The Effect of Offer Verifiability on the Relationship Between Auctions and Multilateral Negotiations[*]

Charles J. Thomas
Federal Trade Commission
Division of Economic Policy Analysis
600 Pennsylvania Ave., NW
Washington, D.C. 20580
E-mail: *cjthomas@ftc.gov*

Bart J. Wilson
Interdisciplinary Center for Economic Science
George Mason University
4400 University Drive, MSN 1B2
Fairfax, VA 22030
E-mail: *bwilson3@gmu.edu*

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Abstract: We use the experimental method to compare second-price auctions to "verifiable" multilateral negotiations in which the sole buyer can credibly reveal to sellers the best price offer it currently holds. We find that transaction prices are lower in verifiable multilateral negotiations than in second-price auctions, despite the two institutions' seeming equivalence. The difference occurs because low-cost sellers in the negotiations tend to submit initial offers that are less than the second-lowest cost. We also compare the two institutions to previously studied first-price auctions and multilateral negotiations with nonverifiable offers. Second-price auctions yield the highest prices, followed in order by verifiable negotiations, nonverifiable negotiations, and first-price auctions.

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1. Introduction

One of the more interesting facets of voluntary exchange is how changes in the strategic environment lead to differences in transaction outcomes. For example, increasing the value of a player's threat-point payoff increases their payoff from Nash bargaining. The theoretical work in Holt [1980] shows that switching from first-price auction rules to second-price auction rules decreases the auctioneer's expected payoff if bidders are risk averse. Finally, comparing the pioneering experimental work in Chamberlin [1948] and Smith [1962] illustrates that changing the nature of the information available to the players can dramatically influence the price and efficiency of an exchange process. With this insight in mind, in this paper we use the experimental method to examine and compare four exchange mechanisms in a procurement setting in which a buyer faces several sellers that have privately known production costs.

The first two institutions are variants of the multilateral negotiations introduced in Thomas and Wilson [2001]. In this common exchange mechanism, a buyer solicits price offers from multiple sellers, and then it elicits more favorable offers by playing the sellers off one another until it accepts one of the offers or breaks off the negotiations. Among other settings, multilateral negotiations are pervasive in industrial procurement, the securing of high-end job offers, and the purchasing of expensive goods such as computers, contractors' services, and automobiles.

The second two institutions are the first-price auction and the second-price auction. These well-known auction formats and their theoretically isomorphic variants, the Dutch auction and the English auction, are used extensively to allocate products as varied as flowers, art, produce, fish, government securities, and offshore mineral rights.[1] More recently, several governments have used auctions to allocate such valuable resources as radio spectra, electric power, and pollution rights.[2]

We hypothesize that the outcome of a multilateral negotiation is critically influenced by the buyer's ability to credibly reveal to a seller the price offers it holds from other sellers. With that hypothesis in mind, in Thomas and Wilson [2001] we investigated *nonverifiable multilateral negotiations*, in which the buyer cannot credibly reveal the best offer it currently holds. In many negotiation settings it is reasonable to assume that the buyer is unable or unwilling to credibly

[1] See Milgrom and Weber [1982] and McAfee and McMillan [1987].
[2] See McAfee and McMillan [1996], Wolfram [1998], and Cason [1995] for details, respectively.

reveal rival sellers' offers. We compared nonverifiable negotiations to first-price auctions, because the two institutions appeared to be conceptually similar. We found that the two institutions' prices are indistinguishable with four sellers, but that negotiated prices exceed auction prices with two sellers.

In this paper we investigate *verifiable multilateral negotiations*, in which the buyer can credibly reveal the best offer it currently holds. Internet-based third-party business-to-business exchanges provide one of the best examples of institutions in which a buyer could credibly reveal its best offer. As an independent third party with a reputation to maintain and legal responsibilities to uphold, a business-to-business exchange can credibly authenticate the best offer that a buyer currently holds. Even though most people likely view auctions as the dominant exchange mechanism in B2B commerce, negotiations are becoming more common on B2B sites. For example, at www.chemconnect.com, a purchasing manager can invite its suppliers into a "Corporate Trading Room" to settle on a transaction for raw chemical materials.[3] We compare verifiable negotiations to second-price auctions because, as we will argue, the two institutions appear to be conceptually similar. Moreover, examining these two institutions naturally complements our earlier work.

