VERIFIABLE OFFERS AND THE RELATIONSHIP BETWEEN AUCTIONS AND MULTILATERAL NEGOTIATIONS*

Charles J. Thomas and Bart J. Wilson

We use the experimental method to compare second-price auctions with ‘verifiable’ multilateral negotiations in which the sole buyer can credibly reveal to sellers the best price offer he currently holds. Despite the two institutions’ seeming equivalence, we find that prices are lower in verifiable multilateral negotiations than in second-price auctions. The difference occurs because low-cost sellers in negotiations often submit initial offers below the second-lowest cost. We also compare the two institutions to previously studied first-price auctions and multilateral negotiations with non-verifiable offers. Second-price auctions yield the highest prices, followed in order by verifiable negotiations, non-verifiable negotiations and first-price auctions.

One of the more interesting facets of voluntary exchange is how changes in the strategic environment lead to differences in transaction outcomes. For example, the pioneering experimental work in Chamberlin (1948) and Smith (1962) illustrates that changing the nature of the information available to participants can dramatically influence the price and efficiency of an exchange process. With this insight in mind, in this article 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 the first-price auction and the second-price auction. These well-known auction formats and their outcome-equivalent variants, the Dutch auction and the English auction, are used extensively to allocate products as varied as flowers, art, produce, fish, government securities, and mineral rights.1 Several governments have recently used auctions to allocate such valuable resources as radio spectra, electric power, and pollution rights.2

The second two institutions are variants of the multilateral negotiations introduced in Thomas and Wilson (2002). In this common exchange mechanism, a buyer solicits price offers from multiple sellers and then he elicits more favourable offers by playing the sellers off one another until he accepts one of the offers or breaks off the negotiations. Among other settings, multilateral negotiations are

* For providing helpful comments we thank the Editor, two anonymous referees, Paul Oyer, David Schmidt, and seminar participants at George Mason University, George Washington University, the INFORMS 2001 Annual Meeting, the Econometric Society 2002 Summer Meeting, and the 2003 International Industrial Organization Conference. We also thank the International Foundation for Research in Experimental Economics for providing financial support, and Todd Swarthout for writing the software. The data and a demonstration copy of the instructions are available upon request. This work was completed in part while the first author was employed by the US Federal Trade Commission. This work reflects the opinions of the authors and does not necessarily reflect the position of the Federal Trade Commission or any individual Commissioner.


pervasive in industrial procurement, the securing of high-end job offers and the purchasing of goods such as computers, contractors’ services and automobiles.

We hypothesise that the outcome of a multilateral negotiation is critically influenced by the buyer’s ability to credibly reveal to a seller the price offers from other sellers. Following that hypothesis, in Thomas and Wilson (2002) we investigate non-verifiable 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 reveal rival sellers’ offers. We compare non-verifiable negotiations to first-price auctions, because the two institutions have conceptual similarities. We find that negotiated prices exceed auction prices with two sellers but that the two institutions’ prices are indistinguishable with four sellers.

In this article 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 (B2B) exchanges are one of the best examples of an institution 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 B2B exchange can credibly authenticate the best offer that a buyer currently holds. Even though auctions currently appear to be the dominant exchange mechanism in B2B commerce, negotiations can be conducted on or facilitated by some sites. For example, at http://www.chemconnect.com, a purchasing manager can invite its suppliers into a ‘Corporate Trading Room’ to settle on a transaction for raw chemical materials. We compare verifiable negotiations with second-price auctions because, as we will argue, the two institutions appear to be conceptually similar. In addition, we integrate the results with the results of our earlier experiment in order to provide a detailed picture of the relationships among the four institutions.

Not only are multilateral negotiations interesting in their own right, their relationship to various auction formats has implications for institutional design. Both multilateral negotiations and sealed-bid auctions are used by different buyers in the same industry, which suggests either that the processes are outcome-equivalent or that certain factors make one process preferable. Identifying these factors should lead to a more informed selection of an exchange process.

Our experimental results reveal that 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 costs. In those cases the low-cost seller’s initial offer in the negotiations tends to be below the second-lowest cost, eliminating the need for further negotiation. When the cost spread is small, the two institutions’ prices are statistically indistinguishable and are approximately equal to the second-lowest cost. After integrating our earlier results on first-price auctions and non-verifiable multilateral negotiations, we find that second-price auctions yield the highest prices, followed in order by verifiable negotiations, non-verifiable negotiations, and first-price auctions. We also find that all four institutions are highly efficient.

