2014

Horizontal Product Differentiation in Auctions and Multilateral Negotiations

Charles J. Thomas
Chapman University

Bart J. Wilson
Chapman University, bjwilson@chapman.edu

Recommended Citation

Thomas, Charles J., and Bart J. Wilson. "Horizontal product differentiation in auctions and multilateral negotiations." *Economica* 81.324 (2014): 768-787.
DOI:10.1111/ecca.12090

Horizontal Product Differentiation in Auctions and Multilateral Negotiations

Horizontal Product Differentiation in Auctions and Multilateral Negotiations[*]

Charles J. Thomas
John E. Walker Department of Economics
Clemson University
222 Sirrine Hall
Clemson, SC 29634
E-mail: *cjt@clemson.edu*

Bart J. Wilson
Economic Science Institute
Chapman University
One University Drive
Orange, CA 92866
E-mail: *bartwilson@gmail.com*

April, 2012

Abstract: We experimentally compare first-price auctions and multilateral negotiations after introducing horizontal product differentiation into a standard procurement setting. Both institutions yield identical surplus for the buyer, a difference from prior findings with homogeneous products that results from differentiation's influence on sellers' pricing behavior. The data are consistent with this finding being driven by concessions from low-cost sellers in response to differentiation reducing their likelihood of being the buyer's surplus-maximizing trading partner. Further analysis shows that introducing product differentiation increases the intensity of price competition among sellers, which contrasts with the conventional wisdom that product differentiation softens competition.

[*]We thank the International Foundation for Research in Experimental Economics for providing financial support, and Jeffrey Kirchner for writing the software. The data and instructions are available upon request. Ovidiu Lasca, Mike Maloney, Curtis Simon, Angie Starrett, Patrick Warren, seminar participants at Clemson University and the University of South Carolina, Editor Peter Sørensen, an Associate Editor, and two referees provided helpful comments and advice.
JEL: C78, D44, C9, L14
Keywords: voluntary exchange, multilateral negotiations, auctions, product differentiation

1. Introduction

Understanding the variety of ways in which voluntary exchange is conducted is a fundamental goal of economics, in part to enable an informed choice amongst exchange methods by using metrics such as profitability or efficiency. For example, in different settings bargaining, auctions, and posted prices all are used to arrange for the trade of goods and services. Variants emerge that blur the lines between what previously appeared to be distinct types of exchange methods.[1] In fact, some of these new methods themselves become "goods and services," with their designers applying for patent protection and being hired to organize markets.[2]

Previous research suggests that a trading mechanism's performance depends on characteristics of the strategic environment in which it is used. For example, Klemperer [2002] argues that one size does not fit all in auction design, with factors such as the number of potential bidders, their relative size or importance, and the likelihood of collusion meriting careful consideration. Similarly, theoretical arguments show that it matters who makes offers in bilateral bargaining when there is one-sided private information.[3]

With the preceding points in mind, in this paper we use the experimental method to evaluate how introducing horizontal product differentiation into a standard procurement setting affects the outcomes of two commonly used means of exchange, auctions and multilateral negotiations. Auctions are used in procurement and to allocate products such as electric power, pollution rights, art, and government securities.[4] Multilateral negotiations combine features of auctions and bilateral bargaining, although they have received much less academic attention than

[1] Consider the "Anglo-Dutch" auction described in Klemperer [2002], the simultaneous ascending auction, used to sell U.S. radio spectrum, described in Milgrom [2000], or the "Buy It Now" feature in auctions on E-Bay.
[2] Companies such as MercExchange, Inc. and Ozro, Inc. have obtained patents covering online auctions and electronic negotiations, respectively. Economists such as Paul Milgrom and Larry Ausubel also hold patents on different auction designs.
[3] Kennan and Wilson [1993] provide an excellent overview of bargaining with private information.
[4] See Wolfram [1998], Cason [1995], Milgrom and Weber [1982], and McAfee and McMillan [1987].

have those two exchange methods.[5] In them, a buyer solicits offers from multiple sellers, and then attempts to play the sellers off one another to receive additional concessions. They are used in settings such as procurement, high-end job markets, and the purchase of contractors' services and automobiles. Given that auctions and multilateral negotiations often are used in similar settings, even by apparently similar buyers in narrowly defined markets, our primary reason for investigating them is to see if they yield equivalent outcomes.

One reason we consider product differentiation is that analyses of auctions and multilateral negotiations typically assume that bidders are homogeneous from the auctioneer's perspective,[6] but frequently in procurement the buyer has preferences over non-price attributes of the sellers' products. For example, when Airbus and Boeing competed for a sizeable contract from Iberia Airlines in 2003, both sellers had to deal with Iberia's privately known preferences.[7] These stemmed from Iberia's evaluation of differences in the sellers' product characteristics, and of how its fleet composition would affect maintenance costs and future procurement episodes. Similar stories abound from companies like Hewlett-Packard, IBM, Kaiser Permanente, Nissan, Pfizer, and Sun Microsystems.[8] Product differentiation's prevalence in procurement makes investigating its effect on behavior worthwhile.

A second reason we consider product differentiation is that prior research finds that some auction formats give the buyer more surplus than do multilateral negotiations, which leaves open the question of why multilateral negotiations are so commonly used. One reason may be that

[5] See Thomas and Wilson [2002, 2005], along with related work in Cason, et al [2003].
[6] For example, see Milgrom and Weber [1982], McAfee and McMillan [1987], Wolfram [1998], Waehrer and Perry [2003], and Thomas and Wilson [2002, 2005].
[7] "Airbus and Boeing Duke it Out to Win Lucrative Iberia Deal," *Wall Street Journal*, March 10, 2003.
[8] See the following articles in *Purchasing*, or at purchasing.com: "HP's Purchasing Organization Looks Beyond Price," September 11, 2008; "It's Not Just About Cost," March 15, 2007; "Procurement Brings Green Initiatives to Life at Kaiser Permanente," December 13, 2007; "Nissan Pushes Suppliers on Quality," October 5, 2006; "Pfizer's Procurement Provides 12 Tips for Reverse Auction Success," December 11, 2008; "Sun's e-Auction Evolution," September 13, 2007.

real strategic environments differ in important dimensions from the settings that so far have been examined. Differentiation may be one such dimension, and when it is present we hypothesize that the dynamic nature of multilateral negotiations allows the buyer to profitably exploit its privately known preferences in a way that one-shot auctions do not. If so, then in this setting the buyer may receive relatively more surplus by using negotiations than by using auctions.

We introduce horizontal product differentiation by using a linear random utility model that we modify so each seller's production cost is its private information.[9] Private information about the buyer's values and the sellers' costs contributes to the main difference between the auctions and the negotiations, namely that the communication allowed by the negotiations provides opportunities for each party to signal or misrepresent its private information in an attempt to secure more of the gains from trade.[10]

We use experiments to evaluate the effect of product differentiation on auctions and multilateral negotiations because theoretical characterization of equilibrium behavior in the setting we consider remains an open problem. Our approach accords with the theoretical perspective of Muthoo [1999, p.342] that a "primary role of bargaining experiments should be to make new discoveries about bargaining – for example, to identify new forces that may have a significant impact on the bargaining outcome. In that way bargaining experiments can help in the further development of the theory of bargaining." Muthoo's insights complement the experimental perspective articulated by Smith [1982]. He advocates heuristic investigations of new environments and institutions, especially when strategic complexity leads to analytic intractability, because "it is through exploratory probes of new phenomena that attention may be redirected, old belief systems may be reexamined, and new scientific questions may be asked"

[9] See Anderson, de Palma, and Thisse [1992] for a comprehensive treatment of discrete choice models.
[10] Similar incentives exist in bilateral bargaining with private information. See Fudenberg and Tirole [1983] for an early treatment.

(p. 942). In this vein, economic experiments have recently played a major role in test-bedding spectrum auctions, wholesale markets for electric power, and NOx allowance auctions.[11]

Introducing product differentiation yields several questions of interest. First, how do the outcomes of auctions and multilateral negotiations compare when there is product differentiation? We find that both institutions yield the buyer the same expected payoff, which helps explain the prevalence of multilateral negotiations despite earlier results suggesting that buyers might prefer auctions: With homogeneous products Thomas and Wilson [2002] find that auctions yield the buyer a higher payoff than do multilateral negotiations with two sellers, but yield the same payoff with four sellers. The present findings suggest that having privately known preferences over the sellers' products allows the buyer to extract relatively more surplus from the sellers when negotiating than when using an auction, at least when there are few sellers.

Second, can we determine how these changes in the institutions' relative performance occur? That is, from the buyer's perspective, does introducing product differentiation improve the negotiations' performance, degrade the auctions' performance, or lead to some other change? To address this issue we measure the intensity of competition among the sellers, and we find a surprising result. With two sellers following the introduction of product differentiation, price competition in both institutions intensifies to different extents. This finding suggests that the buyer benefits from having privately known preferences, and this benefit is greater in the negotiations. With four sellers the intensity of price competition also increases in both institutions, but to lesser extents than with two sellers. These findings contrast with the conventional wisdom that product differentiation softens competition among sellers.[12]

[11] See Banks, et al [2003], Rassenti, Smith, and Wilson [2002], and Porter, et al [2009].
[12] For example, see Tirole [1988, Ch. 7].

The rest of the paper is organized as follows. Section 2 describes the theoretical framework underlying our strategic setting, while Section 3 describes related research. Sections 4 and 5 present our experimental design and findings, while Section 6 briefly concludes.

2. Modeling Framework

In this section we present a model of the strategic environment in which auctions and multilateral negotiations are used. It is identical to the model in Thomas and Wilson [2002, 2005], but for the addition of the buyer's privately known preferences for the sellers' products. The model illustrates details underlying our experimental design and provides guidance for future theoretical analyses. We conclude by describing our conjectures about the effects of introducing product differentiation in multilateral negotiations and auctions.

Building upon the modeling framework used in earlier analyses allows us to compare our new results with prior observations. This comparison lets us clearly see the effect of introducing privately known preferences for the buyer, using as a starting point an established set of results involving homogeneous products.[13]

Consider a setting in which T risk-neutral sellers producing horizontally differentiated products compete to fulfill one indivisible contract for a risk-neutral buyer. Seller i's cost c_i of fulfilling the contract is a privately known independent draw from the commonly known continuous distribution function G, with density g that is strictly positive on the interior of the support $[\underline{c},\bar{c}]$. The buyer places a privately known value V_i on having the contract fulfilled by seller i, where each V_i is an independent draw from the commonly known continuous distribution

[13] Another line of fruitful research would be to evaluate existing models of product differentiation, but that is beyond the scope of our paper. Moreover, in Section 3 we describe how no existing models have all of the features that are relevant to the strategic scenarios we consider.

function H, with density h that is strictly positive on the interior of the support $[\underline{v},\bar{v}]$.[14] The players learn their private information before initiating the exchange process.