In addition to comparing the outcomes of verifiable multilateral negotiations and second-price auctions, we integrate those results with the results of our earlier experiment that compared nonverifiable multilateral negotiations and first-price auctions. The integrated results provide a detailed picture of the relationships among the four institutions.

The outcomes of multilateral negotiations are not only interesting in their own right. Their relationship to the outcomes of various auction formats is interesting because of its implications for institutional design. The fact that some buyers in an industry use multilateral negotiations, while others use one-shot sealed-bid auctions, suggests either that the processes are outcome-equivalent or that there are factors that make one process more favorable than the other. Identifying these factors should lead to a more informed selection of an exchange process.

We study the relationship between second-price auctions and verifiable multilateral negotiations by permitting fairly unstructured negotiation between a buyer and several sellers. Each experimental session anonymously matches a buyer with either two or four sellers, and

[3] The World Chemical Exchange at www.chemconnect.com reports that it in first quarter of 2001, more than $2 billion worth of transactions were conducted at its site.

consists of several periods of negotiations and second-price auctions. When multilateral negotiations are employed, the buyer can communicate electronically in real-time with the sellers, but the sellers cannot communicate with each other. When auctions are employed, the buyer plays a passive role, and none of the players can communicate with each other. We match sellers' costs across sessions and institutions to study whether outcomes depend on which institution is used. Similarly, we vary the number of sellers to see how the outcomes change within an institution.

We find that transaction prices are strictly lower in verifiable multilateral negotiations than in second-price auctions, despite the two institutions' seeming equivalence. Price-setting in the second-price auctions largely reflects the sellers' dominant strategy, and the across-institution price difference emerges when there is a large spread between the lowest and second-lowest

depends critically on the buyer's ability to credibly reveal to a seller its rivals' offers. Specifically, if the offers can be credibly revealed, then the multilateral negotiation should be similar to a second-price or English auction, because sellers should be willing to make concessions until the price reaches their cost. If the offers cannot be credibly revealed, then the multilateral negotiation should be similar to a first-price auction.

To understand why the ability to credibly reveal offers might play a crucial role, consider the problem facing a seller in a multilateral negotiation when its rivals' offers cannot be credibly revealed. When the buyer tries to use a rival's offer to elicit a better offer from the seller, the seller must be concerned that the buyer is not being truthful about the terms or the existence of the rival's offer. Consequently, the seller must be aware of the danger that he could end up bidding against himself by offering price reductions that are undercut by fictitious discounts from a rival. This danger is not present when the best offer can be credibly revealed.

For several reasons, the preceding relationships may not be exact, either empirically or

out of the communication process if it does not make serious offers. These market frictions would tend to reduce negotiated prices, but not necessarily to a level below that of second-price auction prices.

3. Experimental Design and Procedures

Using "*S*" to denote a sequence of second-price auctions and "*V*" to denote a sequence of verifiable multilateral negotiations, we pair two treatments, one with the sequence *VSSV*, and one with the sequence *SSVS*. The first and third sequences consist of 12 transactions; the second consists of 16, while the fourth consists of 6.[7] Later we refer to each of the four sequences as a "regime." We vary these two treatments by changing the number of sellers. One has two sellers per buyer, while the other has four sellers per buyer.

For each of the four treatments, {2 sellers, 4 sellers} {*VSSV*, *SSVS*}, we have four groups of subjects. Each subject is assigned a specific role in a specific group for the duration of the experiment. A seller's characteristics consist of 46 random cost draws from the Uniform distribution on the support [0.00, 6.00], one for each time period. Of the eight groups with four sellers, seller i (i = 1, 2, 3, 4) has the same cost draws across groups. Of the eight groups with two sellers, seller i (i = 1, 2) has the same cost draws across groups. Moreover, the costs of sellers 1 and 2 in the two-seller treatment are the same as the costs of sellers 1 and 2 in the four-seller treatment.

Our experiment consisted of a total of 736 second-price auctions or rounds of verifiable multilateral negotiations using 64 undergraduate student volunteers (48 sellers and 16 buyers). Some students had participated previously in market experiments, but with substantially different trading institutions. No subject participated in more than one of the sessions.