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The article is structured as follows. Section 1 describes the framework we envision underlying both the auction and the negotiation settings, and it explains the reasoning behind our hypothesis that the outcomes of second-price auctions and multilateral negotiations should be identical. Section 2 describes the experimental design and the procedures. Sections 3 and 4 present our within-experiment and across-experiment results, while Section 5 briefly concludes.

1. Conceptual Framework

Consider a setting in which $T$ risk-neutral sellers producing homogeneous products compete to fulfill a contract for a single risk-neutral buyer. $V_B$ is the buyer’s commonly known value for having the contract fulfilled. Each seller’s cost $c$ is a privately known independent draw from the distribution $G$ with density $g$ that is strictly positive over the support $[c, \hat{c}]$. In the auction literature, this is referred to as a symmetric independent private value setting.

The second-price auction proceeds with each seller simultaneously submitting a secret price offer. The seller offering the lowest price is awarded the contract at the lesser of the next highest price offered and $V_B$, provided the lowest price is less than $V_B$. All other sellers receive 0. The winning seller’s profit is $p - c_w$ where $p$ is the transaction price and $c_w$ is the winning seller’s cost. The buyer’s profit is $V_B - p$ and efficiency is $(V_B - c_w)/(V_B - c_1)$, where $c_1$ is the lowest realised cost. Each seller’s dominant strategy is to offer a price equal to its cost.

The verifiable multilateral negotiation proceeds with each seller simultaneously making a secret price offer. If the buyer accepts one of the offers, then the game concludes and the transaction price is the price offered by the winning seller. Payoffs and efficiency are determined as in the auction setting. If the buyer rejects all of the offers, then the buyer credibly reveals to each seller the best standing offer it possesses. The sellers can respond to this communication by making additional price offers, the buyer can accept or reject these new offers and so on. The game continues in this fashion until a transaction occurs.

While auctions have been studied extensively, multilateral negotiations have not been formally modelled, presumably due to their strategic complexity. However, in the auction literature it has been hypothesised that multilateral negotiations bear some relation to second-price or English auctions (Waehrer and Perry, 2003). The general argument is that the buyer should be able to obtain concessions from a seller until the seller’s offer is just equal to its cost, with the implicit assumption that the negotiations conclude when only a single seller remains.

We agree in part with the preceding conjecture but our intuition is that the relationship between multilateral negotiations and various auction formats depends critically on the buyer’s ability to credibly reveal to a seller its rivals’ offers. To understand why, consider each possibility in turn.

If the offers can be credibly revealed, then the multilateral negotiation should be similar to a second-price or English auction, because each seller should be willing to undercut lower competing offers until the price reaches its cost. Consequently, the transaction price will be at or near the second-lowest cost, which is the predicted price in second-price and English auctions.

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If the offers cannot be credibly revealed, then the multilateral negotiation should be similar to a first-price auction, because each seller must determine a ‘stopping rule’ that protects it from repeatedly offering unnecessary price reductions. That is, when the buyer tries to use a rival’s offer to elicit a better offer from a seller, that 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 it could end up bidding against itself 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. The strategy of selecting such a stopping rule is analogous to the strategy of selecting one’s price in a Dutch auction, an auction format that is theoretically isomorphic to a first-price auction.

For several reasons, the hypothesised relationships among the institutions may not hold either empirically or theoretically. First, in practice the outcomes of multilateral negotiations are likely to depend on the players’ ability to haggle. For example, once the buyer determines which seller has the lowest cost in a verifiable multilateral negotiation, the buyer and that seller still may negotiate over the division of the remaining surplus. To the extent that the buyer is able to extract further concessions from the low-cost seller once the price has reached the second-lowest cost, then the negotiated price will be lower than the second-price auction price.

Second, in multilateral negotiations there must be incentives for sellers to make serious offers. That is, sellers have no reason to make offers until the last possible moment, particularly if there are no delay costs and if they are concerned that serious offers either will be used against them by the buyer later in the negotiation or will provoke a sequence of aggressive price cuts. This effect would tend to make negotiated prices exceed second-price auction prices.

Our experimental framework puts a time limit on each negotiation period, and there clearly are frictions that prevent the buyer from receiving infinitely many offers. Consequently, a seller might be concerned that not making serious offers may cause it to inadvertently lose a contract it should have won. This concern would tend to reduce negotiated prices but not necessarily to a level below that of second-price auction prices.