Exchange is conducted via first-price auctions or nonverifiable multilateral negotiations. In both mechanisms, for a given contract the winning seller's payoff (or surplus) is $p - c_w$, where p is the price paid to the winning seller and c_w is the winning seller's cost of fulfilling the contract. All other sellers' payoffs are 0. The buyer's payoff (or surplus) is $V_w - p$, where V_w is the buyer's value from having the winning seller fulfill the contract. Total surplus from the transaction is $V_w - c_w$.

In a first-price auction the sellers simultaneously and secretly submit price offers. The seller offering the buyer the largest payoff wins the contract and is paid the price that it offered, conditional on that payoff being positive. That is, seller i wins and is paid price p_i if $V_i - p_i > \text{Max}_{j\neq i}[0, V_j - p_j]$. In the case of ties, the winner is selected at random from the set of sellers whose offers yield the buyer its greatest positive payoff.

In a nonverifiable multilateral negotiation the sellers simultaneously and secretly submit initial price offers. The buyer can accept one initial offer or reject them all. If the buyer rejects all initial offers, then it can individually engage each seller in non-binding discussions concerning further concessions. A seller has no information about other sellers' offers, so it cannot verify any claims the buyer makes about the attractiveness of those offers.[15] At any time each seller can make a new offer by reducing its price from its current offer. Importantly, each seller's best offer remains valid, so the buyer can hold a seller's offer while it searches for a better one. Negotiations continue until agreement is reached or the parties abandon the process.

[14] The homogeneous product setting considered by Thomas and Wilson [2002, 2005] corresponds to the distribution H being degenerate at a specific value.
[15] This contrasts with the verifiable multilateral negotiations considered in Thomas and Wilson [2005].

With homogeneous products Thomas and Wilson [2002] conjectured that the outcomes of nonverifiable multilateral negotiations and first-price auctions would look similar. This conjecture was guided by the following theoretical arguments involving a variant of the "button auction" described by Milgrom and Weber [1982]. Suppose that a price clock declines from a sufficiently high level that all sellers would be willing to fulfill the contract at the starting price. Each seller signals its willingness to supply at the current price by depressing a button, and signals its lowest offer by releasing its button at that price. A seller cannot re-enter the bidding, and it cannot see when its rivals release their buttons. The auction concludes when the last seller releases its button, and that seller is awarded the contract at the price showing on the clock when it released its button. This auction is similar conceptually to nonverifiable multilateral negotiations, because in either institution a seller must be concerned that it is making unnecessary price concessions when it already is winning the competition. Moreover, the button auction is strategically equivalent to a first-price auction. In both auctions, strategies consist of mappings from costs into prices, and seller i is choosing its price to maximize the objective function $(p_i - c_i)\Pr(p_i \text{ wins})$.

The evidence with homogeneous products showed the conjectured relationship held only partly. Negotiations and auctions yielded the buyer statistically indistinguishable payoffs with four sellers, but negotiations yielded statistically lower payoffs than did auctions with two sellers. The difference in duopoly occurred when a seller with especially low costs faced a rival with especially high costs. Even though the sellers' costs were private information, when there was a large gap between their costs the buyer for some reason was unable to extract significant concessions from the low-cost seller once the high-cost seller effectively dropped out of the negotiations.

With differentiated products we conjecture that multilateral negotiations will perform relatively better for the buyer than will first-price auctions, because the auction outcomes are likely to be inefficient.[16] Inefficiency corresponds to lost gains from trade, and we think the communication available with multilateral negotiations will allow the buyer to obtain some of the surplus that would be lost in the auctions.

3. Related Research

Although to date no theoretical analyses of multilateral negotiations include all of what we consider to be essential elements of the strategic environment, there is related theoretical and experimental research. Recognizing how that research differs from the setting we consider is important in formulating subsequent analyses. For additional references, please consult Thomas and Wilson [2002, 2005].

The first set of relevant papers involves the trade of homogeneous products through exchange methods featuring aspects of bargaining. Shaked and Sutton [1984] model an alternating offer setting in which the buyer can switch to a different seller after some commonly known length of time. Both sellers have the same commonly known production cost, the buyer can bargain with only one seller at a time, and switching to another seller voids any existing offer. The authors find that the buyer obtains greater surplus than if switching were impossible.

McAfee and Vincent [1997] model an auction with a public reserve price, in which the auctioneer cannot commit not to solicit future offers if it rejects all current offers. They show that as the time between offers goes to zero, expected revenues converge to those from a static

[16] First-price auctions are predicted to be 100% efficient with homogeneous products in our setting. To see from a theoretical perspective why first-price auctions might be inefficient with differentiated products, suppose that sellers set their prices according to a function that is strictly increasing in their privately known production costs. The winning seller will not necessarily be the one with the largest difference between the buyer's value and the seller's cost, because equilibrium price-setting functions likely increase less than one for one with the seller's cost.

auction with no reserve price. The inability to forgo seeking future offers gives this auction a feel similar to multilateral negotiations, and results such as theirs support conjectures about the similarity of the institutions' outcomes.

Wang [2000] models a procurement setting in which the buyer has the same privately known value for each seller's product, and the sellers have privately known costs. After the sellers make simultaneous price offers, the buyer can reject all offers, accept the lowest offer and pay it, or negotiate with the seller making the lowest offer. The negotiated outcome consists of the equilibrium payoffs from an alternating offers bargaining model with one-sided incomplete information, because the author assumes that the seller's cost becomes common knowledge once negotiations commence.

Cason, Friedman, and Milam [2003] experimentally evaluate a trading environment in which several sellers and buyers engage in bilateral negotiations that start from the seller's list price. A buyer can abandon negotiations with one seller by incurring a cost to initiate negotiations with another seller. The authors find that efficiency is lower and prices are higher in this setting than in a posted offer environment.

The next set of relevant papers considers the trade of differentiated products through various auction formats. Che [1993] models "scoring" auctions in which sellers make price-quality offers to a buyer who evaluates the offers according to a scoring rule. The main difference between our approach and the literature on scoring auctions is that we assume that sellers do not tailor their product to a particular buyer. Whether product differentiation is endogenous or exogenous is an empirical matter specific to the market in question.

Engelbrecht-Wiggans, Haruvy, and Katok [2007] theoretically and experimentally analyze a procurement setting in which the buyer's value for seller *i*'s product is known by the

buyer and by seller *i*, and the sellers have privately known costs. The authors study a "price-based" mechanism in which the seller offering the lowest price wins the contract at the price that it offered, and a "buyer-determined" mechanism in which the seller offering the highest payoff to the buyer wins the contract at the price that it offered. The latter mechanism is equivalent to the first-price auction in the present paper, but their assumption that a seller knows the buyer's value for its product makes that mechanism isomorphic to a standard auction with homogeneous products.[17] The auction in our setting is not solvable through similar means.

Rezende [2009] models a duopoly procurement setting in which the buyer can credibly reveal its preferences for the sellers' products. The sellers participate in a dynamic auction in which they observe all existing price offers, and in alternate periods they choose whether to cut their existing price offer by a specified amount. The auction concludes if the sellers refrain from cutting price in consecutive periods, after which the buyer can negotiate with one of the sellers. The author finds that the buyer should fully reveal its preferences, but that it may prefer not to learn its actual values for the sellers' products.

4. Experimental Design and Procedures

Using Section 2's framework as a guide, for the experiment we pair two treatments, one with 16 first-price auctions and one with 16 nonverifiable multilateral negotiations. We vary these two treatments by changing the number of sellers from two per buyer to four per buyer, which yields four treatment conditions in total.

For each of the four treatments we have four independent groups of subjects, which we also refer to as sessions. Each subject is assigned a specific role in a specific group for the

[17] Two other differences are that they assume profitable trades always exist, and that the buyer might not select the winner that maximizes its payoff.

duration of the experiment. A seller's characteristics consist of 16 privately known random cost draws from the Uniform distribution on the support [0, 600] (in cents), 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. These design features reduce the variation across subjects, and consequently tighten the standard errors of our estimates.

The buyer's characteristics consist of 16 sets of privately known random preference draws from the Uniform distribution on the support [300, 900]. Each set consists of either two or four draws for each time period, depending on the number of sellers. Analogously to the sellers' costs, the buyers in all 16 groups have the same preference draws for seller i (i = 1, 2, 3, 4).

The presence of product differentiation is the difference between the environment in this experiment and the one reported in Thomas and Wilson [2002]. In that experiment the buyer's value for each seller's product was commonly known to be 600, while here the unbiased *expectation* of the buyer's value is 600. Consequently, a transaction between the buyer and a randomly chosen seller has the same expected total surplus in both environments, but introducing product differentiation increases expected total surplus from the surplus-maximizing transaction.

The first-price auction proceeds with each seller simultaneously submitting a price offer, at which point the winner is determined as described in Section 2. The nonverifiable multilateral negotiation proceeds with each seller simultaneously submitting an initial price offer. If the buyer rejects all initial offers, the negotiations are implemented by the buyer engaging in non-binding, free-form text messaging with each seller over the computer network. The buyer cannot credibly reveal to a seller its preferences or the other sellers' offers. Sellers can respond

to these communications by making lower price offers, the buyer can accept or reject these new offers, and so on. Each seller's best offer remains valid while the negotiations are conducted, so seeking better offers does not void existing ones.

Participants, undergraduate students recruited from the general student population of a large state university, 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 respective exchange rates were 4 and 2 experimental dollars for each US$1. In addition to the $5 show-up payment, the average subject earned $19.17. The average session lasted 90 minutes.

5. Experimental Results

For each period we observe the transaction price, the buyer's value for each seller's product, each seller's cost, each seller's offer in the auctions, and each seller's initial and subsequent offers in the multilateral negotiations. We analyze the data using a linear mixed-effects model for repeated measures,[18] and we pool the data from the present experiment with the data from Thomas and Wilson [2002] that considers homogeneous products.[19] Combining the data permits parsimonious comparisons across institutions within a differentiation regime, and within institutions across differentiation regimes.

[18] See Longford [1993] for a description of this technique commonly employed in experimental sciences.

[19] In particular, we use the data from the first twelve periods of the experiment described in Thomas and Wilson [2002]. That experiment used a crossover design, and so the outcomes following a change from one institution to another are not directly comparable to the outcomes in the present experiment.

5.1. Differentiation's Effect on Payoff Comparisons Across Institutions

We focus our attention on the buyer's payoff rather than on the transaction price, because prices do not provide a meaningful way to compare settings with and without product differentiation, from the perspective of the participants' payoffs.[20] Moreover, even across-institution comparisons using prices may be misleading in settings with product differentiation. For example, auctions may lead to higher transaction prices but a higher buyer's payoff, if in the auctions the buyer more frequently purchases from the seller whose product has the highest intrinsic value. In that case the buyer would prefer the exchange mechanism with higher prices.

