoretical prediction of 175.

Table 2 also includes measures of efficiency. The possibility of seller default in this environment generates two types of efficiency - auction efficiency which is the equal to the fraction of the total possible surplus that was realized at the end of the auction, and final efficiency which is measured in an identical manner, but accounts for situations where the weak seller defaulted and no surplus is realized.[12] The auction efficiencies in the B, R, and W treatments are all similar, scoring about 90% efficient. This compares with an random auction efficiency of 82% which would have been achieved had the auction been won by a randomly selected seller.[13] The auction efficiency achieved by the W&R treatment (87%) appears lower than the other treatments, though it is still higher than what would be generated by random assignment.

In the treatments with asymmetric bidders (W and W&R), weak sellers default in the event of a loss which may lead to a different final efficiency because under default the realized surplus and resulting final efficiency are zero. In the W treatment, renegotiation cannot help the weak seller overcome auction losses and as a result this drastically lowers efficiency to 74% from 91% achieved at the auction stage. While renegotiation was possible in the W&R treatment, the final efficiency was still lower than the auction efficiency due to the fact that some renegotiation offers were rejected leading to default.[14].

How well the buyers fared in each treatment is summarized by buyer surplus. At the auction stage this is measured as the value of the buyer less the price paid in the auction. The buyer's final surplus accounts for changes due to renegotiation and default. If a new price was renegotiated, the surplus is updated using the new transaction price and under default the buyer's surplus is set to -25, the penalty imposed on the buyer. Of course, the buyer's surplus from the auction is inversely related to the auction price. The final surplus is of more interest because it incorporates both renegotiated changes in price and default. It is evident that the final surplus of the buyer is substantially lower with asymmetric

[12] The buyer's value is 150, so the maximum possible surplus is equal to 150 minus the lowest cost realization in the bidding group. The surplus achieved is equal to 150 minus the cost of the winning seller. In the case of default, the calculation of final efficiency assumes the achieved surplus is 0.

[13] This random efficiency is high because of the substantial common value element to the value structure.

[14] Final efficiency changes based on the frequency of default for weak sellers. Out of 240 auctions in the W&R treatment where weak won, 27 (11.25%) resulted in losses and default after renegotiation. In the W treatment, weak won in a 139 cases, 72 (52%) of which resulted in losses and default. Even though default was only 11% of outcomes under W&R, the complete loss of any realized surplus is substantial enough to dramatically decrease efficiency.

Treatment	Price (predicted)		Efficiency			Buyer Surplus	
	Auction	Final	Auction	Random Allocation	Final	Auction	Final
B	61.35 (77.31)	61.35 (77.31)	0.90	0.82	0.90	88.65	88.65
R	59.38 (77.56)	60.79 (77.56)	0.90	0.82	0.90	90.62	89.21
W	62.35 (76.82)	62.35 (76.82)	0.91	0.82	0.74	87.65	64.24
W&R	27.95 (0)	79.10 (175)	0.87	0.82	0.80	122.05	58.47

Table 2: Average price and efficiency by treatment.

Treatment *n* auctions	Strong Wins	Weak Wins	Strong Offer	Weak Offer	Strong Accepted Offer	Weak Accepted Offer
R (n=356)	100% (356)	-	79.62 (331)	-	67.73 (83)	-
W (n=360)	61% (221)	39% (139)	-	-	-	-
W&R (n=330)	27% (90)	73% (240)	81.13 (89)	102.36 (239)	74.33 (12)	100.05 (219)

Table 3: Propensity of strong/weak sellers to win auction. Average offers made and accepted offers by type and treatment (frequencies in parentheses below).

wealth constraints (due to occasional defaults) and there is no indication that renegotiation is helpful to the buyer.

Table 3 provides summary statistics on the propensity of each type of seller to win in each treatment as well as average offers and average accepted offers. As predicted in hypothesis 3, strong sellers win more often than weak sellers in the W treatment (221 versus 139, or strong sellers win 61% of the time) while the weak sellers win more often in the W&R treatment (90 versus 240, or weak sellers win 73% of the time). Turning to renegotiation, we note that the average offer made by strong sellers, 79.62, is higher than the average accepted offer is 67.73 and that the average accepted offer is not much higher than the average auction price for R (61.35) presented in table 2. In contrast, the average offer made by weak sellers in the W&R treatment, 102.36, is roughly equivalent to the average accepted weak offer and much higher than the average auction price (27.95). By hypothesis 4, all strong offers should be rejected while weak offers are more likely to be accepted. In the W&R treatment, buyers accepted 92% of the offers made by weak sellers, whereas only 12 offers (out of 89, or 13%) were accepted from strong sellers. In R, renegotiation is slightly more successful for strong sellers as 25% (83 out of 331) of strong offers are accepted by the buyer.

