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# E-sourcing in Procurement: Theory and Behavior in Reverse Auctions with Noncompetitive Contracts

Richard Engelbrecht-Wiggans
College of Business, University of Illinois, 85 Wohlers Hall, 1206 South Sixth Street, Champaign, Illinois 61820, eplus17@uiuc.edu

Elena Katok
Smeal College of Business, Penn State University, 465 Business Building, University Park, Pennsylvania 16802, ekatok@psu.edu

One of the goals of procurement is to establish a competitive price while affording the buyer some flexibility in selecting the suppliers to deal with. Reverse auctions do not have this flexibility, because it is the auction rules and not the buyer that determines the winner. In practice, however, hybrid mechanisms that remove some suppliers and a corresponding amount of demand from the auction market are quite common. We find that in theory such hybrid mechanisms increase competition and make buyers better off as long as suppliers are willing to accept noncompetitive contracts. It turns out that suppliers often do because under a wide variety of conditions, these contracts have a positive expected profit. Our theory relies on two behavioral assumptions: (1) bidders in a multiunit uniform-price reverse auction will follow the dominant strategy of bidding truthfully, and (2) the suppliers who have been removed from the market will accept noncompetitive contracts that have a positive expected profit. Our experiment demonstrates that bidders in the auction behave very close to following the dominant strategy regardless of whether this auction is a stand-alone or a part of a hybrid mechanism. We also find that suppliers accept noncompetitive contracts sufficiently often (although not always) to make the hybrid mechanism outperform the reverse auction in the laboratory as well as in theory.

*Key words*: multiunit auctions; experimental economics; strategic procurement
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## 1. Introduction

With the growth of the Internet, *e-sourcing* has become an important tool for procurement. E-sourcing is a catchall term that refers to the use of Internet-enabled applications and decision support tools that facilitate competitive and collaborative interactions among buyers and suppliers through the use of online negotiations, reverse (decreasing bid) auctions, and other related tools. According to a September 2002 report by the Aberdeen Group (2002), software vendor's e-sourcing revenues increased from $820 million in 2001 to $1.14 billion in 2002 and are projected to increase to $3.13 billion by 2005.

The use of auctions in e-sourcing might save buyers considerable amounts of money by lowering prices. Such online auctions received much attention in the press when General Electric (GE) claimed savings of more than $600 million and net savings of more than 8% in 2001 by using SourceBid, a reverse auction tool and a part of GE's Global Exchange Network (GEN).[1] The U.S. General Services Administration attributed savings of 12%–48% to the use of auctions (Sawhney 2003), and FreeMarkets, one of the leading online auction software providers, reported that its customers saved approximately 20% on more than $30 billion in purchases between 1995 and 2001.

However, auctions might not be delivering quite as much savings as hoped. The Aberdeen Group (2002) reports that 60% of end-users were unable to fully realize the savings they had negotiated using e-sourcing technologies, primarily because of the lack of effective communication of negotiated terms. Emiliani and Stec (2001) argue that not only do auctions rarely deliver savings as great as advertised, but they also inflict damage on the long-term buyer-supplier relationships by inhibiting collaboration.[2]

[1] According to a case study written by GE's Global Exchange Services (2003), GE's GEN is used by about 35,000 suppliers and handles more than 10,000 e-invoicing enquiries daily. Approximately 37,000 reverse auctions, worth about $28.6 billion, have been conducted between 2000 and the 2nd quarter of 2002, generating $680 million in savings in 2000–2001 and an additional $900 million in savings projected for 2002.

[2] Another common criticism of auctions is that they "squeeze suppliers on price," thus putting small suppliers at a disadvantage. But

The importance of long-term relationships in procurement has been well established (see, for example, Monczka et al. 2005), and auctions as such are not conducive to promoting long-term relationships. However, we should not be too quick to dismiss auctions—they have many benefits. Because auctions are visible, structured, and have clear rules, they make the procurement process transparent and, at least in theory, yield a competitive market price. Without this, the procurement process can become disastrously flawed. For example, one recent notorious illustration of what can happen without competitive bidding is the $7 billion no-bid contract awarded by the U.S. Army to Kellogg, Brown, and Root (KBR), a Halliburton subsidiary, in March 2003.[3]

So, let us look at auctions a bit more closely. Auctions introduce market competition into the procurement process, and this competition does put a downward pressure on price. However, auctions also determine the winner. In the case of e-sourcing, this second function of auctions seems to be the source of the problem. Specifically, if a buyer conducts a sequence of auctions over time, each auction might result in different suppliers winning, and the buyer loses control over whom to deal with. But buyers might want to preserve the final say about whom to deal with for many reasons. We will not explicitly model these reasons, but they could include nonmonetary attributes of the product or the supplier itself.[4]

Our work is motivated by the desire to investigate mechanisms that preserve benefits of auctions but also preserve the buyer's option of dealing with specific suppliers. We investigate a mechanism that combines auctions with noncompetitive contracts; an auction among some of the suppliers sets the price and the buyer contracts "noncompetitively" with other suppliers to provide goods at whatever price the auction sets. This hybrid mechanism retains the price-setting benefits of auctions; the auction component of the mechanism provides a transparent process for injecting market competition into the procurement process. However, the buyer retains some control over deciding which suppliers to deal with (in other words, this decision is not part of the mechanism). The buyer could use this control to extract additional benefits from the relationship, and some of these benefits could, in principle, be shared with suppliers.

The understanding of mechanisms that combine auctions and negotiations—the type of mechanisms most often used in practice—is quite limited. Jap (2002) provides a review of issues in online reverse auctions used for procurement, including how these auctions differ from standard physical auctions (they typically have lower transaction costs and allow for bidder anonymity) and how they differ from auctions in the theoretical auction literature. There are two fundamental differences between online reverse auctions prevalent in practice and the models of auctions in the theory literature. The first difference is that in practice the value of products in procurement settings cannot be reduced to the single dimension of price. This leads to the second difference—the vast majority of auctions actually used in practice do not determine winners. In other words, the buyer (the auctioneer) does not commit to awarding the contract to the lowest bidder but instead reserves the right to select the winner from a set of bidders. This type of mechanism has not been analyzed either theoretically or in the laboratory, but Jap (2002) reports on some empirical findings from interviewing buyers and sellers.