Table 1 reports the model's regression results, with the buyer's payoff as the dependent variable. The treatment effects (*Two* vs. *Four* Sellers, Nonverifiable Multilateral *Negotiation* vs. *First-Price Auction*, and *Differentiation* (*D*) vs. *Homogeneous* Products) and the two- and three-term interaction effects from a 2^3 design are modeled as (zero-one) fixed effects. The 32 independent sessions are modeled as random effects, e_i. Following Thomas and Wilson [2002], we control for across-period surplus variation by including period-specific deviations of the highest and second-highest total surpluses from their theoretical expected values. We denote those deviations by s_1 and s_2.[21] This formulation captures each treatment's expected buyer's payoff in the treatment coefficient, because on average $s_1 = s_2 = 0$. Specifically, we estimate the model

[20] The results in Thomas and Wilson [2002] regarding transaction prices with homogeneous products can be easily translated into payoff terms, because the buyer's value for all sellers' products is a known constant.

[21] For a given probability distribution L of surplus $s_i \equiv V_i - c_i$ from a trade between the buyer and seller i, the expected value of the highest surplus with N sellers is $E[S_1] = \int_{\underline{s}}^{\overline{s}} NsL(s)^{N-1}L'(s)ds$. The expected value of the second-highest surplus is $E[S_2] = \int_{\underline{s}}^{\overline{s}} N(N-1)s[1-L(s)]L(s)^{N-1}L'(s)ds$. The specific formulas for L in the different treatments are reported in Appendix A. With homogeneous products and two sellers, the expected values of the highest and second-highest surpluses are 400 and 200, and with four sellers the expected values are 480 and 360. With horizontally differentiated products and two sellers, the expected values are 440 and 160, and with four sellers the expected values are 554.524 and 376.429.

$$\pi_{ij}^{B} = \mu + e_i + \beta_1 Two_i + \beta_2 Negotiation_i + \beta_3 Two_i \times Negotiation_i +$$
$$\beta_4 s_{1ij} + \beta_5 s_{1ij} \times Two_i + \beta_6 s_{1ij} \times Negotiation_i + \beta_7 s_{1ij} \times Two_i \times Negotiation_i +$$
$$\beta_8 s_{2ij} + \beta_9 s_{2ij} \times Two_i + \beta_{10} s_{2ij} \times Negotiation_i + \beta_{11} s_{2ij} \times Two_i \times Negotiation_i +$$
$$\beta_{12} D + \beta_{13} D \times Two_i + \beta_{14} D \times Negotiation_i + \beta_{15} D \times Two_i \times Negotiation_i +$$
$$\beta_{16} D \times s_{1ij} + \beta_{17} D \times s_{1ij} \times Two_i + \beta_{18} D \times s_{1ij} \times Negotiation_i + \beta_{19} D \times s_{1ij} \times Two_i \times Negotiation_i +$$
$$\beta_{20} D \times s_{2ij} + \beta_{21} D \times s_{2ij} \times Two_i + \beta_{22} D \times s_{2ij} \times Negotiation_i + \beta_{23} D \times s_{2ij} \times Two_i \times Negotiation_i + \varepsilon_{ij}$$

where π_{ij}^{B} denotes the buyer's payoff in period j of session i, with $e_i \sim N(0, \sigma_1^2)$ and $\varepsilon_{ij} \sim N(0, \sigma_{2,i}^2)$.[22] We accommodate heteroskedastic errors by session when estimating the model via maximum likelihood.

Estimates of the treatment effects are easy to compute with this specification. The buyer's expected payoff is μ in a four-seller first-price auction with homogeneous products, $\mu + \beta_{12}$ in a four-seller first-price auction with differentiated products, $\mu + \beta_2$ in a four-seller non-verifiable multilateral negotiation with homogeneous products, and so forth. Across-treatment payoff differences, and differences-in-differences, also are easy to compute.

For comparison purposes, we begin by restating a central finding from Thomas and Wilson [2002] regarding the buyer's expected payoff with homogeneous products.

Finding 0**:** *Consider the setting with homogeneous products. With two sellers the buyer's expected payoff when using multilateral negotiations is significantly lower than when using first-price auctions. In contrast, with four sellers the buyer's expected payoff is statistically indistinguishable when using multilateral negotiations and first-price auctions.*

[22] It is important to note that the linear mixed-effects model for repeated measures treats each *session* as one degree of freedom with respect to the treatments.

***Evidence*:** With two sellers the sum of the coefficients on *Negotiation* and *Two* × *Negotiation* on the left side of Table 1 represents the amount by which the negotiation treatment changes the buyer's expected payoff relative to first-price auctions. The negotiation treatment significantly decreases the buyer's expected payoff by 104.6 (= –3.1 – 101.5) experimental cents below its level in first-price auctions (*p*-value = 0.0001). With four sellers the point estimate of the negotiation treatment is economically small (–3.1) and statistically insignificant (*p*-value = 0.8746). ■

Our explanation of Finding 0 comprises part of our explanation of Finding 1, so we postpone it briefly. To begin our analysis of product differentiation, we evaluate the buyer's expected payoff across institutions.

***Finding 1*:** *Consider the setting with horizontally differentiated products. With a given number of sellers, the buyer's expected payoff is statistically indistinguishable when using multilateral negotiations and first-price auctions.*

***Evidence*:** The estimates in Table 1 provide the evidence for this finding. With two sellers the difference between the buyer's expected payoff in the negotiations and the auctions is 12.4 (= –3.1 – 101.5 + 4.7 + 112.3) and insignificant (*p*-value = 0.5416), as given by the sum of the coefficients on *Negotiation*, *Two* × *Negotiation*, *Differentiated* × *Negotiation*, and *Differentiated* × *Two* × *Negotiation*. With four sellers the difference is 1.6 (= –3.1 + 4.7) and insignificant (*p*-value = 0.9352), as given by the sum of the coefficients on *Negotiation* and *Differentiated* × *Negotiation*. ■

Unlike with homogeneous products, a buyer facing two sellers does not receive a higher expected payoff with first-price auctions than with multilateral negotiations. This relative improvement for the buyer in the negotiations' performance suggests that the buyer can better exploit its privately known preferences as a result of the communications allowed by the multilateral negotiations. Moreover, this finding is consistent with our hypothesis that multilateral negotiations' prevalence stems in part from aspects of strategic environments that are absent from earlier analyses.[23]

In Section 2 we conjectured that introducing product differentiation would yield a relative improvement in the buyer's expected payoff from negotiations over auctions, because negotiations may capture gains from trade lost by the auctions. To evaluate this explanation for Finding 1, we would like to estimate product differentiation's effect on efficiency. However, efficiency in each period is so consistently high in all sessions that there is insufficient variation to estimate a linear mixed-effects model for the ratio of realized total surplus to maximum available surplus. Instead we provide suggestive evidence about efficiency by comparing the expected value of the highest total surplus to the sum of the estimated values of the buyer's expected payoff and the sellers' expected payoffs. Table 2 reports estimates of the winning seller's expected payoff, using the same linear mixed-effects approach with which we estimated the buyer's expected payoff in Table 1. These estimates in fact reflect the sum of the sellers' expected payoffs, because losing sellers earn zero.

[23] A referee noted that the buyer might be risk averse. Not only would this suggest assessing the variance of the buyer's payoff in addition to its mean, but the prospect of a risk averse buyer introduces some potentially interesting differences between auctions and multilateral negotiations. Specifically, in standard auctions the buyer's risk aversion has no effect on the sellers' pricing behavior, because the buyer is not a strategic actor. However, the buyer actively participates in the negotiations. Risk aversion might influence the buyer's behavior, which likely would influence the sellers' behavior. Our analysis is not designed to capture such effects, but assessing such effects might be fruitful in future work.

Table 3 reports the sum of the estimated buyer's expected payoff and winning seller's expected payoff as a fraction of the expected maximum total surplus. Efficiency is high in all treatments, and there is no obvious economically significant change from introducing product differentiation. This evidence suggests that the negotiations' relative performance improvement is not driven by inefficiency in the first-price auctions when there is product differentiation.

Another possible explanation for Finding 1 begins by noting that product differentiation does not obviously affect the original intuition for the conjectured relationship between first-price auctions and nonverifiable multilateral negotiations. As we described in Section 2, Thomas and Wilson [2002] argued that a seller in nonverifiable multilateral negotiations with homogeneous products must be concerned that the buyer is lying about the seller's current standing in the competition. This concern translates into decisions about what pricing concessions to make, and those relate to pricing incentives in auction formats that are strategically equivalent to first-price auctions. Specifically, seller *i* in the negotiations essentially is choosing a "stopping price" p_i to maximize $(p_i - c_i)\Pr(p_i \text{ wins})$, which has the same form as the seller's objective function in a first-price auction. A seller's objective function has the same form with differentiated products, although the probability of winning depends on prices and the buyer's values for the sellers' products. This perspective suggests the same link between auctions and negotiations, whether products are homogeneous or differentiated.[24]

As described in Finding 0, the observed behavior with homogeneous products partly supported the conjectured relationship. Thomas and Wilson [2002] show that the departure occurred in duopoly when one seller had particularly low costs and the other seller had high costs. In such cases it appears that the buyer was unable to obtain significant concessions from

[24] Note that we are not suggesting, for example, that the Bayesian Nash equilibrium in a first-price auction is the same with homogeneous and differentiated products. By considering the pricing behavior of a seller with the highest possible cost draw, one can easily show that the equilibria must differ.

the low-cost seller in the negotiations. With four sellers the buyer's ability presumably is less relevant, because the difference between the lowest and second-lowest costs on average is smaller than when there are only two sellers.

Finding 1 shows that the across-institution difference disappears with differentiation. Given that the difference with homogeneous products appeared for particular realizations of the sellers' costs, the difference with differentiated products may disappear in the same instances. Figure 1 supports this explanation by plotting transaction prices against each period's lowest realized cost. The top two panels show average transaction prices in each period for each institution, with homogeneous products. The left panel represents the setting with two sellers, and the right the setting with four sellers. With two sellers the difference in outcomes between the auctions and the negotiations is evident by the gap in the linear trend lines when the lowest realized cost is less than 225. With four sellers the similarity in outcomes across institutions is equally apparent for all lowest realized costs. The bottom two panels include the trend lines from the top two panels, overlaid by the data and linear trend lines for each institution with differentiated products. As is evident, introducing product differentiation lowers transaction prices in the two-seller nonverifiable multilateral negotiations *precisely when the lowest realized cost is quite low*.[25]

The change in the sellers' pricing behavior may stem from a low-cost seller's reduced likelihood of being the buyer's surplus-maximizing trading partner. That is, low costs are less of a guarantee that the seller is going to make a sale with differentiated products, because the buyer may have a low intrinsic value for that seller's product and a high intrinsic value for the other seller's product. Therefore, a low-cost seller may be more easily persuaded to offer price

[25]The difficulty in discriminating between the solid linear trend lines also provides visual evidence of the similarity of the institutions' outcomes when there is horizontal product differentiation.

concessions when there is differentiation. If so, this may serve to mitigate the buyer's unexpected bargaining handicap that was observed with homogeneous products.