Losses may be excessive at the auction stage in B, R, and W, if bidders fall prey to the Winner's Curse and bid too low, failing to account for the adverse selection issue associated with winning. In the W&R treatment, we also expect losses except that in this case it's not because of the Winner's Curse, but because renegotiation changes the incentives of the auction stage which theoretically results in winning bids at a price of zero and losses amounting to the full true cost. To learn how severe the losses associated with low strategic bidding and the Winner's Curse are in the data, table 4 shows the average earnings per round, broken out by seller type and treatment. It contains average earnings as well as

	Earnings: Auction Prices		Earnings: Final Prices		Losses: Auction Prices		Losses: Final Prices	
	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak
B	-8.72	-	-8.72	-	-20.58	-	-20.58	-
R	-11.31	-	-9.91	-	-23.63	-	-25.47	-
W	-7.27	-5.56	-7.27	-19.27	-21.02	-23.54	-21.02	-50
W&R	-31.92	-49.93	-27.48	19.96	-35.01	-52.67	-34.66	-50

Table 4: Average earnings and losses by winning seller.

	# Losses at Auction Prices		# Losses at Final Prices	
	Strong	Weak	Strong	Weak
B	229 (64%)	-	229 (64%)	-
R	236 (66%)	-	216 (61%)	-
W	129 (58%)	72 (52%)	129 (58%)	72 (52%)
W&R	83 (92%)	229 (95%)	76 (84%)	27 (11%)

Table 5: Propensity to make losses by treatment.

the average size of loss which is conditioned on negative earnings. Table 5 then shows the propensity of sellers to make losses again broken down by seller type and treatment. The very clear picture is that the problem of seller losses is severe in this environment. In all treatments strong sellers have negative earnings conditional upon winning an auction. The only class of sellers that have positive expected earnings are weak sellers in the W&R treatment. In other treatments, winning sellers lose money approximately 50-60% of the time but weak sellers in the W&R treatment only makes losses 11% of the time.

4.2 Analysis of Bidding Behavior

We begin the analysis of sellers' bidding behavior by examining Figures 3 and 4, which are scatterplots of bids versus the combined cost signals. The figures also include regression plots and lines indicating the relevant equilibrium bidding behavior. Figure 3 provides the plots for the strong sellers in the B and R treatments. Theoretically, the bids are identical for strong sellers between these two treatments and visually the behavior is quite similar. However, in both treatments, sellers are bidding more aggressively than predicted.

Figure 4 examines the behavior in the asymmetric wealth treatments, W and W&R, for both strong and weak sellers. Theoretically there are significant differences predicted in bidding behavior between the treatments. In the W treatment, strong sellers are predicted to be more aggressive than weak and indeed the regression line through those points is lower than that for the weak sellers. The opposite is predicted in the W&R treatment and we observe the predicted switch in regression lines. We do not represent the equilibrium in the W&R panel as there is no distinct prediction for the strong sellers; the strong sellers are simply predicted to bid above the weak sellers. The weak sellers are predicted to bid 0 which clearly only a few do.

While the figures help provide an intuitive idea for how the sellers submitted bids, statistical tests for the visual properties noted above can be found in Tables 6 and 7. Table 6 contains three regressions based on the data from the B and R treatments to examine