Reverse auctions are usually a part of e-sourcing toolkits, but they are not used exclusively, and although prevalent, they do not constitute the majority of e-sourcing transactions. In addition to auctions, e-sourcing applications typically provide platforms for online negotiations, such as request for quotes and request for proposals. The question of which is better (auctions or negotiations) is a complicated one. Bulow and Klemperer (1996), for example, show that under some fairly rigorous assumptions, if the seller is able to attract just one more serious bidder to the auction, then he can make higher expected revenue from an auction than from a negotiation even when the negotiation is conducted while maintaining the right to subsequently hold an auction. Kirkegaard and Overgaard (2005) shows that when some of the assumptions are relaxed, the preauction negotiations might be beneficial to the auctioneer after all. The Bulow and Klemperer (1996) model is stylized, and the example they use is selling a company. Although a company is a complex object, the contract for selling it can be easily reduced to a single dimension—price per share—a setting most conducive to auctions.

Bajari et al. (2003) compare auctions and negotiations in a context of contracts that cannot be easily reduced to a single dimension. They examine

it should also be noted that auctions give small suppliers access to a large market that they might not have had access to otherwise.

[3] This contract, known as "Restore Iraqi Oil," was a two-year cost-plus contract worth up to $7 billion to KBR for rebuilding Iraq's oil infrastructure and extinguishing oil well fires. The no-bid contract caused such outrage in Congress and directed a spotlight on Halliburton and Vice President Dick Cheney, who served as the Halliburton CEO from 1995 through 2001, that the contract was subsequently cancelled and opened up for bid. Ultimately, the bulk of the contract was still awarded to KBR and the balance to a joint venture of the California-based Parsons Corporation and the Australian firm Worley Group Limited (Halliburton Watch 2004).

[4] The theory and experiment we present in this paper are for the simplest case in which the product is a commodity and the suppliers are stochastically identical, and we will show that hybrid mechanisms are beneficial to the buyer even in this setting. If the buyer receives additional surplus from dealing with specific suppliers, the potential benefits from hybrid mechanisms will only increase.

private-sector building contracts awarded in northern California between 1995 and 2000 and find that auctions perform poorly when contracts are complex, specifications are incomplete, or the number of bidders is small. They also find that auctions tend to suppress communication between buyers and sellers.

Salmon and Wilson (2005) investigate a setting with two units in which the seller starts out by auctioning off one unit using an ascending-price auction, and then negotiating with the price-setting bidder for the remaining unit. The negotiation process is modeled as the Ultimatum game.[5] Salmon and Wilson (2005) find that because the losing bidder does not wish to reveal his true value, truthful bidding is not an equilibrium for the auction, and actually the only equilibria that exist are in mixed strategies. Salmon and Wilson (2005) find that the hybrid auction/negotiation mechanism is able to raise more money than the benchmark mechanism that consists of two sequential ascending-bid auctions.

Mechanisms that most closely resemble those used by e-sourcing applications are ones that combine auctions with some form of negotiations. Jap (2002) reports that suppliers generally do not like reverse auctions because they feel the "…visibility of their prices to competitors erodes their bargaining power" (p. 521). They feel that the computer interface prevents them from informing buyers about nonprice attributes of their products, and thus causes their products to become "commoditized." And they also fear losing control and bidding too low in the heat of the moment. In fact, according to Jap (2002), suppliers take the use of online reverse auctions by the buyers as a signal about the nature of their relationship, and they respond to this signal:

> If suppliers believe that the use of on-line reverse auctions signals a movement towards market-oriented, arms-length relations, then suppliers will act accordingly. As suppliers believe that buyers are increasingly short-term oriented and concerned about their own gains, then they too may respond in kind. However, if the buyer signals that the on-line auctions are a rare occurrence, used as a stepping stone to a long-term, mutually beneficial financial arrangement, then suppliers will be more motivated to become mutually oriented and may respond more competitively in light of the long-term gains. (p. 521)

In other words, an occasional use of an auction by the buyer is (correctly) interpreted by suppliers as a way to "keep them honest" rather than as a signal that the buyer wishes to switch entirely to using auctions. Therefore, suppliers are more likely to bid aggressively in such auctions, as a signal of good faith (see Goeree 2003 for a model of auctions with an aftermarket) because their own low bid signals a commitment to competitive prices. But if buyers use auctions all the time, then suppliers lose the incentive to signal their commitment and simply compete on price (or choose to not participate in the auctions and take their business elsewhere).

The work most closely related to ours is Engelbrecht-Wiggans (1996) who considers multiunit auctions with noncompetitive contracts in which suppliers have the option to commit to supply the units at a price to be determined by the auction. Doing so saves the supplier some auction participation fee (but typically results in a less desirable price). Under a variety of conditions, even when bidders are homogeneous, at equilibrium some will voluntarily choose the noncompetitive contract, while others will choose to bid in the auction and the auctioneer benefits from having allowed noncompetitive sales.

Our study is a step toward gaining analytical and empirical insight into hybrid mechanisms that combine auctions with noncompetitive contracts. We develop a model of a simple hybrid environment that combines an English auction with noncompetitive contracts. We find that, in theory, this mechanism yields lowers costs to the buyer than a pure auction mechanism while still generating positive profits for suppliers. We then proceed to compare the two mechanisms in the laboratory and find our theoretical benchmarks to be quite accurate. In §2, we present our model and theoretical benchmarks. We describe the experimental design and related hypothesis in §3; present results in §4; and offer conclusions, managerial insights, and directions for future research in §5.

## 2. Theory

A "buyer" wants to procure $Q$ units of some commodity. There are $N$ ($N \geq 3$) possible suppliers. Each supplier $i$ ($i = 1, 2, \ldots, N$) can provide a single unit, has a privately known cost $C_i$ of doing so, and has some say in whether or not he supplies a unit.[6] If too few suppliers agree to provide units, then the buyer incurs some fixed cost $C_o$ ($C_o \geq C_i \ \forall i$ with probability one) for each of the remaining units; this cost can be interpreted in several ways—the cost to the buyer of unsatisfied demand, the cost of going to some unlimited backup supply source, or the cost to the buyer of manufacturing the units in house.

[5] In the Ultimatum game, the proposer makes a take-it-or-leave-it offer to the responder. If the responder rejects the offer, then both players earn zero (or their outside option).

[6] The supplier may have some other use for the commodity if it is not sold to this buyer. If this opportunity cost is not zero, then we assume that it is the same for all suppliers and interpret $C_i$ as the cost net of this opportunity cost. As a result, in effect, the suppliers get zero if they don't sell to the buyer.