5.2 Differentiation's Effect on Sellers' Behavior

While Findings 0 and 1 illustrate the change in the relative performance of auctions and negotiations, considering how that change comes about may deepen our understanding of how product differentiation changes behavior in the two institutions. That is, while for the buyer we know that introducing product differentiation with two sellers improves the negotiations' performance relative to the auctions' performance, is that due to the negotiations becoming better for the buyer, the auctions becoming worse, or some other change?

We hypothesize that the change in performance reflects a change in the intensity of competition among the sellers, which in the next finding we attempt to measure. The well-known Lerner index provides useful guidance in constructing such a measure, although it is inappropriate for comparing the intensity of competition across the treatments we consider. The Lerner index is $\frac{P-MC}{P}$, where P is the market price and MC is the marginal cost of the last unit produced. The Lerner index measures by how much the market outcome differs from the competitive outcome, suitably normalized to allow comparisons across different settings.

Within each treatment we measure the intensity of competition among the sellers as the extent to which the buyer's expected payoff in the treatment's associated competitive outcome differs from the buyer's actual expected payoff in the treatment, normalized by the buyer's expected payoff in the treatment's competitive outcome. We use expected payoffs rather than prices for the reasons articulated at the start of subsection 5.1: There are differences in available surplus across the differentiated and homogeneous treatments, and within the differentiated

treatment there may be differences in match quality across institutions. Moreover, payoffs are often the unit of account when assessing competition.[26]

Our measure of the intensity of competition in a treatment is thusly $\frac{E[\max(0,S_2)]-E[\pi^B]}{E[\max(0,S_2)]}$. $E[\pi^B]$ is the buyer's expected payoff in the treatment, as reported in Table 1. $E[\max(0,S_2)]$ is the expected value of the maximum of zero and the second-highest surplus in the treatment. Our use of $E[\pi^B]$ is clear from our discussion in the prior paragraph, but our use of $E[\max(0,S_2)]$ as the buyer's expected payoff in the competitive outcome merits explanation.

We view the appropriate competitive benchmark to be an efficient exchange mechanism in which competition among the sellers does not change across treatments. An obvious candidate for such a mechanism is one in which sellers have a dominant strategy of setting their price equal to their cost in both the homogeneous product and differentiated product settings, because such pricing behavior fits naturally with the idea of competitive behavior. Such pricing behavior occurs in a "second-surplus" auction: Sellers offer prices, the buyer purchases from the seller i offering the buyer the highest positive $V_i - p_i$, and the buyer's payoff is the second-highest amount of surplus offered (or zero, if the second-highest surplus offered is negative). The winning seller i's payoff is the difference between $V_i - c_i$ and the buyer's payoff. The buyer's expected payoff in such an auction is $E[\max(0,S_2)]$. With homogeneous products this mechanism is the familiar second-price auction, and more generally it corresponds to the efficient market clearing outcome that is worst for the buyer.

An easy way to interpret our measure is through the lens of supply and demand. Suppose sellers' behavior leads to a price in excess of the competitive price. Our measure is the

[26] See Lerner [1934], Tirole [1988], and the U.K. Office of Fair Trading's Market Power Guidelines (OFT Assessment of Market Power [2004]).

difference in consumer surplus in the competitive outcome and consumer surplus in the market outcome, divided by consumer surplus in the competitive outcome.

Our measure also is related to the "Index of Monopoly Effectiveness" introduced in Coursey, Isaac, and Smith [1984].[27] That index measures what fraction sellers obtain of the additional profits available from the monopoly outcome versus the competitive outcome. The maximum expected payoff the sellers can extract is $E[\max(0, S_1)]$, while the sum of the sellers' expected payoffs in the competitive outcome is $(E[\max(0, S_1)] - E[\max(0, S_2)])$. Hence, in our setting their index is

$$\frac{NE[\pi^S] - (E[\max(0,S_1)] - E[\max(0,S_2)])}{E[\max(0,S_1)] - (E[\max(0,S_1)] - E[\max(0,S_2)])} = \frac{NE[\pi^S] - (E[\max(0,S_1)] - E[\max(0,S_2)])}{E[\max(0,S_2)]}.$$

A variant of the index instead measures the effect on the buyer of the sellers' attempts to monopolize. It is the difference between the buyer's expected payoff in the treatment's competitive equilibrium and the buyer's actual expected payoff, divided by the difference between the buyer's expected payoff in the competitive equilibrium and when the sellers extract the entire available surplus. That variant amounts to $\frac{E[\max(0,S_2)] - E[\pi^B]}{E[\max(0,S_2)]}$, which corresponds to the measure we use.

We use consumer surplus as the benchmark because our analysis emphasizes the buyer's institutional choice, and because assessments of competition often consider effects on consumers.[28] We instead could have used producer surplus as in Coursey, et al [1984], because changes in competition typically affect buyers and sellers in an opposing manner. However, we show later that in some cases moving from homogeneous to differentiated products in the auctions can cause both the buyer's and the sellers' equilibrium expected payoffs to fall below

[27] Nearly every experimental economics article with monopoly sellers reports this metric to compare monopoly effectiveness across different supply and demand configurations.

[28] For example, consider the U.S. Department of Justice and Federal Trade Commission Horizontal Merger Guidelines [2010].

their level in our competitive benchmark, even though the sellers arguably are acting less competitively. However, in all cases we find that the buyer does worse after introducing differentiation, which is consistent with less intense competition among the sellers.

Finally, our measure accounts for changes in the buyer's expected payoff that emerge simply through changes in the strategic environment that do not lead to changes in the sellers' behavior. To illustrate the issue, consider a duopoly procurement setting with homogeneous products in which the sellers' costs are uniformly distributed from 0 to 600, the buyer's value for the sellers' product is 1000, and first-price auction rules are used. In equilibrium the expected price equals the expected value of the second-lowest cost, 400, and the buyer's expected payoff is 600. If we shift the costs up by 300, then the sellers' equilibrium price offers shift up by 150 and the expected price is 700. The buyer's expected payoff falls to 300, but the change in the sellers' cost structure arguably induces no change in the intensity of competition between the sellers.[29] By subtracting the buyer's expected payoff in the first-price auction from its expected payoff in a second-price auction (a second-surplus auction in which products are homogeneous), in both settings the measure of competition is 0.

***Finding 2*:** *Consider moving from homogeneous products to horizontally differentiated products, holding fixed the number of sellers and the institution. With two sellers the intensity of competition increases substantially when using multilateral negotiations, and to a lesser extent when using first-price auctions. With four sellers the intensity of competition increases when using multilateral negotiations or first-price auctions, by similar extents.*

[29] Returning to the supply and demand analogy, calling such a change a reduction in competition is akin to saying competition is reduced following a decrease in supply that lowers consumer surplus.

Evidence: Figure 2 plots the 95% confidence intervals for $\frac{E[\max(0,S_2)]-E[\pi^B]}{E[\max(0,S_2)]}$ using the estimates and standard errors for $E[\pi^B]$ from Table 1. Holding fixed the institution and the number of sellers, we also calculate, using the regression reported in Table 1, the estimated differences when moving from homogeneous to horizontally differentiated products and test whether they are significantly different from zero. With two sellers, introducing differentiation in multilateral negotiations significantly reduces our competition measure, which corresponds to more intense competition amongst sellers because the buyer is obtaining a larger fraction of its competitive payoff after introducing product differentiation. The measure of competition falls by 0.938 (*p*-value < 0.0001). The entire effect of high prices that Thomas and Wilson (2002) observed for two seller negotiations is noticeably wiped out with horizontal product differentiation. In first-price auctions the measure of competition also falls significantly, but only by 0.347 (*p*-value = 0.0033). With four sellers, the effects are also statistically significant, though the magnitudes of the effects are much smaller: Introducing differentiation in multilateral negotiations significantly reduces our competition measure by 0.147 (*p*-value = 0.0108), and in first-price auctions significantly reduces our competition measure by 0.134 (*p*-value = 0.0191). ■

This experimental result—that introducing horizontal product differentiation increases the intensity of competition among the sellers—merits further scrutiny because it contrasts with the conventional wisdom that product differentiation softens competition.

One possibility is that the sellers act collusively with homogeneous products, but not with differentiated products. Such behavior would be consistent with the conventional wisdom in the industrial organization literature that collusion is more difficult to sustain when products are differentiated. However, Table 3's reported high efficiency with homogeneous products does

not support this explanation. Collusion in procurement by sellers who cannot communicate with each other involves inefficiency, because the sellers cannot tell who has the lowest cost.[30] Consequently, there is an efficiency loss when the wrong seller is allowed to win the contract.

Another possibility suggested to us is that the sellers actually have become more homogeneous following the introduction of asymmetric information about the buyer's values, in which case the increased intensity of competition is not so counterintuitive. The idea of greater homogeneity is based on the fact that a seller with low costs is less sure it is the buyer's surplus-maximizing choice, while a seller with high costs is less sure it is not. That is, for given cost realizations the sellers now hold more similar beliefs about the likelihood of their being the buyer's surplus-maximizing trading partner. The problem with this explanation is that despite the "flattening out" of the beliefs, the sellers actually are more differentiated. For example, footnote 21 reports that introducing product differentiation increases the difference between the expected highest and second-highest levels of surplus, which is the difference in expected surplus offered by the best and second-best trading partners.[31]

A third explanation for Finding 2 is that non-collusive equilibrium behavior in this setting becomes more competitive after introducing product differentiation, in contrast to what is typically seen in other oligopoly models. Although the derivation of equilibrium solutions for models of auctions and multilateral negotiations in this setting is an open problem, to assess this possibility we numerically approximate the sellers' Nash equilibrium price-setting function in a first-price auction using the parameters from the experiment: The sellers' privately known costs are uniformly distributed from 0 to 600, and the buyer's privately known values are uniformly distributed from 300 to 900. Appendix A describes the approximation techniques.

[30] See McAfee and McMillan [1992].
[31] A similar argument can be made regarding the variance of the difference between two sellers' surpluses as the buyer's trading partner.

Each panel of Figure 3 plots with a smaller dashed line the equilibrium price-setting functions for first-price auctions, either the analytically derived one when products are homogeneous or the numerically derived one when products are differentiated. As is evident from comparing the panels horizontally, introducing product differentiation leads to higher equilibrium price offers by sellers, for all cost realizations. Calculating our competition measure also shows that competition gets less intense after introducing product differentiation with two or four sellers, exactly as the conventional wisdom suggests. With homogeneous products our competition measure is 0 with two or four sellers, because the first-price and second-price auctions are revenue equivalent. With differentiated products our competition measure is 0.077 with two sellers and 0.122 with four sellers.[32] That is, after introducing product differentiation the buyer gets a smaller share of its expected payoff in the competitive equilibrium.[33]

To see how subjects' behavior relates to theoretical predictions, the wider dashed and solid lines in each panel of Figure 3 replicate the linear trend lines from Figure 1 for the observed transaction prices in the first-price auctions in the experiment. The trend lines show that prices are lower than predicted with homogeneous products, but more importantly that they do not increase with differentiated products.[34] As we mentioned in our discussion of Figure 1, a possible explanation for this behavior is that low-cost sellers are concerned they are not the buyer's surplus-maximizing trading partner when products are differentiated. Comparing the experimental results with the numerically approximated equilibrium suggests the sellers

[32] In the numerically approximated equilibrium, the buyer's expected payoff with 2 sellers is 169.943, and $E[\max(0,S_2)] = 184.063$. The buyer's expected payoff with 4 sellers is 330.629, and $E[\max(0,S_2)] = 376.739$.