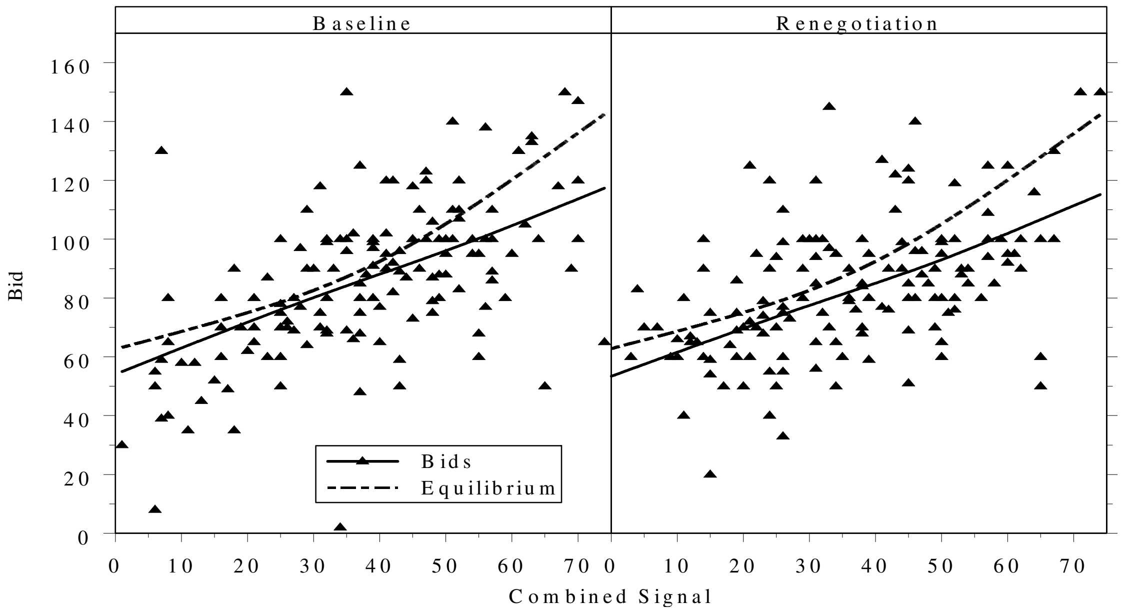

Figure 3: Bids plotted against combined signals for strong sellers in B and R treatments.

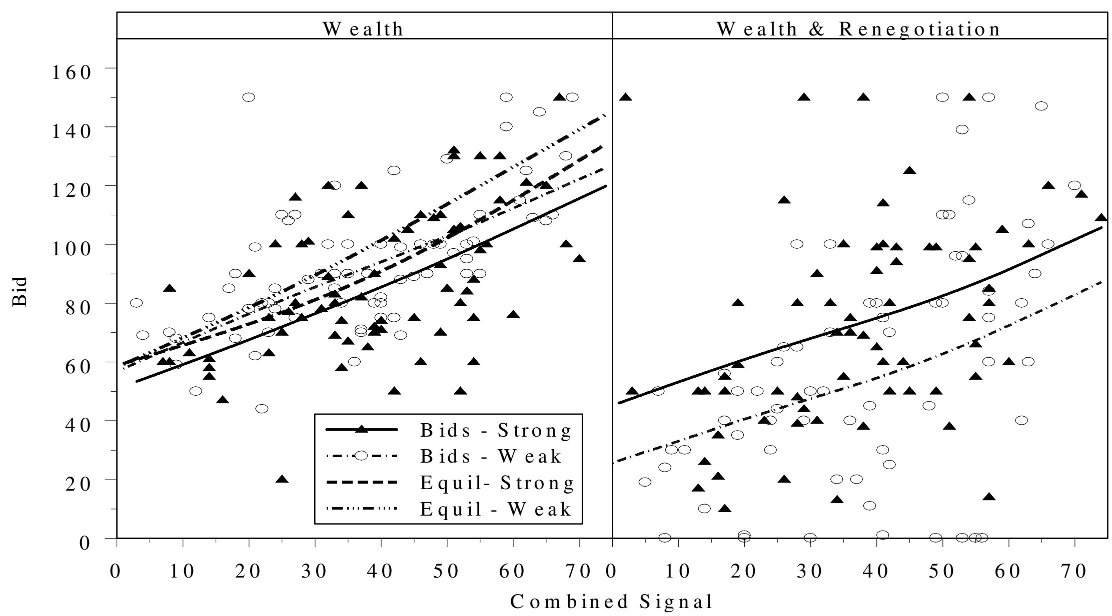

Figure 4: Plots of bids versus combined signals for weak and strong sellers in the W and W&R treatments.

the differences between those two treatments. All regressions use the bid submitted by the seller (all are strong in those treatments) in a round as the dependent variable and have standard errors clustered by subject. The first two specifications are random effect panel regressions and test whether there is a difference in behavior between when renegotiation is and is not present. We also include a dummy variable, L, to capture situations in which sellers have low balances to see if they bid differently from cases when they do not have low balances. The last specification presents a test of whether observed bidding behavior differs from equilibrium behavior in a pooled OLS regression, used to eliminate the constant from the regression.

Result 1 *There is no statistically significant difference in bidding behavior between the B and R treatments.*

The support for the first result is provided by the fact that in models 1 and 2 the dummy variable for the renegotiation treatment, R, is insignificant. We also have provided several interactions between that and other variables and these too are mostly insignificant. Result 1 confirms hypothesis 1.

Result 2 *Bidding behavior in both the B and R treatments is more aggressive than predicted.*

To test the relationship between theory and what sellers actually bid, in model 3 we use the theoretically predicted bid as an independent variable rather than the signal and include an interaction with the treatment. If subjects were bidding as theory predicted, the coefficient on the variable b_i would be equal to 1 and the interaction would be equal to 0. While the coefficient on the interaction is not significantly different from 0, the coefficient on b_i is less than 1 and is significantly different from 1 ($p < 0.001$) as is the linear combination of the two which captures the total effect for the Renegotiation treatment ($p < 0.001$). This provides support for result 2.