One mechanism for determining which suppliers will provide units is a descending-bid (reverse) uniform-price auction. Consider the following stylized version of this auction: The buyer starts by offering a price of $C_o$ per unit and then reduces the price continuously; let $P_t$ denote the price at time $t$. At any time, any supplier can drop out of the auction and once out, cannot bid again. The price continues to decrease until there are exactly $Q$ suppliers left willing to provide a unit.[7]

Each supplier $i$ has the dominant strategy of dropping out of the auction when $P_t = C_i$. At this point, the auction price equals the supplier's cost, and the final auction price equals the cost to the losing supplier who was the last to drop out. We presume that suppliers use this dominant bidding strategy.

The idea behind using an auction is that it establishes a "competitive" price. For there to be competition, there must be at least one supplier who "loses" in the sense of not supplying a unit to the buyer. Therefore, let us assume that $1 \leq Q \leq N - 1$.[8] Furthermore, intuitively, the more suppliers who must lose—the greater the excess supply—the greater the competition will be, and the lower the expected cost will be to the buyer. So, let us examine how the buyer might increase competition.

Possibly, the buyer could find additional potential suppliers, thereby increasing $N$ and the excess supply; we presume that the buyer has already done so and that $N$ cannot be increased any further. Or the buyer could reduce the number of units to be procured through the auction. This also increases the excess supply in the auction but leaves the buyer with fewer than $Q$ units. Our model already allows the buyer to make up for any shortfall at a cost of $C_o$ per unit—but can the buyer do better than this?

Consider the following extension to the auction. Suppose that prior to the auction, the buyer approaches some of the suppliers and offers them an opportunity to commit to providing the units at a price to be established later, by the auction.[9] More specifically, let $M$ denote the number of suppliers to whom the buyer makes this offer. Those who turn down this offer are not allowed to participate in the auction; the auction will have the other $N - M$ suppliers competing for $Q - M$ units. We assume that the suppliers to whom these offers are made have the same opportunity cost for not selling to the buyer as do those who bid (and lose) in the auction. Therefore, just like the bidders in the auction, the suppliers get zero if they don't sell to the buyer. If any of the $M$ selected suppliers turns down the offer, then the buyer will have to make up the resulting shortfall at a cost of $C_o$ per unit. Since, in any case, the buyer acquires $M$ units outside of the auction itself, we refer to $M$ as the number of noncompetitive units.

Intuitively, increasing $M$ increases the fraction of suppliers in the auction who will lose; it increases the amount of excess supply relative to the total supply in the auction. This may increase competition and decrease the auction price. If so, and if the noncompetitive suppliers accept the noncompetitive offers, then the buyer benefits from having made such offers. Furthermore, if there is little enough excess supply, then the expected auction price may well be high enough that noncompetitive suppliers would be willing to accept it rather than be left entirely out of the process. We will show that increasing $M$ does decrease the expected auction price, and that if the excess supply is small enough, then there will be a positive number $M$ of noncompetitive suppliers such that the noncompetitive suppliers obtain a greater expected profit from accepting the offer than from declining it. In short, in theory, there is a range of cases in which the seller can decrease cost by making some noncompetitive offers.

If buying some number of units noncompetitively is a good idea, then why not buy all of them that way? A buyer who knows the distribution of supplier costs could set an appropriate price and benefit from buying all units noncompetitively.[10] However, to set the appropriate price, the buyer must know the distribution of suppliers' costs. If the buyer does not have this information, as she does not in our setting, then she needs an auction to get some sense of the suppliers' costs.[11] Auctions are generally useful for price discovery, and this is how we use them in our setting.

[7] If the price decreases in discrete steps and/or suppliers have positive probability of having exactly the same cost, then there will be a positive probability that more than one supplier drops out at the same time. Our theory approximates reality by assuming a continuous price decrease and continuous value distributions. This ensures that there is zero probability of two or more suppliers dropping out simultaneously. In practice, if multiple suppliers drop out simultaneously, and this causes the supply to become strictly less than demand, the units could be allocated to all the suppliers who stayed in and randomly among the suppliers who dropped out last.

[8] These and subsequent technical restrictions will hold in our experimental settings.

[9] In contrast to Engelbrecht-Wiggans (1996), our auction has no participation cost, and suppliers would prefer to participate in the auction rather than take the noncompetitive route; our model assumes that the buyer decides who to make the noncompetitive offers to, and that these suppliers do not have the option of bidding in the auction.

[10] For example, if the buyer knew that the suppliers' costs were distributed uniformly on $[0, 1]$, then the buyer could make a take-it-or-leave-it offer to buy the desired number of units at a price of one-half. But imagine that the costs are uniform on $[0, \theta]$, where the buyer knows the distribution of $\theta$ (but the suppliers know $\theta$ itself). In this case, there may well be no fixed price offer that does as well for the buyer as an auction would.

[11] Similarly, we assume that the auctions are without reserve; to set a sensible reservation price, the buyer needs to know more

Initially, we assume that the noncompetitive offer is made before the suppliers know precisely what their costs will be for this particular product. At this point, the suppliers are stochastically identical. Therefore it doesn't much matter how the $M$ noncompetitive suppliers get selected, and for our purposes, we can (and will) think of them as being selected randomly. However, in practice, noncompetitive suppliers might be selected based on some nonmonetary attributes, such as a good record for quality or delivery reliability. Committing to a supplier prior to the auction may also be used as a signal by the buyer that she is committed to a long-term relationship.

Proposition 1. *In our auction with $N-M$ suppliers competing for $Q-M$ units, $N-Q$ suppliers will lose, and the per unit auction price will be the $N-Q$th largest of the $N-M$ competing suppliers' costs.*

Proof. This follows immediately from truthful bidding being the dominant strategy. □

Now, assume that the supplier's are independent draws from some continuous cumulative distribution; let $F(x)$ denote the distribution and $\mu_C$ its mean. (Also, without loss of generality for bounded costs, scale the costs, so that $F(0)=0$, $0<F(x)<1\ \forall x \in (0,1)$ and $F(1)=1$.) Except for the fact that our bidders are providing rather than acquiring goods, this is the Vickrey (1961) model with independently drawn, privately known values. As a result, there is zero probability that two or more suppliers have exactly the same cost, and therefore truthful bidding results in there being zero probability that more than $Q$ suppliers are willing to provide a unit at the final price.

To derive our main results, we start by noting that what really matters is how the expected values of certain order statistics compare. Specifically, let $C(i,k)$ (with $1 \le i \le k$) denote the $i$th largest out of $k$-independent samples[12] and $E(i,k)$ the expected value $E[C(i,k)]$. As we observed before, the expected price established by the auction is the $N-Q$th largest of $N-M$ suppliers' costs. Therefore the expected auction price can be written as $E(N-Q, N-M)$. And if the buyer offers few enough—"few enough" could be zero—noncompetitive units, so that all noncompetitive offers will be accepted, then the buyer's expected price per unit can also be written as $E(N-Q, N-M)$. So, the buyer cares about how $E(N-Q, N-M)$ varies with $M$.