[33] As mentioned earlier, after introducing differentiation with two sellers the sellers actually obtain less than their payoff in the treatment's competitive equilibrium. While the pricing response indicates they are acting less competitively, their payoffs fall due to the failure to achieve the maximum surplus that occurs because sellers are choosing prices while uncertain about the buyer's preferences.

[34] The numerically approximated price-setting functions that are plotted actually give a lower bound on transaction prices that would arise if sellers priced according to those functions. For a given minimum cost, the transaction price is weakly higher than the price specified by the price-setting function, because the transaction might involve a higher cost seller (offering a higher price) for whom the buyer has a relatively high value.

overcompensate for this additional uncertainty, in a manner that suggests the buyer receives an information rent from its privately known preferences for the sellers' products.[35]

In summary, Findings 1 and 2 jointly demonstrate that adding uncertainty for the sellers intensifies competition amongst them in both trading formats, to the buyer's benefit. Wilson and Zillante [2010] find similar effects from uncertainty in a laboratory experiment with sixteen buyers facing four sellers, each of whom is privately informed about the quality of its products. If the sellers post flexible, take-it-or-leave-it prices that are publicly observed by all buyers *and* all sellers, rip-offs prevail that are associated with the classic lemons story: low-quality sellers overwhelmingly stock out at prices far greater than the buyer's value for the low-quality product. If the sellers' posted prices instead are observed only by buyers who sequentially visit the sellers, separating outcomes occur: low-quality products sell at low prices, and high-quality products sell at high prices. The authors conclude that "the buyers' uncertainty as to whether or not a seller is peddling a lemon is completely and remarkably counterbalanced by a corresponding uncertainty on the other side of the market as to what are the competing market prices" (p. 2).

6. Conclusion

In this paper we find that introducing product differentiation into a standard procurement setting can affect sellers' pricing behavior in a way that changes the relative performance rankings of auctions and multilateral negotiations. With two sellers the buyer's expected payoff is equal in the auctions and the negotiations when products are differentiated, while its expected payoff in the auctions is higher than in the negotiations when products are homogeneous. With four sellers we find that differentiation leads to no change in the institutions' relative performance rankings, so that auctions and multilateral negotiations continue to yield the buyer

[35] A referee suggested that the sellers' response might reflect risk aversion on their part.

equal expected payoffs. The equivalence we find after introducing differentiation helps explain the prevalence of multilateral negotiations despite the earlier findings with homogeneous products that suggested buyers would tend to prefer auctions. Of course, other factors may play a role.

We also investigate how the sellers' behavior changes after introducing product differentiation, which provides insights into how the institutions' relative performance rankings are influenced. With two or four sellers we find that competition becomes more intense in both the auctions and the negotiations. This finding contrasts with the typical intuition from standard oligopoly models, and with the prediction from a numerical approximation of equilibrium pricing in a first-price auction with differentiated products. This unexpected finding may be due to a low-cost seller's willingness to offer concessions when faced with uncertainty about whether it is the surplus-maximizing trading partner. When the buyer's value is the same for all sellers' products, a low-cost seller is more confident that it will ultimately make the sale.

References

Anderson, S., de Palma, A., and Thisse, J.F. (1992). Discrete Choice Theory of Product Differentiation. (Cambridge and London: MIT Press).

Banks, J., Olson, M., Rassenti, S., Smith, V. (2003). "Theory, Experiment and the Federal Communications Commission Spectrum Auctions," *Journal of Economic Behavior and Organization* 51(3), 303-350.

Cason, T. (1995). "An Experimental Investigation of the Seller Incentives in the EPA's Emission Trading Auction," *American Economic Review* 85, 905-922.

Cason, T., Friedman, D., and Milam, G. (2003) "Bargaining Versus Posted Price Competition in Customer Markets," *International Journal of Industrial Organization* 21, 223-251.

Che, Y.K. (1993). "Design Competition Through Multidimensional Auctions," *RAND Journal of Economics* 24(4), 668-680.

Coursey, D., Isaac, M., and Smith, V. (1984). "Natural Monopoly and Contested Markets: Some Experimental Results," *Journal of Law and Economics* 27, 91-113.

Engelbrecht-Wiggans, R., Haruvy, E., and Katok, E. (2007). "A Comparison of Buyer-Determined and Price-Based Multiattribute Mechanisms," *Marketing Science* 26(5), 629-641.

Fudenberg, D., and Tirole, J. (1983). "Sequential Bargaining with Incomplete Information," *Review of Economic Studies* 50(2), 221-247.

Kennan, J. and Wilson, R. (1993). "Bargaining with Private Information," *Journal of Economic Literature* 31(1), 45-104.

Klemperer, P. (2002). "What Really Matters in Auction Design," *Journal of Economic Perspectives* 16(1), 169-189.

Lerner, A.P. (1934). "The Concept of Monopoly and the Measurement of Monopoly Power," *Review of Economic Studies* 1, 157-175.

Longford, N. T. (1993). Random Coefficient Models. (New York: Oxford University Press).

McAfee, R.P., and McMillan, J. (1987). "Auctions and Bidding," *Journal of Economic Literature* 25, 699-738.

McAfee, R.P., and McMillan, J. (1992). "Bidding Rings," *American Economic Review* 82, 579-599.

McAfee, R.P., and Vincent, D. (1997). "Sequentially Optimal Auctions," *Games and Economic Behavior* 18, 246-276.

Milgrom, P. (2000). "Putting Auction Theory to Work: The Simultaneous Ascending Auction," *Journal of Political Economy* 108(2), 245-272.

Milgrom, P., and Weber, R. (1982). "A Theory of Auctions and Competitive Bidding," *Econometrica* 50, 1089-1122.

Muthoo, A. (1999). Bargaining Theory with Applications (Cambridge: Cambridge University Press).

Porter, D., Rassenti, S., Shobe, W., Smith, V., and Winn, A. (2009). "The Design, Testing and Implementation of Virginia's NOx Allowance Auction," *Journal of Economic Behavior and Organization* 69, 190-200.

Rassenti, S., Smith, V., and Wilson, B.J. (2002) "Using Experiments to Inform the Privatization/Deregulation Movement in Electricity," *The Cato Journal* 21(3), 515–544.

Rezende, L. (2009). "Biased Procurement Auctions," *Economic Theory* 38, 169-185.

Shaked, A., and Sutton, J. (1984) "Involuntary Unemployment as a Perfect Equilibrium in a Bargaining Model." *Econometrica*, 52(6), 1351-1364.

Smith, V.L. (1982). "Microeconomic Systems as an Experimental Science," *American Economic Review* 72(5), 923-955.

Thomas, C.J., and Wilson, B.J. (2002). "A Comparison of Auctions and Multilateral Negotiations," *RAND Journal of Economics* 33(1), 140-155.

Thomas, C.J., and Wilson, B.J. (2005). "Verifiable Offers and the Relationship Between Auctions and Multilateral Negotiations," *Economic Journal* 115, 1016-1031.

Tirole, J. (1988). The Theory of Industrial Organization. (Cambridge, MA: The MIT Press).

U.K. Office of Fair Trading (2004). Assessment of Market Power.

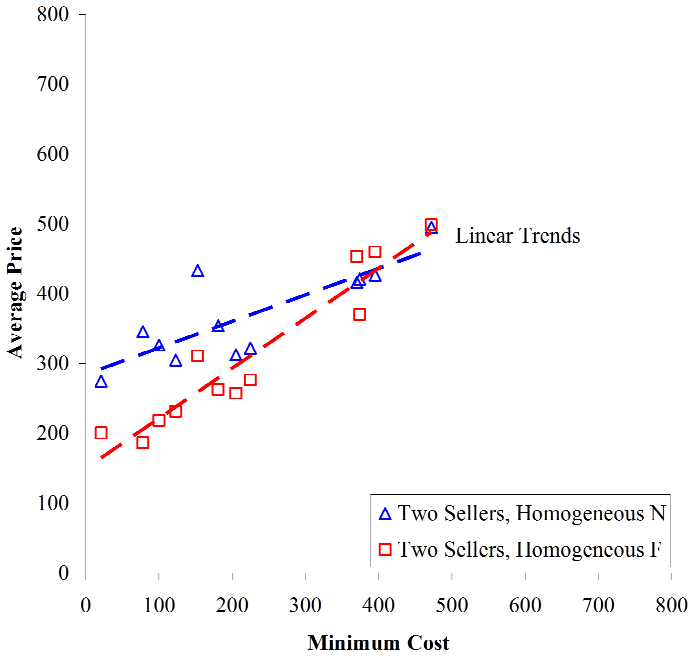
U.S. Department of Justice and Federal Trade Commission (2010). Horizontal Merger Guidelines.

Waehrer, K., and Perry, M. (2003). "The Effects of Mergers in Open-Auction Markets," *RAND Journal of Economics* 34 (2), 287-304.

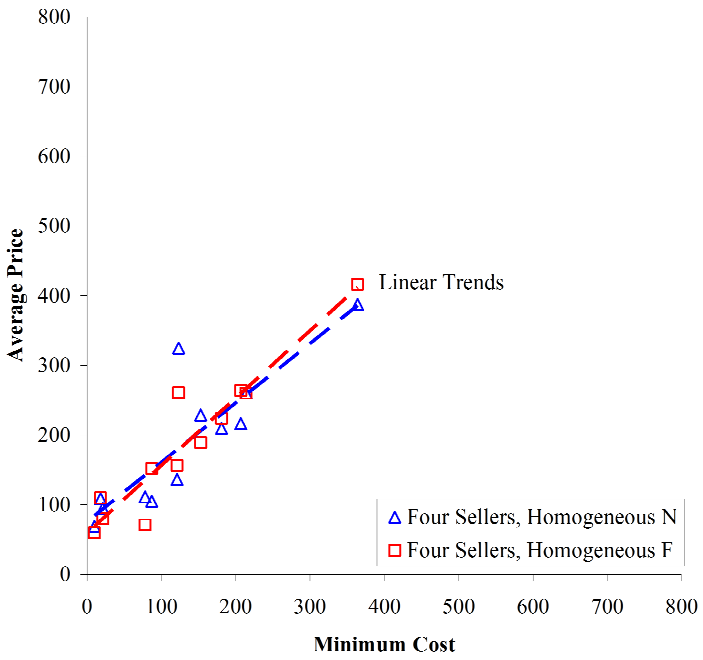
Wang, R. (2000). "Bidding and Renegotiation in Procurement Auctions," *European Economic Review* 44, 1577-1597.

Wilson, B.J., and Zillante, A. (2010). "More Information, More Ripoffs: Experiments with Public and Private Information in Markets with Asymmetric Information," *Review of Industrial Organization* 36 (1), 1-16.