For the W and W&R treatments we predict in hypothesis 2 that bidding behavior should shift between the treatments. In the W treatment, weak bidders should bid less aggressively than strong. In the W&R treatment, this relationship is reversed. We provide tests of the comparative static predictions and also a general test of how well the theory explains the behavior in the W treatment.

Result 3 *In the W treatment, strong sellers bid more aggressively than weak sellers. In the W&R treatment, weak sellers bid more aggressively than strong sellers.*

The statistical support for result 3 is derived from the first two columns in table 7. Column 1 provides a regression specification looking at how bids in the W treatment depend on the combined cost signal and on type. Column 2 provides the same specification for the W&R treatment. We find that the dummy variable for the strong seller is negative and significant in the W treatment specification and positive and significant in the W&R treatment. This is the comparative static predicted by hypothesis 2.

Result 4 *In the W treatment, sellers of both types bid more aggressively than predicted.*

	(1)	(2)		(3)
Combined cost signal, x_i	0.817***	0.819***	Equilibrium Bid, b_i	0.914***
	(0.034)	(0.046)		(0.019)
Renegotiation, R	-2.595	-2.251	$b_i * R$	-0.027
	(2.347)	(3.498)		(0.024)
$R * x_i$		-0.002		
		(0.068)		
Balance<50, L		14.48		
		(17.66)		
$R * L$		-81.93***		
		(21.97)		
Constant	55.52***	55.35***		
	(2.236)	(2.516)		
Observations	2,864	2,864		2,864
Clusters	96	96		96

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 6: Random effects regressions with bid as dependent variable using data from B and R treatments only.

To examine whether we observe behavior corresponding to the specific predictions of the theory, for the W&R treatment it is informative enough to examine the right side panel in Figure 4. We have no specific prediction for strong sellers in that treatment but the weak sellers are predicted to bid 0. They clearly do not, though as we just saw, they do bid more aggressively than the strong sellers. So while the specific prediction fails, the comparative static still holds. For the W treatment we do have specific predictions of bid functions for both types and regressions testing conformance with those bid functions are contained in columns 3 and 4. These are again pooled OLS regressions with the standard errors clustered on the subjects without an intercept term. Similar to what was observed in the B and R treatments, we find that bidders of both types bid more aggressively than predicted as the coefficients on the predicted bid are significantly less than 1 (for both $p < 0.001$). This provides the support for result 4.

4.3 Analysis of Renegotiation Behavior

The renegotiation stage involves a take-it-or-leave-it offer between the winning seller and the buyer. Theoretically, all offers made by strong sellers should be rejected as these sellers can absorb any losses made in the auction. In contrast, when renegotiation is allowed, weak bidders are predicted to bid zero which almost always implies losses at the auction stage and as a result any offer made by weak sellers less than or equal to 175 will be accepted by buyers to avoid default by the weak seller. As seen in the previous analysis of bidding behavior, zero bids by weak sellers are infrequent, and so as stated in hypothesis 4, we expect that a weaker property will hold which is that a buyer should be more likely to accept an offer if the auction price is lower.

A first look at the accept/reject decisions is seen in Figure 5 which provides histograms

	W Only	W&R Only	W Only	
			Strong Bidders	Weak Bidders
	(1)	(2)	(3)	(4)
Combined cost signal, x_i	0.937***	0.808***		
	(0.054)	(0.098)		
Strong seller, S	-6.591***	17.08**		
	(2.237)	(6.672)		
$S * x_i$	-0.027	0.053		
	(0.055)	(0.113)		
Equilibrium bid, *bid*			0.926***	0.918***
			(0.020)	(0.019)
Constant	56.42***	23.93***		
	(2.820)	(4.487)		
Observations	1,433	1,320	715	718
Clusters	48	44	48	48

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 7: Random effects regressions with bid as dependent variable using data from noted treatment and bidder type only.