Furthermore, a noncompetitive supplier has a greater expected profit from accepting rather than declining the offer whenever $E(N-Q, N-M)$ exceeds the expected cost $\mu_C$. Note that $E(1,1)=\mu_C$. So, an expected profit-maximizing noncompetitive supplier cares about how $E(1,1)$ compares to $E(N-Q, N-M)$.

Our results follow from the following three basic properties of order statistics (see, for example, Arnold et al. 1992): (Property 1) $E(i,k)$ increases as $k$ increases; (Property 2) $E(i,k)$ decreases as $i$ increases; (Property 3) if $F(\cdot)$ is such that $E(\mathit{median}) \ge \mathit{mean}$, then $E(\lfloor k/2 \rfloor, k) > E(1,1)$. For example, if the distribution $F$ is symmetric, then $E(\lfloor k/2 \rfloor, k) > E(1,1)$.[13]

Proposition 2 (Corollary to Property 1). *The bigger $M$, the lower the expected price established by the auction, and therefore the lower the buyer's expected cost per unit so long as all $M$ noncompetitive suppliers accept the noncompetitive offer.*

Proof. Property 1 implies that $E(N-Q, N-(M-1)) > E(N-Q, N-M)$. □

So the buyer benefits from procuring units noncompetitively *if* suppliers are willing to accept noncompetitive offers, but when might the suppliers be willing to provide units noncompetitively?

Proposition 3 (Corollary to Property 1). *If $N \ge 3$, $Q$ is close enough to $N$, and $M=1$, then the noncompetitive contract has positive expected value, and an expected profit-maximizing supplier may be presumed to accept the contract.*

Proof. Consider $Q=N-1$. Then, up to $N-2$ contracts can be offered noncompetitively and $N-2 \ge 1$. For $Q=N-1$, we have that $N-Q=1$, and therefore $E(N-Q, N-M) = E(1, N-M)$. By Property 1, $E(1, N-M) > E(1,1)$, and therefore $E(N-Q, N-M) - E(1,1) > 0$. □

This proposition ensures that a single noncompetitive contract has positive expected value regardless of the suppliers' cost distribution if there is little enough excess supply. The next proposition shows that there are many distributions for which noncompetitive contracts will have positive expected value to the supplier even if the buyer wants substantially less than almost all of the available supply, and/or if the buyer wants to offer more than one noncompetitive contract.

Proposition 4 (Corollary to Properties 2 and 3). (a) *If $\mu_C$ is at most the expected median cost and* $0<$

about the distribution of the suppliers' costs than we are willing to assume.

[12] Actually, these results on order statistics—and their corollaries—hold more generally. For example, let $\theta$ denote some (unknown) underlying state of Nature and assume that the $C_i$s are independent draws from some conditional distribution $F(c \mid \theta)$. Then our results hold for each possible $\theta$, and because we are interested in averages, they also hold unconditionally for such conditionally independent costs $C_i$.

[13] The $\lfloor x \rfloor$ notation denotes the "floor" function—the closest integer to $x$ from below.

*$M \leq 2Q - N$, then the noncompetitive contracts have positive expected value, and expected profit-maximizing suppliers may be presumed to accept the contracts.* (b) *If $\mu_C$ is equal to the expected median cost and $M = 2Q - N + 1$, then the noncompetitive contracts have zero expected value.* (c) *If $\mu_C$ is at least equal to the expected median cost and $2Q - N + 2 \leq M < N$, then the noncompetitive contracts have negative expected value, and expected profit-maximizing suppliers may be presumed to decline the contracts.*

Proof. (a) First, the hypothesized condition $M \leq 2Q - N$ implies that $2Q - 2N \geq M - N$, and therefore that $N - Q \leq \lfloor (N-M)/2 \rfloor$. Second, the condition $N - Q \leq \lfloor (N-M)/2 \rfloor$ together with Property 2 implies that $E(N-Q, N-M) \geq E(\lfloor (N-M)/2 \rfloor, N-M)$. Property 3 implies $E(\lfloor (N-M)/2 \rfloor, N-M) > E(1,1)$. Therefore $E(N-Q, N-M) - E(1,1) > 0$. (b) This follows directly from the fact that the price-setting bid in this auction is the median bid. (c) This proof is simply the mirror image of that for Part A. □

Note that the condition $0 < M \leq 2Q - N$ implies that $Q > N/2$. So, if the mean cost is less than or equal to the expected median cost and the buyer wants just more than half the available supply, then a single noncompetitive contract will have positive expected value to the supplier, and the more that the buyer's demand exceeds half of the available supply, the greater the number of noncompetitive contracts that can be offered without them becoming unprofitable to the suppliers. In particular, if there is only one unit of excess supply (i.e., $Q = N - 1$), then the noncompetitive contracts will have positive expected value to the suppliers as long as $M < Q$, i.e., as long as the buyer auctions at least one unit.

For symmetric distributions, the expected value of the median equals the mean, and therefore the necessary condition for in each of the three parts to Proposition 4 holds. This gives the following result:

Proposition 5 (Corollary to Proposition 4). *For any symmetric distribution $F$, the expected value of the contract will be positive if, and only if, and $M < 2Q - N + 1$, zero if, and only if, $M = 2Q - N + 1$, and negative if, and only if, $M > 2Q - N + 1$. In short, the expected value of the contract has the same sign as $M - (2Q - N + 1)$.*

Unlike Proposition 3, Proposition 4 does require that the distribution $F$ satisfies certain restrictions. In particular, part A of Proposition 4 requires that the mean cost is less than the expected median cost. However, many distributions satisfy this condition (such as all symmetric distributions; in general, more than half of all theoretically possible cost distributions satisfy the condition). Furthermore, the condition may well be satisfied by real suppliers' actual cost distributions. In particular, imagine that there is some standard source or technology that puts an upper limit on suppliers' costs. Then, suppliers usually cannot do much better than this limit, but occasionally a supplier may discover a superior technology that would lower this supplier's costs. In this case, most of the probability is concentrated near the upper end of the distribution, with the rest scattered at lower values, and the necessary condition will hold. In this case, because the buyer wants to have as many noncompetitive sales as possible, we know exactly the number of noncompetitive contracts that should be offered.