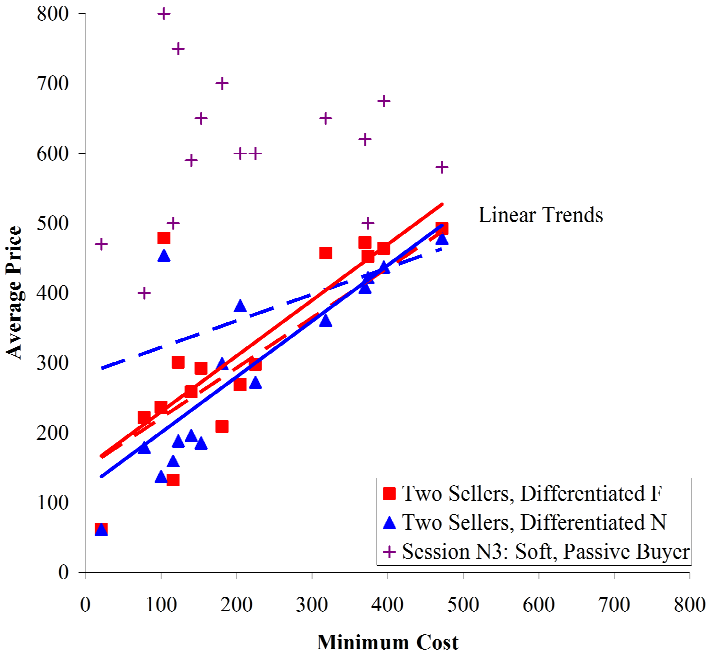
Wolfram, C. (1998). "Strategic Bidding in a Multiunit Auction: An Empirical Analysis of Bids to Supply Electricity in England and Wales," *RAND Journal of Economics* 29, 703-725.



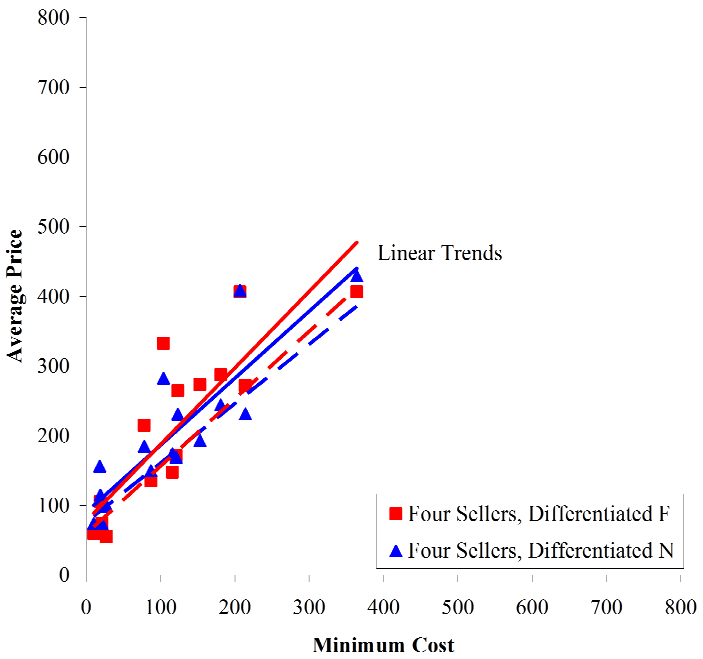
Panel (a). Two Sellers, Homogeneous Products



Panel (b). Four Sellers, Homogeneous Products



Panel (c). Two Sellers, Differentiated Products



Panel (d). Four Sellers, Differentiated Products

Figure 1. Average Period Prices Versus Minimum Cost

[+]While included in the random effects analysis of Tables 1-4, the outlier prices of an unusually soft, passive buyer in a negotiation session are excluded for illustrative purposes from the average price in the panel.
N.B. The dashed trend lines from panels (a) and (b) are correspondingly included in panels (c) and (d).

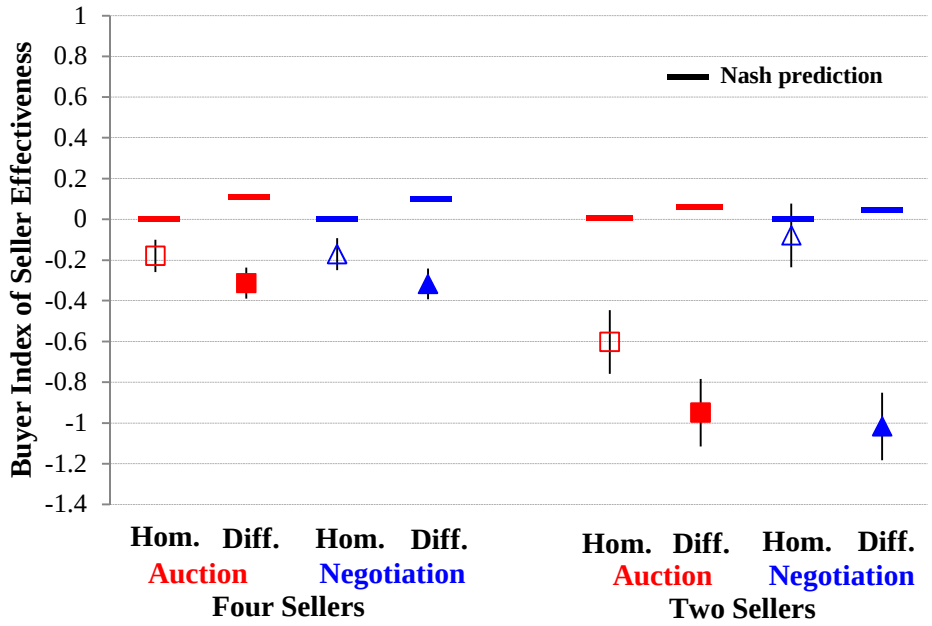
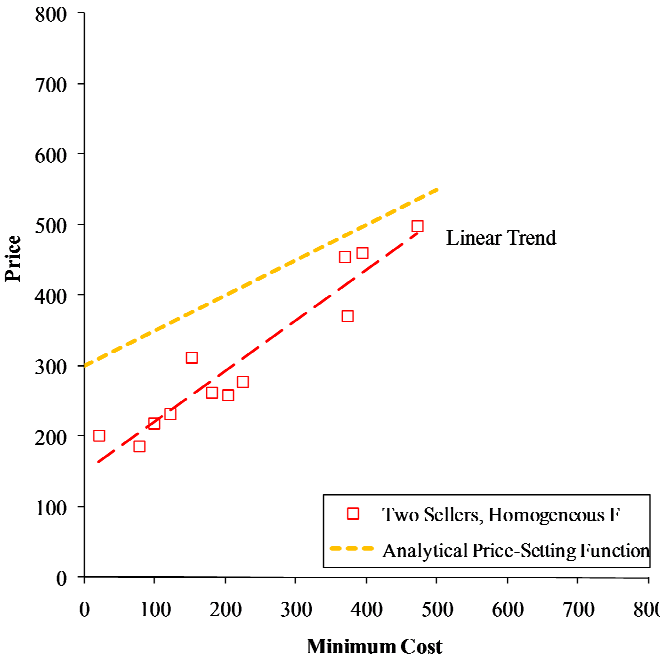
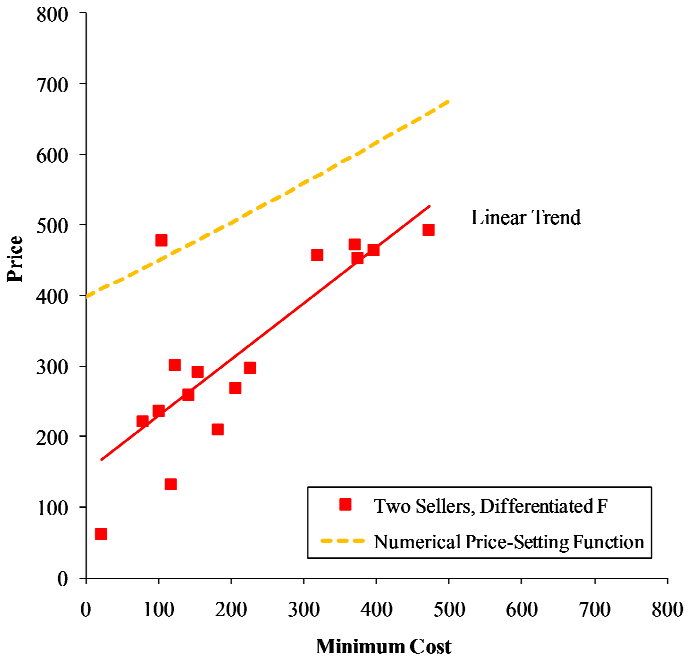


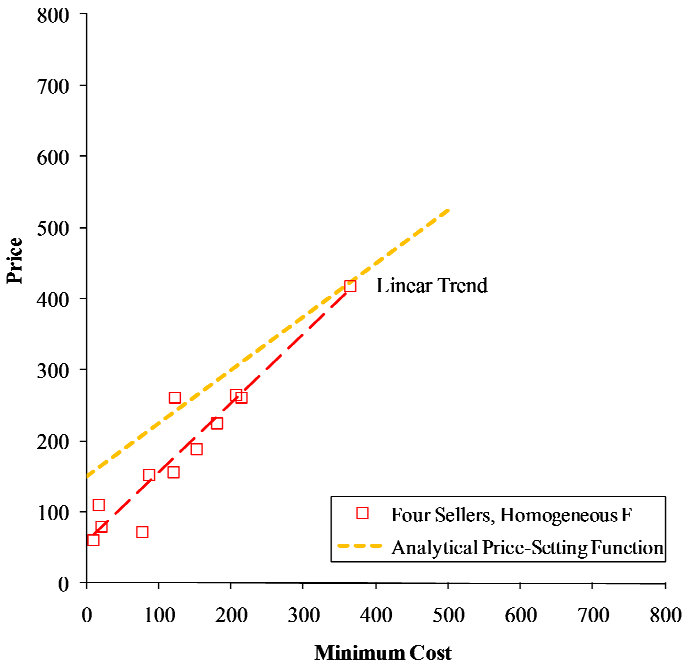
Figure 2. 95% Confidence Intervals for [E[max(0,S_2)] - $E[\pi^B]$]/ E[max(0,S_2)] using Estimates for $E[\pi^B]$ from Table 1