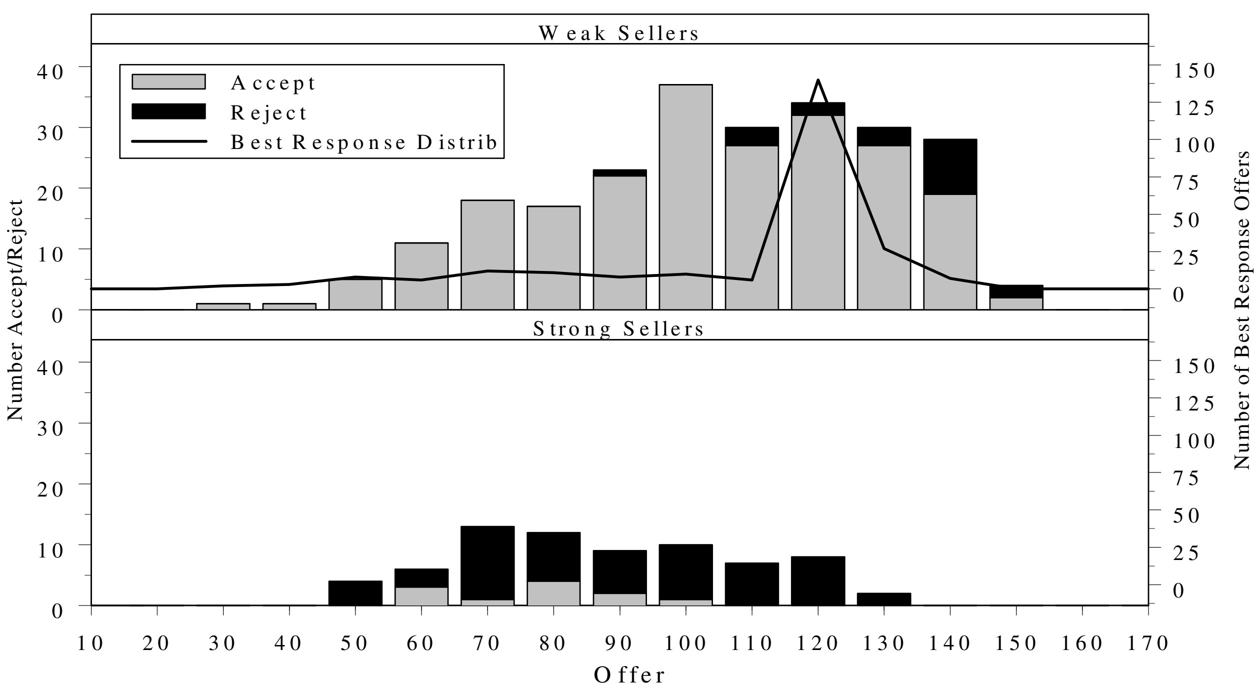

Figure 5: Histograms of offers by seller type.

	(1)	(2)		(3)
Auction price, p^*	0.003	0.008*	Best Response Offer	0.907
	(0.003)	(0.005)		(0.049)
Renegotiation offer, f	-0.011***	-0.014***		
	(0.002)	(0.005)		
Weak seller, WS	0.902***	0.976***		
	(0.036)	(0.027)		
$WS * p^*$		-0.011**		
		(0.006)		
$WS * f$		-0.003		
		(0.005)		
Wealth & Renegotiation, $W\&R$	-0.059	0.023		
	(0.198)	(0.204)		
$f < p^* + 10$	0.197**	0.131		
	(0.075)	(0.094)		
Clusters	23	23		39
Observations	659	659		239

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 8: Marginal effects from probit regressions with acceptance of renegotiation offer as the dependent variable.

of all offers by seller type indicating which offers are accepted versus rejected. It is clearly the case that offers by strong sellers are almost always rejected, as predicted, and offers by weak sellers are typically accepted. There is also an indication that offers by weak sellers at high levels do get rejected.

Columns 1 and 2 in Table 8 provide marginal effects from probit regressions with agreement to a new offer as the dependent variable. Standard errors are clustered at the subject level. We include a dummy, $f < p^* + 10$, to account for offers that are near the auction price and a limited number of offers made by sellers below the auction price.

Result 5 *Buyers are more willing to accept offers made by weak sellers than strong.*

Result 6 *Buyers willingness to accept is decreasing in the level of the offer.*

Support for result 5 is derived from the positive coefficient on the dummy for a winning weak seller which is significant across both specifications. As what is shown in the table are the marginal effects, the fact that the coefficient is above 0.90 indicates that this is by far the most substantial determinant in whether an offer is accepted or rejected. This provides robust verification that buyers are much more willing to accept the offers of weak sellers than they are strong sellers. The support for result 6 is found in the negative and significant coefficient on the offer variable. Thus both parts of hypothesis 4 on renegotiation behavior have been supported.

The offer/reject behavior we observe is consistent with the comparative statics of the model but there are important deviations from the theoretical predictions. The average offer made by weak sellers is 102.36 (see table 3), which is relatively far from the predicted offer of 175, or even the value of the buyer 150. This is a substantial deviation from the theoretical prediction and it is worth investigating to determine why sellers are making such low offers. The key question is whether the sellers are making offers more generous than they have to, perhaps due to fairness considerations, or are the buyers rejecting more high offers than they should according to the subgame perfect prediction which causes the sellers to best respond with lower price requests. Figure 5 does show that high offers tend to be rejected even from weak sellers and they might be doing this with high enough propensity to make such offers unprofitable.