Proposition 6 (Corollary to Propositions 2 and 4). *If $\mu_C$ is at most equal to the expected median cost, then the hybrid mechanism that minimizes the buyer's cost has $M = 2Q - N$ noncompetitive sales.*

As with "optimal" reservation prices (e.g., Myerson 1981), noncompetitive purchases destroy efficiency. If $P_M$ denote the probability that the mechanism with $M$ noncompetitively priced units yields an efficient allocation, then define the "relative efficiency" of mechanisms with $M_1$ and $M_2$ noncompetitive sales by $P_{M_1}/P_{M_2}$. Our auction always allocates units efficiently; $P_0 = 1$. For $M > 1$, the question is: How likely is it that the $M$ noncompetitive suppliers are all from the set of suppliers with the $Q$ lowest costs (assuming that these $M$ suppliers are chosen at random)? This is a straightforward combinatorial question.[14] In particular, the number of ways to choose $M$ out of $Q$ is $Q!/(M!(Q-M)!)$ and the number of ways to chose $M$ out of $N$ is $N!/(M!(N-M)!)$. Therefore $P_M = Q!(N-M)!/(N!(Q-M)!)$.

So far, we assumed that the noncompetitive supplier must decide whether or not to accept the offer before he knows his own cost and before he knows the price set by the auction. We now consider three alternatives to this "no information" assumption:[15] (1) The noncompetitive supplier knows his cost at the time he needs to make his decision (call this the "cost only" case), (2) he knows the outcome of the auction but not his cost (call this the "price only" case), or (3) he knows both his cost and the auction price before making his decision (call this the "full information" case). We examine the effect of these alternative information assumptions for the setting in which the buyer is under the biggest disadvantage: the buyer wants $Q = N - 1$ units and procures $M = 1$ of them noncompetitively.

We start by writing down the expected cost in the auction. For a reverse auction for $N - 1$ units from $N$ suppliers, the dominant strategy is for everyone to bid truthfully, and under this strategy, the

[14] Under our assumptions, there is zero probability of two (or more) suppliers having exactly the same cost, and therefore there is only one set of suppliers that is efficient.

[15] We thank an anonymous referee for suggesting to use this theoretical extension.

auction price will be the highest of the suppliers' costs. So, the expected price per unit will be $C_{AU} = \int xNF^{N-1}(x)\,dF(x)$, and the total expected cost to the buyer of the $N-1$ units will be $(N-1)C_{AU}$.

Now imagine that the buyer offers to buy one unit noncompetitively from one supplier. If this "noncompetitive supplier" accepts the offer, then the buyer pays this supplier whatever price the remaining $N-1$ suppliers set in the auction for the remaining $N-2$ units; refer to this as the "NC-auction." If the noncompetitive supplier turns down the offer, the buyer incurs a cost of $C_o$. Recall that we assumed that the buyer's outside cost is at least as high as the highest possible supplier's cost, i.e., $C_o \geq 1$.

The expected price in the NC-auction will be $C_{\text{NC-auction}} = \int x(N-1)F^{N-2}(x)\,dF(x)$, and the total expected cost to the buyer for the $N-2$ units purchased at the NC-auction will be $(N-2)C_{\text{NC-auction}}$. In addition, the buyer must pay for the one unit that she obtains noncompetitively. The price of this unit depends on whether the noncompetitive supplier accepts the offer, and the price will be either the price set by the NC-auction or $C_o$. We assume that the noncompetitive supplier accepts the offer if and only if doing so gives him at least as great an expected profit as does declining it.[16]

The supplier's expected profit from accepting the noncompetitive contract depends on what the supplier knows at the time of the decision. The supplier can know both, his own cost and the auction price ("full information"), his "cost only," the auction "price only," or neither ("no information"). We now derive the expected cost to the buyer of the noncompetitive unit in each of these four cases.

For the no-information case, we already showed (Proposition 3) that the noncompetitive supplier should always accept the offer. So the expected cost to the buyer of this one unit is $C_{\text{no info}} = C_{\text{NC-auction}}$, and the total expected cost of all $N-1$ units is $(N-1)C_{\text{NC-auction}}$. For the price-only case, the supplier accepts the offer if, and only if, $C_{\text{NC-auction}} \geq \mu_C = \int x\,dF(x)$. So, the expected cost to the buyer of this one unit is $C_{\text{price only}} = \int_{x<E[\text{cost}]} C_o(N-1)F^{N-2}(x)\,dF(x) + \int_{x\geq E[\text{cost}]} x(N-1)F^{N-2}(x)\,dF(x)$, and the total expected cost of all $N-1$ units is $C_{\text{price only}} + (N-2)C_{\text{NC-auction}}$. For the cost-only case, the supplier $i$ accepts the offer if, and only if, $C_{\text{NC-auction}} \geq C_i$. So the expected cost to the buyer of this one unit is $C_{\text{cost only}} = C_{\text{NC-auction}}F(C_{\text{NC-auction}}) + C_o(1-F(C_{\text{NC-auction}}))$, and the total expected cost of all $N-1$ units is $C_{\text{cost only}} + (N-2)C_{\text{NC-auction}}$. Finally, for the case of full information, the supplier accepts the offer if and only if the supplier's cost is less than or equal to the NC-auction price. So the expected cost to the buyer of this one unit is $C_{\text{full info}} = \int [xF(x) + C_o(1-F(x))](N-1)F^{N-2}(x)\,dF(x)$, and the total expected cost of all $N-1$ units is $C_{\text{full info}} + (N-2)C_{\text{NC-auction}}$.

When the costs come from a standard uniform distribution, then the previous expressions simplify as follows:

$$C_{\text{auction}} = \frac{N}{N+1}, \quad C_{\text{no info}} = C_{\text{NC-auction}} = \frac{N-1}{N},$$

$$C_{\text{price only}} = C_o\left(\frac{1}{2}\right)^{N-1} + \left(\frac{N-1}{N}\right)\left(1-\left(\frac{1}{2}\right)^{N}\right),$$

$$C_{\text{cost only}} = \left[\frac{N-1}{N}\right]^2 + \frac{C_o}{N}, \quad \text{and}$$

$$C_{\text{full info}} = \left[\frac{N-1}{N+1}\right] + \frac{C_o}{N}.$$

Figure 1 shows the expected buyer savings (relative to using an auction) from using the hybrid mechanism with each of the four information conditions, as a function of the number of suppliers, and for two different possible outside costs $C_o$.