2. 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 pattern of sequences $VSSV$, and one with the pattern of sequences $SSVS$. The first and third sequences consist of 12 transactions; the second consists of 16, while the fourth consists of 6. Later we refer to each of the four sequences as a ‘regime’. We vary these two treatments by changing the number of sellers from two per buyer to four per buyer, which yields four treatments in total.

\footnote{We employ these patterns, rather than the more common $SVS$ and $VSV$ patterns of sequences, to permit comparisons with the experimental results in Thomas and Wilson (2002).}
For each of the four treatments 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.

Each seller privately learned its random cost draw for a given period at the beginning of the period. In a second-price auction, after learning his cost each seller had four minutes to submit his secret price offer, though this limit was never binding. The sale was awarded to the seller that submitted the lowest offer, provided that offer was less than the buyer’s value of 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.

In a verifiable multilateral negotiation, 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 instructions indicated that the seller could lower his offer at any time in the second (negotiation) phase of the period by submitting a new binding offer. Once the buyer received all initial offers, the clock was reset to four minutes for the negotiation phase. At any time during the negotiation phase, a seller could (only) lower his offer, and the buyer could accept a single offer. Furthermore, a buyer and a seller could use text messaging over the computer network to engage in nonbinding discussions concerning a transaction. The buyer could negotiate individually with any seller while retaining standing offers from the other sellers. In contrast, sellers could only communicate with the buyer. A transcript of the discussions between the buyer and the seller remained on the screen for the duration of the period. Once the buyer accepted an offer, the final market price was announced electronically to all market participants. 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.

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 rates were 4 and 2 experimental dollars for each US$1, respectively. Based upon the theoretical second-price auction outcomes for the realised cost draws, these exchange rates reflect an average cash payoff of $21.50 for all subjects. In addition to the $5 fee show-up fee, the average subject’s earnings were $20.50. The average session lasted 75 to 90 minutes.4

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4 There were only two cases in which the buyer did not accept any offer. Both were in the two-seller treatment when both sellers’ costs were relatively close to 6.00.

5 See Thomas and Wilson (2002) for further design details such as the number of participants and the instructions to the subjects, because the present experiment closely follows the design in that paper.

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3. 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. We use the data in three findings that compare transaction prices and efficiency for the different institutions and numbers of sellers.

We derive our quantitative results by analysing the data using a linear mixed-effects model for repeated measures.\(^6\) Table 1 reports the model’s regression results for each of the four regimes, with the transaction price as the dependent variable. The treatment effects (Two vs. Four Sellers, and Verifiable Negotiation vs. Second-Price Auction) and an interaction effect from the 2 × 2 design are modelled as (zero-one) fixed effects, while the 16 independent sessions are modelled as random effects, \(e_i\). Specifically, we estimate the model

\[
Price_{ij} = \mu + e_i + \beta_1 Two_i + \beta_2 Verifiable_i + \beta_3 Two_i \times Verifiable_i + \varepsilon_{ij},
\]

where \(e_i \sim N(0, \sigma^2_e)\) and \(\varepsilon_{ij} \sim N(0, \sigma^2_{ij})\). The sessions are indexed by \(i\) and the repeated periods are indexed by \(j\) (e.g., \(j = 1, 2, \ldots, 12\) for the first regime of 12 periods). We accommodate heteroscedastic errors by session when estimating the model via maximum likelihood. Estimates of the treatment effects are easy to compute with this specification. The expected price is \(\mu\) in a four-seller second-price auction, \(\mu + \beta_1\) in a two-seller second-price auction, \(\mu + \beta_2\) in a four-seller verifiable multilateral negotiation, and \(\mu + \beta_1 + \beta_2 + \beta_3\) in a two-seller verifiable multilateral negotiation. Across-treatment price differences, and differences-in-differences, also are easy to compute.