In addition to reading self-paced instructions displayed by the software, the subjects followed along as the experiment monitor read aloud from a handout with both additional and review information.[8] The public instructions explained (and made common knowledge) that the sellers' costs were assigned randomly each period and that the distribution of the draws was

U[0.00, 6.00]. The instructions also revealed that the buyer's value was 6.00. Revealing the buyer's value is consistent with prior buying auction experiments in which bids are constrained to be nonnegative, which effectively bounds the buyers' bids between zero and their respective values. Here, we effectively bound the sellers' price offers between their respective costs and 6.00.

The random cost draw for a given period was disclosed to the subject at the beginning of the period. In the second-price auction environment, after learning his cost each seller had four minutes to submit his private offer to sell, though this limit was never binding. The computer automatically awarded the sale to the seller that submitted the lowest offer once all of the offers had been submitted, provided that the lowest offer was less than 6.00. The winning seller was paid the lower of the second-lowest price and the buyer's value. At the end of the auction, the final market price was announced electronically to all market participants, after which the session proceeded to the next period.

In the verifiable multilateral negotiation environment, after learning his cost each seller had 30 seconds in the first phase of the period to submit his initial offer to the buyer. The

next period. At all times, the best submitted offer was visible to all participants, and they all were informed in the instructions that this was the case.

The subjects were not told the number of trading periods in the session or in any institutional regime within the session. Moreover, the subjects did not know the nature of any future trading institution, as the instructions for an institution were displayed only prior to commencing trade. It was public information that the same set of sellers was matched with the same buyer for the duration of the experiment. Such repeated play is a common feature of naturally occurring markets and previous auction experiments.[10]

Participants received $5 for showing up on time, plus their salient earnings. In the four-seller sessions, the buyers' exchange rate was US$1 for 7 experimental dollars, and the sellers' exchange rate was US$1.50 for 1 experimental dollar. In the two-seller sessions, the exchange amounts were 4 and 2 experimental dollars for each US$1, respectively. To equalize the buyers' and sellers' earnings expectations, the exchange rates are more favorable to the sellers because a buyer receives a payoff every period, but a seller only expects to win every two or four periods. Based upon the theoretical second-price auction outcomes for the observed cost draws, these exchange rates reflect an average cash payoff of $21.50 for all types of agents. In addition to the $5 fee for showing up on time, the average subject's earnings for this experiment were $20.50. The average session lasted 75 to 90 minutes.

4. Within-Experiment Results

For each period of play, our data set includes the transaction price, each seller's cost, each seller's initial and subsequent offers in the multilateral negotiations, and a verbatim record of the communications between buyers and sellers. The latter is not part of our statistical analysis, but it provides qualitative insights about the players' strategies and their beliefs about other's strategies. The data permit us to compare the transaction prices and efficiency for the different institutions and numbers of sellers, a summary of which is in Table 1.

We present our within-experiment results as a series of three findings. Our qualitative results are displayed in tables and figures, and our quantitative results are derived by analyzing

[10] For example, see Coppinger, Smith and Titus [1980], Cox, Roberson, and Smith [1982], Cox, Smith, and Walker [1983], and Kagel, Harstad, and Levin [1987].

the data using a linear mixed-effects model for repeated measures.[11] Table 2 reports the model's regression results for each of the four regimes. The dependent variable is the observed transaction price. The treatment effects (*Two* vs. *Four* Sellers, and *Verifiable* Negotiation vs. *Second-Price Auction*) and an interaction effect from the 2 2 design are modeled as (zero-one) fixed effects, while the 16 independent sessions are modeled as random effects, e_i. Specifically, we estimate the model

$$Price_{ij} \quad e_i \quad {}_1 Two_i \quad {}_2 Verifiable_i \quad {}_3 Two_i \quad Verifiable_i \quad {}_{ij},$$

where $e_i \sim N(0, \ {}^2_1)$ and $\sim \ (0, \ {}^2_{2,i})$

Figure 1(a) displays by treatment the transaction prices in each of the first twelve periods, averaged over the four sessions in each treatment. Figures 1(b) through 1(d) display the same information for the remaining three regimes. As with the data presented in Table 1, visual examination of the average prices in the two-seller and four-seller *SSVS* treatments suggests that in each period the transaction prices are higher with fewer sellers. The same conclusion holds for the *VSSV* treatments.