Note that the graphs show that the no-information case does better than the auction for all $N$. Indeed, it follows from Propositions 2 and 3 that this must be the case, not only when costs come from a standard uniform distribution, but also more generally. Second, the graphs show that the no-information case does better than the other three information cases for all $N$. The following proposition ensures that this happens for other cost distributions as well:

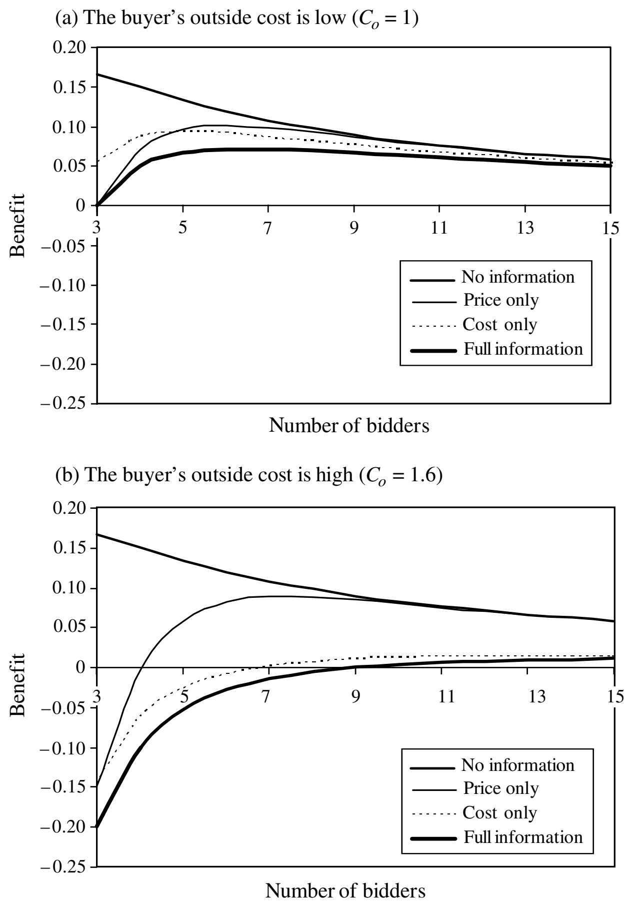
Proposition 7. *The expected cost of the hybrid mechanism in the no-information case is always less or equal to that of the hybrid mechanism in any other case.*

Proof. We need simply compare the expected cost of the one noncompetitive unit in each of the different cases across cases. Recall that $C_{\text{no info}} = \int x(N-1)\cdot F^{N-2}(x)\,dF(x)$. Since, by assumption, $x \leq C_o$, we have that

$$\begin{aligned} C_{\text{price only}} &= \int_{x<E[\text{cost}]} C_o(N-1)F^{N-2}(x)\,dF(x) \\ &\quad + \int_{x\geq E[\text{cost}]} x(N-1)F^{N-2}(x)\,dF(x) \\ &\geq \int_{x<E[\text{cost}]} x(N-1)F^{N-2}(x)\,dF(x) \\ &\quad + \int_{x\geq E[\text{cost}]} x(N-1)F^{N-2}(x)\,dF(x) = C_{\text{no info}}. \end{aligned}$$

[16] So long as there is zero probability that the expected cost equals the expected price, there is zero probability that both options give the same expected profit and it does not matter what the supplier does when the two expected profits are the same. If there is positive probability of such ties, different decisions by the supplier can have dramatic effects on the buyer's expected cost.

**Figure 1** **Potential Savings Under Four Information Conditions as a Function of the Number of Suppliers**




*Note.* For the cases in which the buyer's outside cost is relatively high and relatively low.

Similarly, $x \leq C_o$ implies that $C_{\text{NC}-auction} \leq C_o$, and therefore we have that

$$\begin{aligned} C_{\text{cost only}} &= C_{\text{NC-auction}} F(C_{\text{NC-auction}}) + C_o(1 - F(C_{\text{NC-auction}})) \\ &\geq C_{\text{NC-auction}} F(C_{\text{NC-auction}}) \\ &\quad + C_{\text{NC-auction}}(1 - F(C_{\text{NC-auction}})) \\ &= C_{\text{NC-auction}} = C_{\text{no info}}. \end{aligned}$$

Finally, $x \leq C_o$ implies that

$$\begin{aligned} C_{\text{full info}} &= \int [xF(x) + C_o(1 - F(x))](N-1)F^{N-2}(x)\,dF(x) \\ &\geq \int [xF(x) + x(1 - F(x))](N-1) \\ &\qquad \cdot F^{N-2}(x)\,dF(x) = C_{\text{no info}}. \quad \square \end{aligned}$$

Third, the graphs also suggest something surprising: if the number of suppliers is large enough, then the hybrid mechanism can do better than an auction for the buyer even in the case of full information. And this happens even though the buyer must pay strictly more than the maximum possible suppliers' cost if the noncompetitive supplier declines the offer. Indeed, this is also true for other cost distributions (at least as long as they have a bounded density function). Roughly speaking, if the cost density function exists and is bounded above, if $C_o$ is not too much above the highest possible cost to the suppliers, and if $N$ is large enough, then the expected cost under the hybrid mechanism for the full information case is less than the expected cost under the auction. More formally, we have Proposition 8.

Proposition 8. *If the density function $f(x) = dF(x)/dx$ exists and is bounded above, then there exists a $C^* > 1$ and $N^*$ such that the expected cost under the hybrid mechanism for the full information case is less than the expected cost under the auction whenever $C_o \leq C^*$ and $N \geq N^*$.*

Proof. First some preliminaries. Define $G(y) = F^{-1}(y)$. Since $f(x)$ exists, so too does $g(y) = dG(y)/dy$. Let $f^*$ be an upper bound on $f(x)$. Therefore $f(x) \leq f^*$ for all $x$, and $g(y) \geq 1/f^*$ for all $y$.

Let $k > 1$ be any constant. For any such fixed $k$, define $N^*$ as the smallest integer $N \geq 4$ such that

$$\frac{N(N-2)}{(N-1)^2} > F\left(1 - \frac{N-3}{k(N+1)f^*}\right). \tag{1}$$

Because

$$\frac{N(N-2)}{(N-1)^2} = 1 - \frac{1}{(N-1)^2}$$

increases monotonically to 1 as $N$ goes to infinity, and because

$$F\left(1 - \frac{N-3}{k(N+1)f^*}\right) < F\left(1 - \frac{1}{5kf^*}\right) < 1 \quad \forall N \geq 4,$$

Condition (1) is true for all $N$ sufficiently large, so clearly there is a smallest such integer $N$. For future reference, note that (1) implies

$$1 - G\left(\frac{N(N-2)}{(N-1)^2}\right) < \left(\frac{N-3}{k(N+1)f^*}\right) \quad \forall N \geq N^*. \tag{2}$$

Next, define $C^* = 1 + (k - 1(N^* - 3))/(k(N^* + 1)f^*)$. Clearly, $C^* > 1$. Note that both $N^*$ and $C^*$ depend on $k$; different $k$'s give different $(N^*, C^*)$ pairs that satisfy the proposition.