### Table 1

**Average Transaction Price, Nash Predicted Second-Price Auction Price,* and Efficiency**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Two Sellers</th>
<th>Four Sellers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed Price</td>
<td>Nash Prediction</td>
</tr>
<tr>
<td>SSVS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periods 1–12: S</td>
<td>4.17</td>
<td>3.62</td>
</tr>
<tr>
<td>Periods 13–28: S</td>
<td>4.49</td>
<td>4.26</td>
</tr>
<tr>
<td>Periods 29–40: V</td>
<td>2.53</td>
<td>3.90</td>
</tr>
<tr>
<td>Periods 41–46: S</td>
<td>4.89</td>
<td>4.63</td>
</tr>
<tr>
<td>VSVS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periods 1–12: V</td>
<td>3.46</td>
<td>3.62</td>
</tr>
<tr>
<td>Periods 13–28: S</td>
<td>4.69</td>
<td>4.26</td>
</tr>
<tr>
<td>Periods 29–40: S</td>
<td>4.03</td>
<td>3.90</td>
</tr>
<tr>
<td>Periods 41–46: V</td>
<td>3.35</td>
<td>4.63</td>
</tr>
</tbody>
</table>

* The Nash predicted second-price auction prices are conditional on the cost draws.

** Efficiency is defined to be \(100\% \times (6 – \text{winner’s cost})/(6 – \text{lowest cost draw})\).

\(^6\) See Longford (1993) for a description of this technique commonly employed in experimental sciences.

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**Finding 1** For all regimes and institutions, reducing the number of sellers from four to two increases transaction prices. The magnitude of the price increase is the same across institutions.

*Evidence.* Table 1 reports the average transaction price for the first 12 periods, by institutional regime and by the number of sellers. The average price in the second-price auctions is 3.03 with four sellers and is 4.17 with two sellers, which is a 37.6% increase. The average price in the multilateral negotiations is 2.50 with four sellers and is 3.46 with two sellers, which is a 38.4% increase. Prices are predicted to increase from 2.61 with four sellers to 3.62 with two sellers, which is a 38.7% increase. Both institutions track this prediction very closely. Similar price comparisons can be made for the remaining periods.

The results in both institutions suggest that the transaction price increases as the number of sellers decreases. The estimates in Table 2 formally test this finding. The coefficient on the $Two$ dummy variable measures the primary effect of the two-seller treatment. It is positive and highly significant in each regime, raising prices by $\hat{\beta}_1 = 1.13, 1.61, 0.82$ and 2.26 experimental dollars, respectively ($p$-value = 0.0013, 0.0000, 0.0191 and 0.0000). Because the coefficient $\hat{\beta}_3$ on the interaction term is insignificant in Regimes 1, 3, and 4, we cannot reject the null hypothesis that the price change induced by reducing the number of sellers is the same across institutions.

The preceding finding is a baseline result that establishes that changing the number of sellers affects transaction prices in the manner predicted by standard oligopoly models. We now turn to our primary findings that compare the transaction prices and the efficiency of second-price auctions and verifiable multilateral negotiations.

**Finding 2** For all regimes with paired auctions and negotiations, verifiable multilateral negotiation prices are lower than second-price auction prices, with both two and four sellers. The magnitude of the across-institution price difference is invariant to the number of sellers.

*Evidence.* The average prices that are reported in Table 1 support this finding. With four sellers, in Regime 1 the average price is 3.03 in the second-price auctions and 2.50 in the verifiable multilateral negotiations. With two sellers, the average price is 4.17 in the second-price auctions and 3.46 in the verifiable multilateral negotiations. Price comparisons in Regimes 3 and 4 are similar.

The estimates in Table 2 formally test this finding. With four sellers, the estimated difference between the expected prices of the multilateral negotiations and the second-price auctions is given by $\hat{\beta}_2$. The coefficient’s 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 favour of the alternative that verifiable prices are less than second-price auction prices. The estimated price is given by $\hat{\mu}$ with four sellers in second-price auctions, so the *Verifiable* treatment lowers four-seller prices by 19%, 50% and 27% to $\hat{\mu} + \hat{\beta}_2 = 2.49, 1.59$ and 1.94.
With two sellers, the estimated difference between the expected prices of the multilateral negotiations and the second-price auctions is given by $\beta_2 + \beta_3$. The sum’s point estimates for Regimes 1, 3, and 4 are $-0.71$, $-1.56$ and $-1.40$ experimental dollars, respectively, and are statistically significant (p-values = 0.0319, 0.0016 and 0.0012), so we reject the null hypothesis in favour of the alternative that verifiable prices are less than second-price auction prices. The estimated price is given by $\hat{\mu} + \hat{\beta}_1$ with two sellers in second-price auctions, so the Verifiable treatment lowers two-seller prices by 17%, 39% and 28% to $\hat{\mu} + \hat{\beta}_1 + \hat{\beta}_2 + \hat{\beta}_3 = 3.50$, 2.47 and 3.53. Because the coefficient $\hat{\beta}_3$ on the interaction term is insignificantly different from zero, we cannot reject the null hypothesis that the magnitude of the across-institution price difference is invariant to the number of sellers.