The estimates in Table 2 from the linear mixed-effects model for repeated measures provide a formal test of this finding. The coefficient on the *Two* dummy variable, which measures the primary effect of the two-seller treatment, is positive and highly significant in all four regimes, raising transaction prices by $\hat{}_1$ = 1.13, 1.61, 0.82, and 2.26 experimental dollars, respectively (*p*-value = 0.0013, 0.0000, 0.0191, and 0.0000). Because the coefficient $_3$

prices of the multilateral negotiations and the second-price auctions, holding the number of sellers constant at four. The point estimates for Regimes 1, 3, and 4 are –0.59, –1.62, and –0.73, respectively, and are statistically significant (*p*-values = 0.0402, 0.0005, and 0.0276), so we reject the null hypothesis in favor of the alternative that verifiable prices are less than second-price auction prices. This is not too surprising, given our visual examination of the four-seller transaction prices in Table 1 and Figure 1. With four sellers in second-price auctions, the estimated transaction prices are given by $\hat{\ }$, so the *Verifiable* treatment lowers four-seller transaction prices by 19%, 50%, and 27% to $\hat{\ }$ $\hat{\ }_2$ = 2.49, 1.59, and 1.94.

For two sellers the total effect of the *Verifiable* treatment significantly lowers transaction prices in Regimes 1, 3, and 4 by $\hat{\ }_2$ $\hat{\ }_3$ –0.70, –1.56, and –1.40 experimental dollars, respectively, below the level for two sellers in second-price auctions (*p*-values = 0.0319, 0.0016, and 0.0012). Because the coefficient $\hat{\ }_3$ on the interaction term is insignificantly different from zero, we cannot reject the null hypothesis that the across-treatment magnitudes do not change with the number of sellers. With two sellers in second-price auctions, the estimated transaction prices are given by $\hat{\ }$ $\hat{\ }_1$, so the *Verifiable* treatment lowers two-seller transaction prices by 17%, 39%, and 28% to $\hat{\ }$ $\hat{\ }_1$ $\hat{\ }_2$ $\hat{\ }_3$ 3.50, 2.473, and 3.53.

It is worth noting that verifiable negotiation prices are always lower than second-price auction prices, regardless of the sequencing of the institutions. This robustness to the ordering makes more compelling our inference from Finding 2 that the observed effects are due to the institutional treatment rather than to unidentifiable factors or sampling variation.

Despite the robustness of the price ranking of the verifiable negotiations and the second-price auctions, there is some weak evidence of a hysteresis or learning effect in Regime 2, which matches second-price auctions across the two sequence treatments. Those sessions that use verifiable multilateral negotiations in Regime 1 have somewhat higher second-price auction prices, $\hat{\ }_2$ = 0.41 (*p*-value = 0.0898), as perhaps the sellers learn to play their dominant strategy. However, in Regime 3 those same sellers nearly play according to the dominant strategy for a second-price auction.

two-seller and four-seller treatments, which is consistent with the sellers' unique dominant strategy in the second-price auction. Moreover, a 95% pr

second-price auction prices are similar, as the winning offer is competed down to the second-lowest cost.

Table 4 reports the results of a test supporting this "gap" explanation using an OLS regression of the difference between the average second-price auction price and the average verifiable negotiation price on the lowest cost, second-lowest cost, and regime dummy variable interactions. The price difference between the second-price auctions and the multilateral negotiations increases as the lowest cost decreases, holding the second-lowest cost constant. Similarly, the price difference between the second-price auctions and the multilateral negotiations increases as the second-lowest cost increases, holding the lowest cost constant.

The preceding results illustrate one reason to perform laboratory tests of theoretical predictions. If one considered verifiable multilateral negotiations to be like English auctions, then their predicted outcomes would be identical to the outcomes of second-price auctions. However, we find that the two institutions' outcomes differ when the sellers are responsible for making the initial offer, because the sellers' initial offers are less than the English auction's starting price, which is the buyer's value. This negotiating behavior may be explained by the sellers' rates of time preference, as they may be trying to hasten the negotiations by making aggressive initial offers.[15]