Now look at the expected costs. The expected cost under the auction minus the expected cost of the hybrid mechanism is

$$\begin{aligned} &(N-1)C_{\text{AU}} - \{C_{\text{full info}} + (N-2)C_{\text{NC-auction}}\} \\ &\quad = (N-1)\int xNF^{N-1}(x)\,dF(x) \\ &\qquad - \int [xF(x) + C_o(1 - F(x))](N-1)F^{N-2}(x)\,dF(x) \\ &\qquad + (N-2)\int x(N-1)F^{N-2}(x)\,dF(x) \end{aligned}$$

$$= \int x(N-1)^2 F^{N-1}(x)\,dF(x) - \int x(N-2)(N-1)F^{N-2}(x)\,dF(x) - \int (N-1)C_o(1-F(x))F^{N-2}(x)\,dF(x)$$

(integrating the last term, simplifying it, and integrating the first two terms by parts)

$$= \int (N-1)^2(1-F^N(x))\frac{dx}{N} - \int (N-2)(1-F^{N-1}(x))\,dx - \frac{C_o}{N}$$

(substituting $x = F^{-1}(y) = G(y)$ and $dx = dG(y)$ and rearranging)

$$= \int [(N-2)-(N-1)^2 y/N]y^{N-1}\,dG(y) + (1-C_o)/N$$

$$= \int_{y\le N(N-2)/(N-1)^2} [(N-2)-(N-1)^2 y/N]y^{N-1}\,dG(y) + \int_{y> N(N-2)/(N-1)^2} [(N-2)-(N-1)^2 y/N]y^{N-1}\,dG(y) + (1-C_o)/N$$

(using the facts that the square bracketed term is nonnegative in the first integral's range and is between 0 and $-1/N$ in the second integral's range, and that $g(y) \ge 1/f^*$ for all $y$)

$$\ge \int_{y\le N(N-2)/(N-1)^2} [(N-2)-(N-1)^2 y/N]y^{N-1}\frac{dy}{f^*} - \int_{y> N(N-2)/(N-1)^2} dG(y)/N + (1-C_o)/N$$

(using the previous noted relation (2))

$$\ge \int_{y\le N(N-2)/(N-1)^2} [(N-2)-(N-1)^2 y/N]y^{N-1}\frac{dy}{f^*} - \frac{N-3}{kN(N+1)f^*} + (1-C_o)/N \quad \forall N \ge N^*$$

$$> \int [(N-2)-(N-1)^2 y/N]y^{N-1}\frac{dy}{f^*} - \frac{N-3}{kN(N+1)f^*} + (1-C_o)/N \quad \forall N \ge N^*$$

$$= \frac{N-3}{N(N+1)f^*} - \frac{N-3}{kN(N+1)f^*} + (1-C_o)/N$$

$$= \left\{\frac{(k-1)(N-3)}{k(N+1)f^*} + (1-C_o)\right\}\Big/ N \ge 0 \qquad \forall C_o \le C^* \text{ and } N \ge N^*.$$

Therefore the expected cost under the auction minus the expected cost of the hybrid mechanism is strictly positive, which is what we wanted to show. □

Our theory also presumes that agreements are binding; if a supplier agrees to provide a unit at whatever price the auction sets, that supplier cannot back out of the agreement once he sees what price the auction actually set. The real world is not quite so stark; firms can break contracts, though often at some cost. However, our theory's prediction that hybrid mechanisms can do better for the buyer than an auction does not depend critically on this assumption that agreements are binding. Imagine, for example, that instead of deferring his decision until he has better information, a supplier makes his decision with no information about his cost or the auction outcome, but then, once he has better information, may, at some cost, back out of an agreement to supply a unit. Intuitively, such reneging leaves the buyer no worse off than if the supplier's initial decision were deferred until he had the better information.

Regardless of how high the cost of reneging, the supplier is at least as well off with the option to renege as without. Therefore, if the supplier is forced to make a decision before he knows his cost or the auction outcome, he is at least as likely to accept the contract if he has an option to renege as if he does not have it. After the cost and the auction price become known, there is the possibility that the supplier would find himself in a situation in which it is not worth while to renege, but in which he would not have accepted the offer had he been able to defer his decision, and this benefits the buyer. Consequently, the buyer does at least as well by offering the contract to the supplier before he has any information rather than letting him defer the decision even if the supplier may renege. In short, reneging by the supplier hurts the buyer no more than does letting the supplier defer his decision until he has better information.

## 3. Design of the Experiment

The no-information case offers the greatest possible benefit to the buyer, and it is also in this case that the noncompetitive supplier's behavior is most likely to differ from expected profit-maximizing behavior, thus posing the biggest challenge to the theory. The bidding behavior in the auction part of the mechanism is not affected by the information conditions, and the less information the noncompetitive supplier has about his own cost and the final price, the less likely he is to accept the noncompetitive offer. For example, in the full information condition, the noncompetitive supplier's decision is to simply accept the offer when it is profitable and turn it down when it is not—hardly an interesting setting for an experiment. Therefore we will use the no-information case for our laboratory test.

Our design compares the performance of the noncompetitive sales mechanism (NC) and a uniform-price descending-bid "oral" auction mechanism (AU) in the procurement setting. The bidders play the roles of suppliers, and the auctioneer is the buyer who wishes to minimize the total cost of procuring two units. Three suppliers (who together have the capacity to produce three units) compete for the right to supply the commodity to the buyer. So, in our experimental setting, $N = 3$, $Q = 2$, and $M = 1$.[17]

Suppliers' costs are random draws from a uniform distribution from 0 to 100 tokens (rounded up to the nearest integer), so $F$ is $U(0, 100)$. The buyer also has an outside option of purchasing units at a cost of 100 tokens (the highest possible cost). In the AU treatment, the price starts at 100 tokens and goes down by 1 token every second. When the price becomes too low and a bidder wishes to stop bidding, he clicks the "stop" button. As soon as one of the bidders stops bidding, the total supply falls from three to two units, and the auction ends at the price at which the bidder dropped out. The two remaining bidders each supply one unit and earn the difference between the auction price and their own cost.