In order to answer this question we need to understand how a rational seller would best respond to the buyers, given how buyers tend to make accept/reject decisions. Due to the multi-dimensional nature of the problem, Figure 5 does not offer a detailed enough perspective of the rejection probabilities as the buyer sees not just the offer but also the auction close price - both of which may figure into the accept/reject decision. Due to the size and sparseness of the full grid, we cannot infer acceptance propensities from the observed data alone. We can, however, estimate acceptance probabilities over the entire space. We have done so and present the estimated probability of acceptance[15] for any combination of auction price and offer (assuming a weak seller) in Figure 6. What we see is that despite the subgame perfect prediction, offers over 100 have a rapidly declining probability of being accepted.[16]

Using this probability of acceptance, we can calculate the expected utility of any offer from the point of view of a seller at a given auction close price and cost realization to determine the empirical best response offer. In Figure 5 we provide one way of summarizing these best response offers as we include a distribution plot of what the optimal offers would have been for each of the cases in which offers were made by weak sellers in the experiments. What we observe is that there is a spike in optimal offers in the range of 120-130 which is well below 175 and also roughly corresponds to the peak of the distribution of actual offers, though the "peak" is more of a plateau as the bulk of the actual offers, 62%, are in the range of 100-140. In the third column of Table 8 we provide a pooled OLS regression with standard errors clustered on the subject of the actual offer on the best response offer. We find that the actual offer is on average 90% of the best response offer and the difference is significant (test of whether the coefficient is equal to 1 yield a $p-$value of 0.068). This analysis suggests that while sellers were making offers less aggressively than the theory predicts, the main reason for this deviation from the theory is the rejection behavior of the buyers making very high offers not profitable.

[15] The logit model is $Accept = \beta_0 + \beta_1 * price + \beta_2 * price^2 + \beta_3 * price^3 + offer$, where $price$ is the winning low bid from the auction, and $offer$ is the proposed offer of the weak seller in renegotiation. The dependent variable was a binary indicating whether or not the buyer accepted the offer. Standard errors were clustered at the individual level.

[16] Of course since these accept/reject decisions were not elicited using the strategy method it is not necessarily the case that this estimated acceptance probability represents the true average strategy of the buyers. The problem is that certain very high and very low offers are not observed with much frequency. On the other hand we do observe a great deal of heterogeneity in the offers which should be enough to indicate that for the bulk of the offer range we do have enough information to make reliable claims over the average strategy of the buyers.

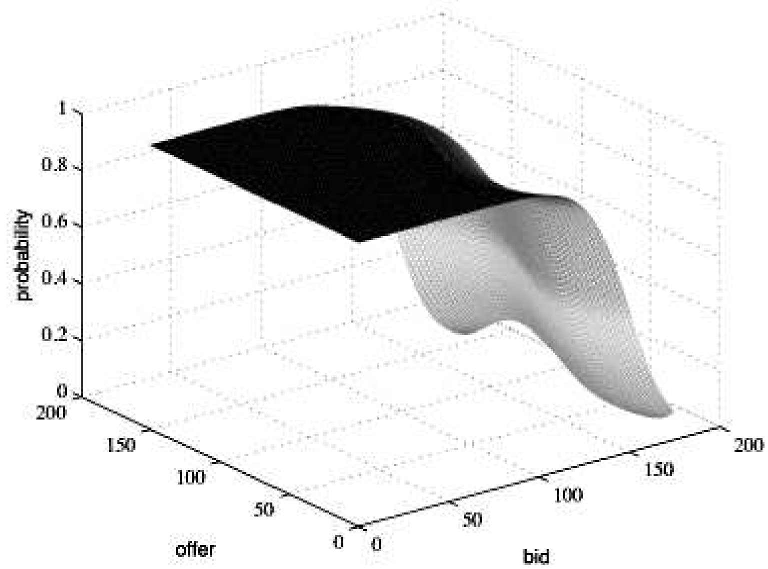

Figure 6: Estimated probability of buyer accepting offer given a closing bid.

4.4 Analysis of Outcomes

In this section, we formally analyze price, efficiency, and buyer surplus outcomes at the auction stage and after any default or renegotiation. Table 9 presents six pooled OLS regressions with standard errors clustered at the session level. The first two specifications focus on auction price and final price. In theory, the auction and final prices should be equivalent between the B and R treatments while the W&R treatment should result in the lowest auction price and the highest final price across all treatments.