5. Across-Experiment Results

We designed this experiment to be comparable to the one reported in Thomas and Wilson [2001], which evaluates and compares behavior in first-price auctions and nonverifiable multilateral negotiations. That experiment was conducted in the same manner as the present one, with the following institutional differences. In the first-price auction, sequences of which are denoted by *F*, the seller offering the lowest price wins the auction and is paid the price it offered. In the nonverifiable multilateral negotiation, sequences of which are denoted by *N*, the sellers are not informed via the mechanism of the buyer's best current offer. Thus, whatever claims about competing offers the buyer makes in its communications with the sellers cannot be verified. We limit our across-experiment analysis to the first twelve periods (Regime 1), in which subjects have no prior experience with any of the four institutions, because the results of the earlier

[15] It also does not appear that this effect diminishes as the sellers gain experience.

experiment exhibited permanent institutional influences in later rounds that are not present here. We denote the expected price in institution k by P_k ($k = F, N, S, V$).

Finding 4**:** *In Regime 1, prices are weakly lowest in first-price auctions, followed in order by nonverifiable multilateral negotiations, verifiable multilateral negotiations, and second-pricer by*

informed about their rivals' price-setting and consequently set higher prices than in the first-price auctions. In the nonverifiable multilateral negotiations, the sellers' lack of concrete information about their rivals potentially influences behavior.

In the four-seller nonverifiable multilateral negotiation, having three rivals taking hidden actions is sufficient to induce behavior as aggressive as in the corresponding first-price auction. However, in the two-seller setting, having only a single rival acting secretly does not induce such aggressive behavior. In Thomas and Wilson [2001], we find that the divergence in outcomes of the first-price auction and nonverifiable multilateral negotiation with two sellers is driven by occasions in which there is a large gap between the lowest and second-lowest cost. It appears that in negotiations with two sellers, a seller with low costs is sufficiently confident about the likelihood its rival has high costs that the additional information available in the verifiable multilateral negotiations has relatively little value. Hence, the prices are the same in both negotiation formats. In contrast, the additional information increases the sellers' prices and profits when there are four sellers.

6. Conclusion

In this paper we use the experimental method to examine how the verifiability of offers

price auctions. Second-price auction prices always strictly exceed the other prices. With two sellers, nonverifiable and verifiable negotiation prices are statistically indistinguishable, while with four sellers, first-price auction and nonverifiable negotiation prices are statistically indistinguishable.

In addition to providing evidence about behavior in multilateral negotiations, our results have implications for institutional design. First, we find that providing sellers with more information about their rivals' price-setting behavior surprisingly leads to higher rather than lower prices in multilateral negotiations. Moreover, this difference would be even larger if the verifiable multilateral negotiations began with nonserious offers at the buyer's value, as then the prices in the verifiable negotiations would be even higher. This price ranking is reminiscent of the price ranking of second-price and first-price auctions. One could argue that in both first-price auctions and nonverifiable multilateral negotiations, similar factors contribute to the sellers' being more aggressive in their price-setting behavior, relative to the dominance-solvable second-price auctions and to the more informationally rich verifiable multilateral negotiations.

Second, we find that buyers in our setting should prefer to employ first-price auctions rather than either type of multilateral negotiation, assuming that multilateral negotiations are more costly than auctions in terms of the time spent determining the transaction price. As the latter assumption appears reasonable, this conclusion raises the question of why first-price auctions are not observed more frequently in common transactions. One explanation is that reputation effects create a barrier for buyers trying to implement first-price auctions. For example, a car buyer is a short-run player in the market for new automobiles, and hence is unlikely to be concerned about maintaining a reputation. If the car buyer approaches several dealers and tells them that he wants their best offer, as in a first-price auction, then the sellers would be foolish to actually submit their first-price offers. If the buyer thought he had received first-price offers, then he still would want to haggle with the dealers. Moreover, the dealers might be willing to make concessions if asked, because each knows that if he currently has the second-lowest offer, then he may yet get a profitable sale by reducing his price. Thus, the buyer's inability to commit to the procurement format likely inhibits his use of what appears to be the preferred institution. In our experiment, the buyer was exogenously committed to this format, which provided a constraint on his behavior that likely does not generally exist in actual transactions.

The implications of our results and inferences about their generality are limited by the scope of our experiment and would benefit from further research. First, it would be useful to extend our analysis to settings with different numbers of sellers or with asymmetries across sellers. Second, it would be interesting to let the buyer select his preferred institution, or be unable to commit not to haggle upon receiving the sellers' initial offers. Third, if participation is costly, then any comparison of institutions must consider the sellers' incentives to participate.