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It is worth noting that verifiable negotiation prices are always lower than second-price auction prices, regardless of the institutional sequence that the subjects face. 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.

**Finding 3** For all regimes and institutions, the level of efficiency is unaffected by any primary or interaction effects, with one exception. There is weak evidence in Regime 1 that the primary effect of changing from second-price auctions to verifiable multilateral negotiations slightly decreases efficiency.

Evidence. Table 1 reports average efficiency by institutional regime and by number of sellers. The observed high efficiency levels are consistent with those reported in previous auction experiments. An (unreported) regression analysis of a linear mixed-effects model with the efficiency level as the dependent variable reveals that reducing the number of sellers from four to two has no effect on efficiency in either institution. It also shows that in Regime 1 we reject the null hypothesis at a level of 0.0764 that efficiency in the four-seller verifiable negotiations equals efficiency in the four-seller second-price auctions. Efficiency in the four-seller negotiations is lower by 4 percentage points. We fail to reject the null in Regimes 3 and 4.

Findings 2 and 3 report that transaction prices with both two and four sellers are strictly lower in verifiable multilateral negotiations than in second-price auctions but that efficiency is almost always the same. Switching from verifiable negotiations to second-price auctions therefore transfers surplus from the buyer to the most efficient seller, which suggests that from the perspective of price the buyer should prefer using verifiable multilateral negotiations over second-price auctions.

Examination of the data reveals that the negotiating behaviour is driving the departure from our predicted relationship between the two institutions, although not for the reasons we hypothesised in Section 1. Figure 1 plots each period’s average transaction price per treatment against that period’s second-lowest cost. For both the two-seller and four-seller treatments, the second-price auction prices are highly correlated with the second-lowest cost, which is the price that would result if all sellers used their dominant strategy in the second-price auction. Moreover, a 95% prediction interval for a linear regression of the second-price auction price on the second-lowest cost contains the 45° line, which corresponds to bidding according to the dominant strategy. In sharp contrast, the verifiable negotiation prices are not strongly correlated with the second-lowest cost. In fact, many of them are less than the second-lowest cost and lie outside the aforementioned 95% prediction interval.

Having shown the nature of the across-institution price difference, we can now explain why it occurs. Figure 2 plots the winning seller’s initial offer against the

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7 For example, see Coppinger et al. (1980), Cox et al. (1982, 1983) and Kagel et al. (1987).

8 Obviously, the sellers are not bidding precisely according to their dominant strategy, because the transaction price sometimes is higher than the second-lowest cost.
Fig. 1. Average Transaction Price versus Second-Lowest Cost
Fig. 2. Winning Seller’s Initial Offer versus Second-Lowest Cost
second-lowest cost for each period of verifiable negotiations in all sessions. Although we provide session-specific markers in Figure 2 for the interested reader, the broader point is that the initial offer of the winning seller (nearly always the low-cost seller, as illustrated by the efficiency results in Finding 3) is often less than the second-lowest cost. Consequently, when this is the case, the price is less than the corresponding second-price auction price.9

Our hypothesised outcome-equivalence of second-price auctions and verifiable multilateral negotiations relies on the assumption that negotiating sellers make non-serious initial offers at the buyer’s value (6.00), so that offers subsequently decline to the second-lowest cost. Figure 2 illustrates that this clearly is not how the sellers behave. Sellers submit initial offers at prices greater than their costs, but generally less than 6.00. One possible consequence of this behaviour is that when the gap between the lowest and second-lowest cost is large, the low-cost seller’s initial offer may be less than the second-lowest cost, resulting in second-price auction prices exceeding negotiated prices. When the gap between the lowest and second-lowest cost is small, the low-cost seller’s initial offer is likely to exceed the second-lowest cost. In that instance, negotiated prices and second-price auction prices are similar, because the winning offer is competed down to the second-lowest cost.