Result 7 *Auction and final prices are equivalent between the B and R treatments. Auction prices are lowest and final prices highest in the W&R treatment.*

Result 7 is in favor of the theoretical price predictions given by hypothesis 5 and is supported by the coefficient on the treatment dummy, R, which is found to be not significantly different from the baseline treatment (B) in both the auction price and final price regressions. The W&R treatment is the only treatment which is significantly different from the others which matches the prediction that the final prices from it would be higher than in the other treatments. Prices in W&R are significantly lower at the auction stage than all other treatments, and significantly higher after renegotiation than all other treatments.

Models 3 and 4 examine efficiency at the auction stage and final efficiency, respectively. Recall that final efficiency only differs from auction efficiency when bidders default and final efficiency is set to zero. Similar to what was observed for auction prices, we find no significant differences between the B, R, and W treatments for auction efficiency. On the other hand, auction efficiency is significantly lower in the W&R treatment. Default was possible in the W and W&R treatments and as a result final efficiency changed from

	Price		Efficiency		Buyer Surplus	
	Auction	Final	Auction	Final	Auction	Final
	(1)	(2)	(3)	(4)	(5)	(6)
Lowest Combined Signal	0.344***	0.314***	-0.0007***	-0.003***	-0.344***	-0.602***
	(0.037)	(0.030)	(<0.001)	(<0.001)	(0.037)	(0.104)
Random Efficiency			0.512***	0.404***		
			(0.102)	(0.105)		
Wealth, W	1.048	1.044	0.013	-0.162***	-1.048	-24.49***
	(2.572)	(2.564)	(0.011)	(0.024)	(2.572)	(2.361)
Renegotiation, R	-2.083	-0.665	-0.002	-0.001	2.083	0.767
	(1.751)	(2.101)	(0.013)	(0.012)	(1.751)	(2.246)
Wealth & Renegotiation, $W\&R$	-33.49***	17.67***	-0.030**	-0.098***	33.488***	-30.018***
	(5.847)	(3.790)	(0.012)	(0.016)	(5.847)	(5.183)
Constant	40.22***	42.05***	0.521***	0.74***	109.78***	125.697***
	(3.112)	(2.812)	(0.091)	(0.118)	(3.112)	(6.717)
Clusters	12	12	12	12	12	12
Observations	1,406	1,406	1,406	1,406	1,046	1,046

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 9: Pooled OLS regressions on noted variables clustered at session level.

the auction stage for these treatments. The final efficiency levels of the W treatment are significantly lower than either the B or R treatments. Renegotiation did not help overcome the efficiency loss from default as the coefficient on the W&R treatment is still negative, significant, and a larger magnitude that what was observed in the auction efficiency regression.

Models 5 and 6 examine the buyer's surplus, which is measured (at the auction stage) as the difference between the buyer's value and the transaction price. The buyer's surplus may change if the winning seller defaults, in which case the surplus is set to -25, or if renegotiation took place and the surplus calculation uses the new transaction price. The buyer's surplus is an important indicator for whether or not the buyer should allow renegotiation in the procurement process. At the auction stage, significant differences only exist for between the B and W&R treatments, with W&R yielding much higher potential buyer surplus due to the very low auction prices. That high buyer surplus is not realized due to the renegotiation phase. In the final surplus regression we find that there is still no difference between the surplus achieved in B and R treatments, as expected, while there is a substantial reduction in the W and W&R treatments below what is achievable in the B treatment. This is of course due to the existence of weak sellers who occasionally default on projects. We can test the difference in the coefficients from model 6 on the W and W&R treatments to find a lack of a significant difference ($p = 0.319$). The indication here is that despite the higher prices paid in the W&R treatment, there is no drop in surplus to the buyers as there is also a drop in the frequency of defaulting sellers. We hesitate to over interpret this finding too much as an indication that renegotiation fails to harm buyers. This finding is to a great extent dependent on how we parameterized the recontracting costs. By changing them we could have likely ended up with a different result here. The important take away though is that even with the hefty price increase stemming from renegotiation that doesn't guarantee that the buyer is worse off as there is this important trade-off regarding default probability to consider. In this case we see that renegotiation may not be hurting buyers as much as indicated by the prices but neither is it helping as the buyer surplus is not increasing.

5 Conclusion

The use of renegotiation following competitive bidding in procurement settings is commonly justified as a way to help alleviate losses associated with the Winner's Curse / underbidding and prevent default by winning sellers who were unable to anticipate the full cost when placing bids. Due to the potential of post-auction renegotiation changing incentives in the auction, the effect of such post-auction interactions should be analyzed carefully to understand whether they will be effective in solving the intended problems. If bidders anticipate successful renegotiation, there is an incentive to strategically lower bids below standard levels to provide credible commitment of post-auction default which confers upon them a significant advantage in post-auction bargaining.