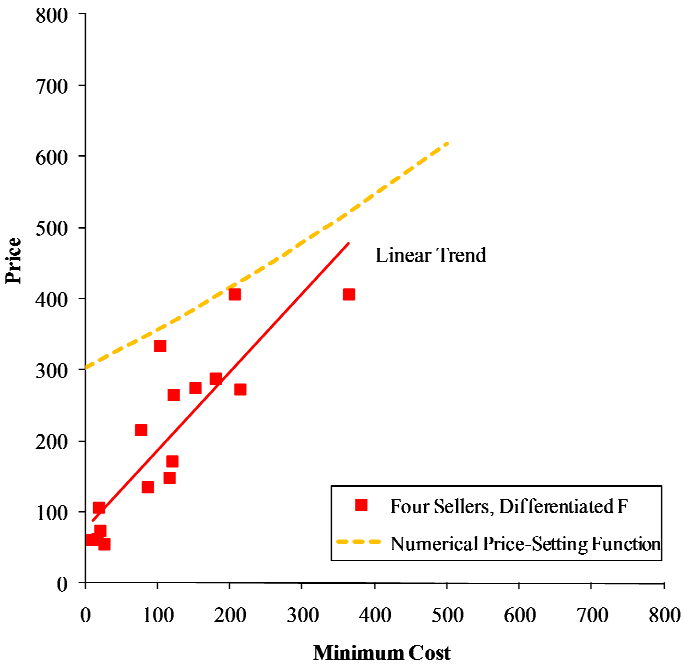
Panel (a). Two Sellers, Homogeneous Products



Panel (c). Two Sellers, Differentiated Products



Panel (b). Four Sellers, Homogeneous Products



Panel (d). Four Sellers, Differentiated Products

Figure 3. Analytical and Numerical Price-Setting Functions and Observed Average Period Prices

Table 1. Estimates of the Linear Mixed-Effects Model for Buyer's Expected Payoff

					Dummy Variable for Differentiated × Baseline			
Homogeneous Baseline (Thomas and Wilson, 2002)	Estimate	Std. Error	Degrees of Freedom	*p*-value	Estimate	Std. Error	Degrees of Freedom	*p*-value
Constant	424.5	13.5	400	<0.0001	70.3	19.7	24	0.0016
Two	-104.1	20.4	24	<0.0001[†]	-31.9	28.4	24	0.2721
Negotiation	-3.1	19.3	24	0.8746	4.7	27.8	24	0.8665
Two × *Negotiation*	-101.5	28.9	24	0.0018	112.3	40.5	24	0.0105
s_1	1.0	0.2	400	<0.0001	0.0	0.2	400	0.9192
$s_1 \times$ *Two*	-0.2	0.2	400	0.1804	0.2	0.2	400	0.2317
$s_1 \times$ *Negotiation*	0.1	0.2	400	0.6542	0.0	0.3	400	0.9364
$s_1 \times$ *Two* × *Negotiation*	-0.6	0.2	400	0.0084	0.4	0.3	400	0.1095
s_2	0.0	0.1	400	0.7652	0.0	0.1	400	0.7868
$s_2 \times$ *Two*	0.1	0.1	400	0.3078	-0.1	0.2	400	0.4237
$s_2 \times$ *Negotiation*	-0.2	0.2	400	0.3584	0.0	0.2	400	0.8651
$s_2 \times$ *Two* × *Negotiation*	0.1	0.2	400	0.5566	0.1	0.2	400	0.7761
			448 Obs.					

[†]One-sided test.

Table 2. Estimates of the Linear Mixed-Effects Model for Winning Seller's Expected Payoff

					Dummy Variable for Differentiated × Baseline			
Homogeneous Baseline (Thomas and Wilson, 2002)	Estimate	Std. Error	Degrees of Freedom	*p*-value	Estimate	Std. Error	Degrees of Freedom	*p*-value
Constant	36.5	11.5	400	0.0016	9.7	16.4	24	0.5611
Two	36.7	18.4	24	0.0286[†]	-13.3	25.4	24	0.6057
Negotiation	8.1	17.3	24	0.6417	-9.8	24.2	24	0.6872
Two × *Negotiation*	84.7	26.8	24	0.0043	-92.4	37.0	24	0.0196
s_1	0.0	0.1	400	0.8392	0.1	0.1	400	0.6155
$s_1 \times$ *Two*	0.3	0.1	400	0.0088	-0.3	0.1	400	0.0210
$s_1 \times$ *Negotiation*	-0.2	0.1	400	0.2516	0.1	0.1	400	0.3977
$s_1 \times$ *Two* × *Negotiation*	0.6	0.2	400	0.0001	-0.5	0.2	400	0.0095
s_2	0.0	0.1	400	0.9225	0.0	0.1	400	0.8503
$s_2 \times$ *Two*	-0.1	0.1	400	0.1850	0.1	0.1	400	0.6179
$s_2 \times$ *Negotiation*	0.2	0.1	400	0.0233	-0.2	0.1	400	0.0768
$s_2 \times$ *Two* × *Negotiation*	-0.2	0.1	400	0.1277	0.1	0.2	400	0.3448
			448 Obs.					

[†]One-sided test.

Table 3. Sum of Estimated Buyer's Expected Payoff and Winning Seller's Expected Payoff, as a Fraction of Expected Maximum Total Surplus

	Homogeneous Products	*Differentiated Products*
Four Sellers First-Price Auctions	96.04%	97.56%
Four Sellers Multilateral Negotiations	97.08%	97.54%
Two Sellers First-Price Auctions	98.40%	97.36%
Two Sellers Multilateral Negotiations	95.45%	98.05%

Appendix A. Numerical Approximation of Nash Price-setting Functions

In this appendix we describe the iterative procedure by which we numerically approximate the sellers' Nash equilibrium price-setting functions in a first-price auction with horizontally differentiated products. We evaluate the same 2-seller and 4-seller settings as in the experiment: the sellers' costs are Uniformly distributed from 0 to 600, and the buyer's values are Uniformly distributed from 300 to 900. The surplus from a transaction between the buyer and seller i is $s_i \equiv V_i - c_i$. Given the distributions of V_i and c_i when products are differentiated, surplus ranges from -300 to 900, the density $L'(s)$ is triangular, and the distribution $L(s)$ is

$$L(s) = \begin{cases} \dfrac{(300+s)^2}{2(600)^2} & \text{for } s \in [-300, 300] \\ 1 - \dfrac{(900-s)^2}{2(600)^2} & \text{for } s \in [300, 900]. \end{cases}$$

When products are homogeneous, surplus ranges uniformly from 0 to 600, so $L(s) = s/600$.

We solve for a symmetric equilibrium from the perspective of seller 1. Our iterative approach begins by finding seller 1's best-response to an initial price-setting function used by seller 1's rivals. In the next iteration seller 1's rivals use the best-response function derived in the prior step, and we find seller 1's best-response to that. The procedure stops when seller 1's

best-response function is within a given distance of the rivals' price-setting function, and seller 1's final best-response function is our approximation of the equilibrium price-setting function.

Given how seller 1's rivals set prices, seller 1's best-response for each cost c is the price p that maximizes $(p - c)\Pr(p \text{ wins})$. The probability function depends on the rivals' price-setting function, and that probability function's nature creates the difficulty in deriving analytic equilibrium solutions. Roughly speaking, with homogeneous products the probability a particular price wins is a length, while with differentiated products the probability is an irregularly shaped volume.

We approximate the probability function in seller 1's objective function in the following manner. Given the rivals' price-setting function, we take two million random draws of values and costs for each rival, and of values for seller 1. We discretize the price space, and for each price p in $\{0, 1, 2, \ldots, 900\}$ the probability that p wins is the fraction of the two million cases in which with price p seller 1 offers the buyer a positive payoff that exceeds the payoff from the rivals.

We approximate seller 1's best-response to its rivals' price-setting function in the following manner. We discretize the cost space, and for each cost c in $\{0, 5, 10, \ldots, 600\}$ we find the price in $\{0, 1, 2, \ldots, 900\}$ that gives seller 1 the highest expected payoff.

Having found seller 1's best-response at a discrete set of costs, we fit a cubic to those points. The fitted cubic is set as the rivals' price-setting function, and we repeat the procedure described above. We use the same set of value and cost draws for each iteration. The procedure concludes when the maximum difference between the rivals' price-setting function and seller 1's best-response is less than 1, evaluated at each cost in $\{0, 5, 10, \ldots, 600\}$. The procedure

converged in fewer than 10 iterations, and with different initial price-setting functions the process converged to approximately the same price-setting function.

With the approximated price-setting function in hand, we used the same random draws to calculate the buyer's expected payoff.

Appendix B. Experiment Instructions (Not for publication)

Buyer/Auction/Differentiation

<page 1>
This is an experiment in the economics of market decision making. Various foundations have provided funds for this research. The instructions are simple, and if you follow them carefully and make good decisions, you may earn a considerable amount of money that will be paid to you in CASH at the end of the experiment.

In this experiment we are going to create a market in which you will be a buyer of a fictitious good in a sequence of periods.

<page 2>
This is what your screen will look like for the experiment. Notice in the upper left portion of your screen that the row labeled 'Value' has been filled in with numbers. This indicates the value to you of buying a single unit of this good from a particular seller.

Notice that for Seller 1 you have a value of 810 and for Seller 2 the value is 975. You can only buy one unit from one seller each period.

If you're able to buy (we'll describe the selling process soon), you will receive the difference between your value and the price paid (the market price).

To sum up: Value – Price Paid = Profit.

<page 3>
Notice that your cash profits depend upon your ability to buy a unit at a price below the values given on your record sheet. Also note that if you buy a unit at a price equal to its value, your profit will be zero. You cannot buy a unit at price greater than your value.

Your earnings will be automatically entered into your record sheet at the close of each period. Earnings (profits) are accumulated over several periods, with your total earnings at the end of the experiment being your total profit over all periods. The 'Summary Information' frame at the bottom of the screen displays your total profit.

<page 4>

In this experiment there are <insert number of sellers> sellers total, each attempting to sell one unit to 1 buyer. You can only purchase one unit each period.

No seller knows what any of your values are. But, you may ask, "How do I buy this good?" Good question. Continue for the answer.

<page 5>
We will now explain the buying procedures in the following periods. The computer will conduct your buying for you.

Let's go through a sample period. Each seller will submit an offer for a unit to sell to you. An 'offer' is the selling price of the seller.

Once all of the offers have been submitted by the sellers, they will be displayed for you in the 'Seller Offer Prices' in the row labeled 'Price'. In this example, Seller 1 submitted an offer of 600, and Seller 2 submitted an offer of 650.

<page 6>
The computer will choose to purchase from the seller who submitted the offer that yields you your greatest profit. Your record sheet will be filled in as shown for period 1. In this example you purchased a unit from Seller 2 at a price of 650, yielding a profit of 975 – 650 = 325.

In the event that two or more sellers tie for the greatest profit for the buyer, the computer will select a winner at random.

The column labeled 'Market Type' summarizes how the market price was determined that period. In this case, the 'Best Offer' determined the market price.

<page 7>
Let's review the important items:

(1) The seller who submits the offer with the greatest profit for you will be the only person to sell the unit to you, as long as that price is not greater than your value.

(2) The price you pay is equal to that offer of the seller.

(3) Your profit is: Value – Paid.

<page 8>
This is the end of the instructions. If you wish to review the instructions, you may go back at this time. If you feel you now understand the instructions and are prepared to proceed with the actual experiment, click on the 'Start' button. If you have a question that you feel was not adequately answered by the instructions, please raise your hand and ask the monitor before proceeding. Your earnings may suffer if you proceed into the market without understanding these instructions.