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Table 2. Estimates of the Linear Mixed-Effects Model for Price

$$Price_{ij} \quad e_i \quad {}_1 Two_i \quad {}_2 Verifiable_i \quad {}_3 Two_i \quad Verifiable_i \quad {}_{ij},$$

where $e_i \sim N(0, \ {}^2_1)$, ${}_{ij} \sim N(0, \ {}^2_{2,i})$.

	Estimate	Std. Error	Degrees of Freedom*	*t*-statistic	*p*-value
Regime 1: Periods 1 – 12					
	3.080	0.179	176	17.251	0.0000
Two	1.133	0.299	12	3.787	0.0013†
Verifiable	-0.590	0.257	12	-2.300	0.0402
Two *Verifiable*	-0.119	0.389	12	-0.305	0.7652
			192 Obs.		
			H_a: ${}_2 + {}_3$ 0		0.0319
Regime 2: Periods 13 – 28					
	2.886	0.168	240	17.159	0.0000
Two	1.608	0.238	12	6.747	0.0000†
Verifiable History	0.409	0.221	12	1.845	0.0898
Two *Verifiable History*	-0.119	0.310	12	-0.386	0.7066
			256 Obs.		
			H_a: ${}_2 + {}_3$ 0		0.2069
Regime 3: Periods 29 – 40					

Table 3. Estimates of the Linear Mixed-Effects Model for Efficiency

$$Efficiency_{ij} \quad e_i \quad {}_1 Two_i \quad {}_2 Verifiable_i \quad {}_3 Two_i \quad Verifiable_i \quad {}_{ij},$$

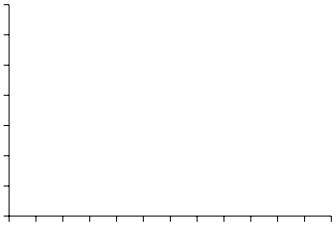
where $e_i \sim N(0, \ {}^2_1)$, ${}_{ij} \sim N(0, \ {}^2_2)$.

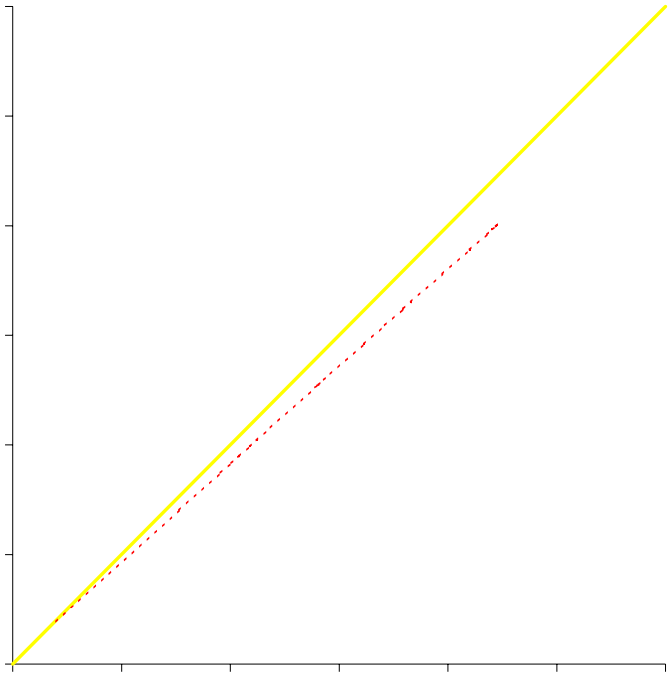
	Estimate	Std. Error	Degrees of Freedom*	*t*-statistic	*p*-value
Regime 1: Periods 1 – 12					
	97.51	1.43	176	68.05	0.0000
Two	0.61	2.03	12	0.30	0.7697
Verifiable	-3.93	2.03	12	-1.94	0.0764
Two *Verifiable*	2.67	2.87	12	0.93	0.3702
			192 Obs.		
				H_a: ${}_2 + {}_3$ 0	0.5456
Regime 2: Periods 13 – 28					
	96.75	1.40	240	68.88	0.0000
Two	1.94	1.99	12	0.98	0.3479
Verifiable History	1.34	1.99	12	0.67	0.5133
Two *Verifiable History*	-2.17	2.81	12	-0.77	0.4539
			256 Obs.		
				H_a: ${}_2 + {}_3$ 0	0.6812
Regime 3: Periods 29 – 40					
	97.02	2.11	176	45.90	0.0000
Two	0.60	2.99	12	0.20	0.8432
Verifiable	-2.00	2.99	12	-0.67	0.5170
Two *Verifiable*	-1.81	4.23	12	-0.43	0.6764
			192 Obs.		
				H_a: ${}_2 + {}_3$ 0	