This ‘gap’ explanation is supported by an (unreported) OLS regression of the difference between each period’s average second-price auction price and average verifiable negotiation price on the lowest cost, second-lowest cost and regime dummy variable interactions. The estimates show that the price difference between the auctions and the negotiations increases as the lowest cost decreases, holding the second-lowest cost constant. Similarly, the price difference increases as the second-lowest cost increases, holding the lowest cost constant.

Our results illustrate an important reason to perform laboratory experiments. 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 because the sellers are responsible for making the initial offers and those offers are less than the English auction’s starting price at the buyer’s value.

The reason why sellers sometimes make low initial offers is not clear. One possibility is that they may wish to hasten the negotiations by being aggressive early, if the transaction costs of negotiating are large relative to the stakes. The data support this explanation versus the ‘friction’ effect we mentioned in Section 1, because the initial offers do not increase over time as the sellers learn they are often leaving money on the table yet maintaining high efficiency.

4. Across-Experiment Results

We designed this experiment to be comparable to the one reported in Thomas and Wilson (2002), which evaluates behaviour in first-price auctions and non-verifiable multilateral negotiations. That experiment was conducted in the same

9 We should point out that the negotiation transcripts reveal that there are no further price concessions once the best offer is less than or equal to the second-lowest cost. Therefore, the behaviour that in Section 1 was offered as one reason why the two institutions might differ does not appear in the data.

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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 and is paid the price it offered. In the non-verifiable 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, the buyer’s claims about competing offers cannot be verified. We limit our across-experiment analysis to the first 12 periods (Regime 1), in which subjects have no prior experience with any of the four institutions, because the results in our earlier paper 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 by non-verifiable multilateral negotiations, verifiable multilateral negotiations and second-price auctions. With two sellers, the ranking of prices is $P_F < P_N = P_V < P_S$. With four sellers, the ranking of prices is $P_F = P_N < P_V < P_S$.

Evidence. Table 3 reports the results of a linear mixed-effects analysis that combines the 16 sessions in Thomas and Wilson (2002) with the 16 reported here, with the transaction price as the dependent variable. Two new fixed effects require explanation. Negotiation equals 1 for non-verifiable and verifiable multilateral negotiation sessions and it equals 0 otherwise. Verifiable equals 1 for verifiable multilateral negotiation sessions and it equals 0 otherwise. Thomas and Wilson (2002) find that $P_F = P_N$ with four sellers and that $P_F < P_N$ with two sellers. In Finding 2 above we find that $P_V < P_S$ with both two and four sellers. With four sellers, the estimated difference between verifiable and non-verifiable multilateral negotiation prices is given by $\beta_3$, the coefficient on the Verifiable dummy variable. We find that $\beta_3 = 0.61$, which is significant (p-value = 0.0345), so we reject the null hypothesis in favour of the alternative that verifiable prices exceed non-verifiable prices.

Table 3

<table>
<thead>
<tr>
<th>Across-Experiment Estimates of the Linear Mixed-Effects Model for Price</th>
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<tbody>
<tr>
<td>$\text{Price}_{ij} = \mu + e_i + \beta_1 \text{Two}_i + \beta_2 \text{Negotiation}_i + \beta_3 \text{Verifiable}_i + \beta_4 2\text{nd Price Auction}_i + \beta_5 \text{Two}_i \times \text{Negotiation}_i + \beta_6 \text{Two}_i \times \text{Verifiable}_i + \beta_7 \text{Two}<em>i \times 2\text{nd Price Auction}<em>i + \varepsilon</em>{ij}$, where $e_i \sim N(0, \sigma^2_1), \varepsilon</em>{ij} \sim N(0, \sigma^2_2)$</td>
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<tr>
<td>---</td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Regime 1: Periods 1–12</strong></td>
</tr>
<tr>
<td>$\mu$</td>
</tr>
<tr>
<td>$\text{Two}$</td>
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<tr>
<td>$\text{Negotiation}$</td>
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<tr>
<td>$\text{Verifiable}$</td>
</tr>
<tr>
<td>$2\text{nd Price Auction}$</td>
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<tr>
<td>$\text{Two} \times \text{Negotiation}$</td>
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<tr>
<td>$\text{Two} \times \text{Verifiable}$</td>
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<tr>
<td>$\text{Two} \times 2\text{nd Price Auction}$</td>
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<tr>
<td>$H_0$: $\beta_3 + \beta_6 \neq 0$</td>
</tr>
</tbody>
</table>

*One-sided test.