We use a combination of theory and laboratory experiments to analyze the effects of post-auction renegotiation in procurement auctions with and without asymmetric bidders. Asymmetry is introduced through wealth constraints where sellers differ in the ability to sustain losses without bankruptcy. Weak sellers will default in the event of a loss, imposing a penalty on the buyer and incurring a default penalty. Strong sellers will never default, absorbing all losses.

Our experimental results provide strong support for the comparative static predictions of the theory. First, in an environment with no wealth constraints, renegotiation is never successful as almost all offers made by strong sellers are rejected by buyers. As a result, bids placed by strong sellers do not adjust to the presence or absence of a renegotiation option. Weak sellers who cannot absorb losses are shown to shift their behavior substantially between the situations in which renegotiation is versus is not present. As predicted, buyers accept renegotiation offer requests by weak sellers quite often. This high acceptance rate encourages bidding low to win and then using their credibility of default to obtain substantial price concessions from the buyer. The end result is that weak sellers are substantially advantaged in situations in which renegotiation is allowed as they win the majority of the auctions and are able to negotiate very favorable prices. The upside for the buyers is that the sellers default substantially less often and depending on the costs of default that might be enough to offset the price increases. Such a determination depends on the utility function of the buyer.

The important aspect of these results is that we find little evidence that renegotiation is used to correct for any problems stemming from the Winner's Curse. The primary effect of renegotiation is to give those with the credibility to default an incentive to distort their bidding behavior during the auction so that they can win and then bargain for advantageous prices with the buyer. While renegotiation almost incidentally diminishes the number of defaults, it does so in a way that does not deal very directly with the cause of the defaults and can cause other negative consequences through the distortions in the bidding behavior.

There are certainly a number of differences in the experimental environment specified here and many external procurement cases. One key point is that the experimental design specified clearly whether renegotiation would or would not be allowed at the conclusion of an auction. In the field, many buyers may be less clear regarding whether renegotiation would be considered or not. While this is certainly a difference between our environment and the field, our results are still informative in regard to these situations. Sellers will form beliefs regarding the probability with which they think the buyer might be willing to engage in renegotiation and the greater that belief, the more likely sellers will try to exploit the renegotiation stage as seen in our results. The clear indication is that buyers are likely best off by sending very clear signals that renegotiation will not be considered.

There are also practices commonly in use that may counter the adverse consequences of renegotiation. One common practice is to discard "low" bids from an auction. The first difficulty for a procurer in implementing this practice is to define what "low" means. Some may just automatically throw out the lowest bid or a certain number of low bids. Other rules involve discarding bids that are a certain distance below the average. In each case, the idea is to remove offers which clearly appear too low and are more likely to lead to default. In certain cases, practices of this sort may be effective. Of course the problem is in determining which bids are too low. If the cutoff used is too high, a buyer could end up excluding valid bids and paying more than necessary. If the cutoff is not high enough, there may still be bids allowed which are low enough that a seller who wins could still establish a credible commitment to default. So the likelihood of success of this method depends on the procurer setting the threshold correctly. For a procurer who is well informed about the likely costs of the project, this may be possible but an environment in which costs are known up-front is not one in which the Winner's Curse would be a concern . So the environments in which a buyer could successfully use this practice are ones in which it likely isn't needed.

Another notable difference with many field examples of procurement is that our environment does not allow for long-run, repeated interactions or the formation of reputations. With repeated interactions, a norm may develop with sellers asking for renegotiated prices only when necessary to prevent default and buyers accepting when the request appears credible. Cooperation could be sustained through some form of trigger strategy. While such mutual cooperation is feasible, if a buyer has a seller with whom they have such a cooperative relationship, that buyer is unlikely to be using auctions as a procurement mechanism since they could just negotiate directly with the cooperative contractor. In some procurement situations, auctions are actually opposed because they are thought to stifle the communication and cooperation necessary to complete a project (Bajari, McMillan, and Tadelis (2009)). Alternatively, long-run interactions could also lead to the formation of reputations in which sellers that are notorious for bidding low just to gain an option for renegotiation could be excluded from future auctions. In situations where buyers would have this sort of long run information on the behavior of the sellers, such exclusion is likely possible and could be beneficial.

Perhaps the best way to interpret our results is to note that they apply most appropriately to situations in which such long-term relationships aren't likely to exist. In such cases, both sides will act according to their immediate self-interest which leads to the possibility of renegotiation primarily serving to advantage firms with a higher probability of default. These firms will then use their strategic leverage to obtain very favorable prices upon renegotiation. While this may lessen the likelihood of default, it is not occurring in such a way as to compensate for the Winner's Curse. Consequently, in environments that are a reasonable match with the one studied here, low-bid procurement auctions with the possibility of renegotiation should be avoided in favor of other contracting mechanisms such as contingent contracting, performance bonds or average bid auctions.

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