<pages 1-4; same as above>
<page 5>
We will now explain the buying procedures. Your job is to attempt to buy a unit of the good in each period by accepting an offer for it. An 'offer' is the selling price offered to you.

Let's go through a sample period. Each period is comprised of two phases.

Phase 1:
Each seller submits an offer which will be displayed in the row labeled 'Price' in the 'Seller Offer Prices' tab. In this example, Seller 2 submitted an offer for 800.

<page 6>
After all of the offers have been submitted by the sellers, the period advances to **Phase 2**. At any time during Phase 2, you can accept one of the offers and then the period ends. If you accept an offer, then the record sheet will be filled in as shown. The accepted offer will be displayed in the column labeled 'Price Paid' so that you will have a record of the contract prices you accepted.

The rightmost columns in the record sheet will record the history of all the final submitted offers by seller number.

<page 7>
Phase 2 (continued):
Instead of immediately accepting one of the seller's offers, you and the sellers have an opportunity to send messages to each other about a transaction. Messages that you send to a seller (and vice versa) can only be read by you and the seller. You can send private messages to any seller. Sellers can only send messages to you; they cannot send messages to each other.

In the tab in the upper right portion of the screen, you can type your message in the line and click on the 'Send' button.

You are free to discuss all aspects of the market, with the following exceptions: you may not discuss side payments, make physical threats, or engage in inappropriate language and behavior. You may discuss any aspect of the transaction, and you may make agreements with the sellers. However, note that you are in no way bound to the terms of any such arrangements when you actually accept an offer.

At any time, the seller can submit a new offer to you, which you can then accept if you so desire. Hence, you should review the offers carefully to see if they have changed. Sellers must lower their submitted offer. Suppose that Seller 1 lowered his offer to 700. (Seller 1's previous offer was 750.)

The clock in the lower left portion of your screen indicates how much time is remaining in Phase 2 of the period. If you do not accept an offer within the allotted time, you will not purchase a unit that period and your profit will be zero.

<page 8>
The column labeled 'Market Type' summarizes how the market price was determined that period. In this case, 'Negotiations' determined the market price because you had the opportunity to discuss the transaction with the sellers before accepting one offer.

Let's review the important items:

(1) At any time during Phase 2, you may accept the offer of any one seller.

(2) During Phase 2, you can also discuss a transaction with any seller and a seller can submit a new, lower offer.

(3) Your profit is: Value - Price Paid.

<page 9>
This is the end of the instructions. Your earnings in the experiment will be converted into cash at the rate of **<insert exchange rate>** computer dollars for **1 U.S. dollar**. If you wish to review the instructions, you may go back at this time. If you feel you now understand the instructions and are prepared to proceed with the actual experiment, click on the 'Start' button. If you have a question that you feel was not adequately answered by the instructions, please raise your hand and ask the monitor before proceeding. Your earnings may suffer if you proceed into the market without understanding these instructions.

Seller/Auction/Differentiation

<page 1>
This is an experiment in the economics of market decision making. Various foundations have provided funds for this research. The instructions are simple, and if you follow them carefully and make good decisions, you may earn a considerable amount of money that will be paid to you in CASH at the end of the experiment.

In this experiment we are going to create a market in which you will be a seller of a fictitious good in a sequence of periods.
<page 2>
This is your record sheet for the experiment. You can sell at most one unit each period. Notice that you have a cost of 575 for the first period. During the experiment you will only see your cost for the current and past periods.

If you're able to sell (we'll describe the selling process soon), you will receive the difference between the price you receive (the market price) and your cost.

To sum up: Price Received – Cost = Profit.

<page 3>

Notice that your cash profits depend upon your ability to sell a unit at a price above the cost given on your record sheet. Also note that if you sell a unit at a price equal to its cost, your profit will be zero. You cannot sell a unit below your cost.

Your earnings will be automatically entered into your record sheet at the close of each period. Earnings (profits) are accumulated over several periods, with your total earnings at the end of the experiment being your total profit over all periods. The 'Summary Information' frame at the bottom of the screen displays your total profit.

<page 4>
We will now explain the selling procedures. Your job is to attempt to sell a unit of the good in each period by submitting an offer for it. An 'offer' is your selling price offered to the buyer.

Let's go through a sample period. Given your first period cost of 575 you will submit an offer for this unit. Suppose you wanted to sell the unit for 795. To do so, click on the drop down box below the words 'Submit Offer' in the upper left portion of your screen and select the buyer to whom you are willing to make the offer. Then you type 795 in the box below that and click on the 'Submit' button.

Upon submitting the offer, you will be asked to confirm the offer by clicking 'Yes' or 'No'.

<page 5>
After all of the offers have been submitted by the sellers, how are the winning seller and market price determined? Good question, but first here is some information on the buyer(s).

In this experiment there are <insert number of sellers> sellers total, each attempting to sell one unit to 1 buyer. A buyer can only purchase one unit each period.

There is also a maximum amount that a buyer is willing to pay to purchase a unit from a seller.

<page 6>
Once all of the offers have been submitted by the sellers, a buyer will choose to purchase from the seller that yields the greatest profit, as long as the profit is greater than zero. A buyer's profit is Value – Price Paid. If all of the offers are greater than the buyer's values, then the buyer will not purchase a unit that period.

If you submitted the offer that yields the buyer his greatest profit, you will sell a unit and your record sheet will be filled in as shown for period 1. If you do not sell the unit, the column labeled 'Profit' will have a dash entered into it. The offer that the buyer accepted will be displayed in the column labeled 'Market Price,' so that you will have a record of all contract prices.

In the event that two or more sellers tie for the greatest profit for the buyer, the computer will select a winner at random.

The column labeled 'Market Type' summarizes how the market price was determined that period. In this case, the 'Best Offer' determined the market price.

<page 7>
Let's review the important items:

(1) In order to make a profit, your offer must be greater than your cost.

(2) You can change your offer if you have not already confirmed it.

(3) The seller who submits the offer yielding the buyer the highest payoff will be the only person to sell a unit to the buyer.

(4) Your profit is: Price Received – Cost.

<page 8>
This is the end of the instructions. Your earnings in the experiment will be converted into cash at the rate of **<insert exchange rate>** computer dollars for **1 U.S. dollar**. If you wish to review the instructions, you may go back at this time. If you feel you now understand the instructions and are prepared to proceed with the actual experiment, click on the 'Start' button. If you have a question that you feel was not adequately answered by the instructions, please raise your hand and ask the monitor before proceeding. Your earnings may suffer if you proceed into the market without understanding these instructions.

Seller/Multilateral Negotiation/Differentiation

<pages 1-3; same as above>
<page 4>
We will now explain the selling procedures. Your job is to attempt to sell a unit of the good in each period by submitting an offer for it. An 'offer' is your selling price offered to the buyer.

Let's go through a sample period. Given your first period cost of 575 you will submit an offer for this unit.

Phase 1:
Suppose you wanted to sell the unit for 1000. To do so, click on the drop down box below the words 'Submit Offer' in the upper left portion of your screen and select the buyer to whom you are willing to make the offer. For these instructions, choose Buyer 1. Then you type 1000 in the box for your offer and click on the 'Submit' button.

Upon submitting the offer, you will be asked to confirm the offer by clicking 'Yes' or 'No'.

<page 5>
After all of the offers have been submitted by the sellers, the period advances to **Phase 2**. At any time the buyer can accept one of the offers and then the period ends. If the buyer accepts your

offer, then the record sheet will be filled in as shown. If you do not sell the unit, the column labeled 'Profit' will have a dash entered into it. The accepted offer will be displayed in the column labeled 'Market Price' so that you will have a record of the contract prices accepted by a buyer.

<page 6>
Phase 2 (continued):
Instead of immediately accepting one of the seller's offers, the buyer and the sellers have an opportunity to send messages to each other about a transaction. Messages that you send to the buyer (and vice versa) can only be read by you and the buyer. However, the buyer can also send private messages to the other sellers. In the tab in the upper right portion of the screen, you can type your message in the line and click on the 'Send' button.

The column labeled 'Market Type' summarizes how the market price was determined that period. In this case, 'Negotiations' determined the market price because the buyer had the opportunity to discuss the transaction with the sellers before accepting one offer.

You are free to discuss all aspects of the market, with the following exceptions: you may not discuss side payments, make physical threats, or engage in inappropriate language and behavior. You may discuss any aspect of the transaction, and you may make agreements with the buyer. However, note that you and the buyer are in no way bound to the terms of any such arrangements when you actually send an offer.

If at any time you would like to submit a new offer to the buyer, you can do so, but the buyer need not accept it. Furthermore, your new offer must be less than your previous offer. You cannot increase your submitted offer.

<page 7>
In this experiment there are <insert number of sellers> sellers total, each attempting to sell one unit to 1 buyer. A buyer can only purchase one unit each period.

There is also a maximum amount that a buyer is willing to pay to purchase a unit from a seller.

<page 8>
Once a buyer accepts an offer from a seller, you can no longer exchange messages with the buyer.

Let's review the important items:

(1) In order to make a profit, your offer must be greater than your cost.

(2) You can change your offer if you have not already confirmed it.

(3) At any time, you can withdraw an offer to 1 buyer and submit one to another buyer.

(4) The buyer can accept at most one offer from a single seller.

(5) Your profit is: Price Received – Cost.

<page 9>
This is the end of the instructions. Your earnings in the experiment will be converted into cash at the rate of **<insert exchange rate>** computer dollars for **1 U.S. dollar**. If you wish to review the instructions, you may go back at this time. If you feel you now understand the instructions and are prepared to proceed with the actual experiment, click on the 'Start' button. If you have a question that you feel was not adequately answered by the instructions, please raise your hand and ask the monitor before proceeding. Your earnings may suffer if you proceed into the market without understanding these instructions.

Handout Read Out Loud to All Participants
(After Subjects Finished Reading the Above Instructions)

Other Information

- There are a total of **<insert number of sellers>** sellers in your market who can sell to a single buyer.
  Throughout the entire experiment, the same **<insert number of sellers>** sellers will be matched with the same buyer.

- Seller costs are assigned randomly. Each seller has an equally like chance of receiving any cost between $0 and $600, inclusive. That is, each seller is equally likely to receive $0, $1, … , $599, $600. All sellers will receive their own random draw each period for their own cost.

- Furthermore, the chance of a seller being assigned any particular cost in this range, for example, 345, is not changed if that cost was assigned earlier to one seller or to another. It is therefore possible for one seller to get the same cost for different periods or for two sellers to have the same cost in the same period.

- The seller's profit is the difference between his/her cost and the price received, or Price received - cost = Seller's Profit.

- <if *Differentiation* Treatment> The buyer value has a different randomly assigned value for each seller each period. The value for a particular seller has an equally like chance of being between $300 and $900, inclusive. That is, each value is equally likely to be $300, $301, … , $899, $900.

- The buyer's profit is the difference between his/her value and the price paid, or Value - Price paid = Buyer's Profit.