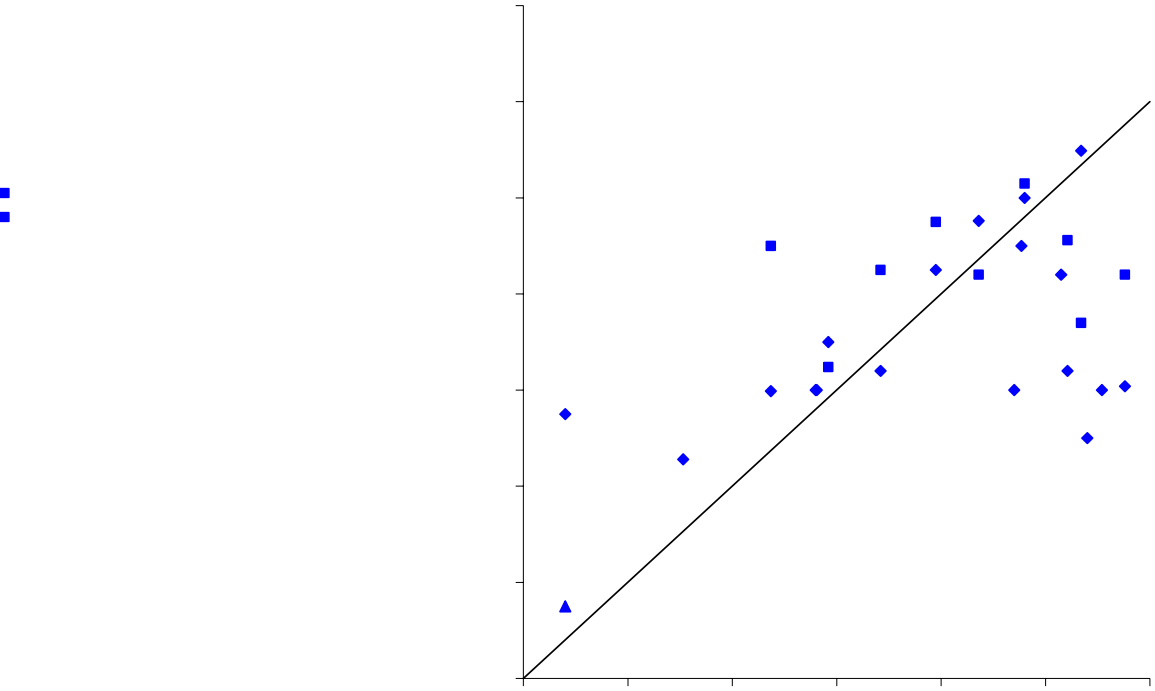
Table 5. Across-Experiment Estimates of the Linear Mixed-Effects Model for Price

$$Price_{ij} = e_i + {}_1Two_i + {}_2Negotiation_i + {}_3Verifiable_i + {}_4 2ndPriceAuction_i + {}_5Two_i \times Negotiation_i + {}_6Two_i \times Verifiable_i + {}_7Two_i \times 2ndPriceAuction_i + {}_{ij},$$

$$\text{where } e_i \sim N(0, {}^2_1), \quad {}_{ij} \sim N(0, {}^2_{2,i}).$$







Appendix

The following selections are the written negotiations from the real-time ordered transcript and the descriptions of the offering activity. They illustrate that when the initial offer of the low-cost seller (o_1) is greater than the second-lowest cost ($c_{(2)}$) the final price is equal to the second-lowest cost. However, when the initial offer for the low-cost seller is less than the second-lowest cost, the final price is the initial offer of the low-cost seller.

Examples when $o_1 > c_{(2)}$

Four Seller

Examples when o_1