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With two sellers, the estimated difference between verifiable and non-verifiable multilateral negotiation prices is given by $\hat{\beta}_3 + \hat{\beta}_6$, the sum of the coefficients on the Verifiable and Two x Verifiable dummy variables. We find that $\hat{\beta}_3 + \hat{\beta}_6 = -0.29$, which is insignificant at conventional confidence levels (p-value = 0.2555).

The most interesting aspect of Finding 4 is that credible verification of offers does not affect prices in multilateral negotiations with two sellers but it increases prices with four sellers. One way to understand this result is to consider the first-price auction and second-price auction as baseline polar cases. Behaviour in the first-price auction reflects sellers’ concern and lack of information about their rivals’ price-setting behaviour. In contrast, behaviour in the second-price auction reflects sellers’ lack of concern about their rivals’ price-setting, which follows from the existence of a dominant strategy. In the verifiable multilateral negotiations, sellers are well informed about their rivals’ price-setting and consequently set higher prices than in the first-price auctions. In the non-verifiable multilateral negotiations, the sellers’ lack of concrete information about their rivals potentially influences behaviour.

In the four-seller non-verifiable multilateral negotiation, having three rivals taking hidden actions is sufficient to induce behaviour as aggressive as in the corresponding first-price auction. However, having only a single rival acting secretly does not induce such aggressive behaviour. In Thomas and Wilson (2002), we find that the divergence in outcomes of the first-price auction and non-verifiable 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.

5. Conclusion

We use the experimental method to examine how verifiable offers affect both the outcomes of multilateral negotiations, and the relationship between the outcomes of multilateral negotiations and different auction formats. At the within-experiment level, with both two and four sellers, we find that transaction prices are lower in verifiable multilateral negotiations than in second-price auctions but that the institutions are equally efficient. Sellers in the second-price auctions largely follow their dominant strategy, so the market price is approximately equal to the second-lowest cost. Prices are lower in the verifiable multilateral negotiations, because in some instances the low-cost seller’s initial offer is below the second-lowest cost, which eliminates the need for further negotiation. This unanticipated offering behaviour contradicts in part our hypothesis that the two institutions would have identical outcomes.

At the across-experiment level, with both two and four sellers we find a consistent ranking of prices across the four institutions. Prices are always lowest in
first-price auctions, followed in turn by non-verifiable negotiations, verifiable negotiations, and second-price auctions. Second-price auction prices always strictly exceed the other prices. With two sellers, non-verifiable and verifiable negotiation prices are statistically indistinguishable, while with four sellers, first-price auction and non-verifiable negotiation prices are statistically indistinguishable.

In addition to providing evidence about behaviour in multilateral negotiations, our results have implications for institutional design. First, we find that providing sellers with more information about their rivals’ price-setting behaviour 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 non-serious 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 that is consistently found in experimental data. One could argue that in both first-price auctions and non-verifiable multilateral negotiations, similar factors contribute to the sellers’ being more aggressive in their price-setting behaviour, 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 use first-price auctions over 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 preceding assumption seems reasonable, our result raises the question of why first-price auctions are not observed more frequently in common transactions. One explanation is that reputation effects limit buyers’ ability 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 buyer approaches several dealers and requests their best offer, as in a first-price auction, then the dealers would be foolish to submit their actual first-price offers. The reason is that the buyer still would want to haggle with the dealers. Moreover, the dealers might be willing to make concessions, because each knows that he may yet get a profitable sale by reducing his price. Thus, the buyer’s inability to commit to the procurement format may inhibit his use of what appears to be the preferred institution. In our experiment, the buyer was exogenously committed to this format, which provided a behavioural constraint that probably does not exist in typical transactions.

Given the exploratory nature of our first two experiments investigating multilateral negotiations, our results and inferences about their generality would benefit from further research. For example, 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. It may also be useful to vary the size of the stakes, to see if doing so influences the sellers’ initial offers in verifiable negotiations. As Smith (2002) discusses, any experimental test inherently contains several such auxiliary hypotheses that are not initially of central importance. However, if future replications of our experiment with an $m$-fold increase in payoffs do not exhibit different behaviour, but replications with a larger increase do, then that finding may lead to additional important advances in our under-
standing of both transaction costs and the relationship between auctions and multilateral negotiations.

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Submitted: 16 April 2002
Accepted: 28 July 2004

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