In the NC treatment, one of the three suppliers is randomly selected and given an option to supply one unit at the price to be determined by the auction in which the other two bidders compete. This supplier may decline the option, in which case he earns zero for the round, or he may accept the option, in which case he earns the difference between the price that will be determined by the auction and his own cost for the round; the supplier must make his decision before he learns his cost in this round. If the noncompetitive supplier declines the option, then the buyer purchases one unit at his outside option cost of 100, and the right to supply the second unit is still auctioned off.[18]

We conducted six sessions for each treatment, with six participants in each session in June 2004. Each round, the participants were randomly rematched in groups of three. The costs and matching were randomly drawn in each session within a treatment, and each participant was in the noncompetitive role 10 times, in a random order (we designate a random cost and matching draw with a "draw number" 1 through 6), but were identical in the 2 treatments. So, in total, our study consists of six independent observations for each of the two mechanisms, and the mechanisms' performance can be compared pairwise across sessions. Each session started with 10 practice rounds. The practice rounds included two bidder auctions for one unit in the NC treatment, included three bidder auctions for two units in the AU treatment. The values and matching for the 10 practice rounds were identical in all 12 sessions. At the end of each round, bidders saw a history of the costs and prices in the session so far, including: Actual costs of all six suppliers; average cost of each supplier; average cost in each period; average cost across all suppliers and periods. They also saw similar information about auction prices that included: Auction prices that resulted in each market; average price in each market; average price each period; average price across all markets and all periods. Appendix A-2 displays the screen shot of the actual information that participants in the noncompetitive treatment saw at the end of the 10 practice rounds.

We used a random number generator in Microsoft Excel to draw the costs, and for the practice rounds, we selected a sample of draws that resulted in overall average cost of close to 50 (51.07 in actuality) and an overall average auction price, assuming that all bidders follow the dominant bidding strategy, of close to 66.7 (the actual prices varied slightly by session). The purpose of providing this summary information was to promote faster understanding on the part of the participants in the NC treatment about what the average costs and auction prices are likely to be. The practice rounds were also conducted in the AU treatment for the purpose of keeping the experimental protocol parallel in the two treatments.

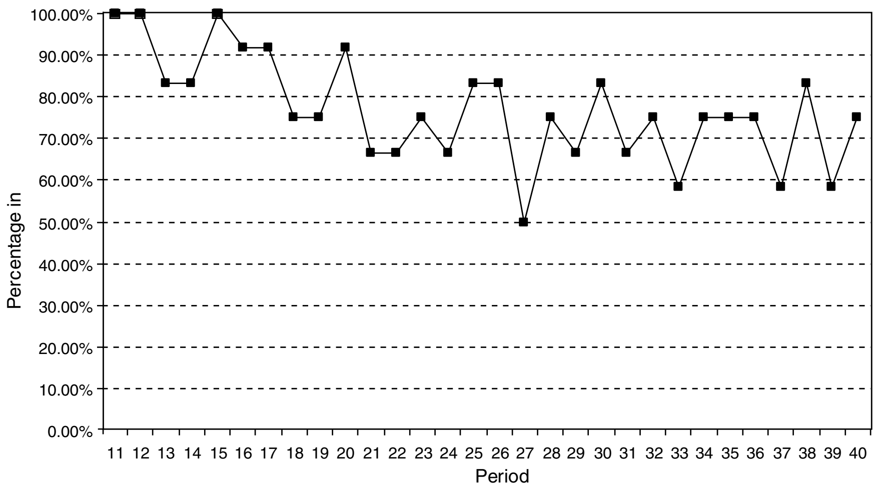
Starting in period 11, the participants played the 30 rounds of the game. Each round in both treatments started with the summary information about past costs and prices. In the NC treatment, one of the three suppliers was also asked to decide whether to accept or decline the option to supply one unit at the end of the auction at the auction price. The other two suppliers in the NC treatment, as well as all three suppliers in the AU treatment, simply had a "continue" button on their screen. The round then proceeded to the auction. After the auction, all suppliers learned the outcome of the current round that included: A reminder of what they did in this round (either bid in the auction, supplied a unit after the auction, or did not participate); Cost this round; Auction price; Profit.

All sessions were conducted at Penn State's Smeal College of Business Laboratory for Economic Management and Auctions on June 1–2, 2004. Participants, mostly undergraduate students from diverse fields of study, were recruited using the online recruitment system. Cash was the only incentive offered. Participants were paid their total individual earnings

[17] Two units is the smallest number of units we can have and still have a multiunit auction, and three suppliers is the smallest number of suppliers we can have competing to provide two units. With three suppliers and two units, the only possible hybrid mechanism will procure one unit noncompetitively and one unit via an auction.

[18] Complete experimental instructions are in Appendix A-1. All appendices are available at http://mansci.pubs. informs.org/ecompanion.html.

**Figure 2** **Actual Average Proportion of Suppliers Opting in for All Six Sessions Over Time**




from all 40 rounds (10 practice rounds and 30 actual rounds), plus a \$5 show-up fee at the end of the session. The software was built using the z-Tree system (Fischbacher 1999). Each session lasted about 90 minutes and average earnings were approximately \$25 in the AU treatment and \$24 in the NC treatment.

## 4. Results

### 4.1. Noncompetitive Suppliers' Decisions

The critical assumption of our theory is that the noncompetitive supplier's objective is to maximize his expected profit, and therefore he should accept the option to supply one unit after the auction at the price determined by the auction as long as this option has a positive expected value. Figure 2 shows the actual average acceptance rates over time.

Acceptance rates start out at 100%, decrease over the first 10 periods, and then settle down at about 70%. The actual average acceptance rate is 89.1% in periods 11–20, 71.7% in periods 21–30 (the decrease from 89.1% to 71.7% is statistically significant, with a one-sided matched-pair $t$-test $p$-value of 0.0106). The average acceptance rate in periods 31–40 is 70% (the decrease from 71.7% to 70% is not statistically significant; one-sided matched-pair $t$-test $p$-value is 0.3856). There is heterogeneity among the sessions: acceptance rate is nearly 100% throughout in sessions 3 and 6, only 60% in session 2, and close to 70% in the other three sessions.

The initial high acceptance rate and the initial fall is not surprising: Recall that in periods 1–10, participants experience the outcomes of an ascending auction with two bidders and one object, and observe information about costs and prices. By the end of period 10, the average actual costs are close to the theoretical average of 50, and the average actual auction price is close to the theoretical average of 66.7 (see Appendix A-2). The fact that acceptance rates are close to 100% early on is evidence that participants are able to process the average cost and price information correctly, and determine that accepting the noncompetitive contract is profitable on average.

To obtain a clearer picture of how individuals make decisions to accept or to decline noncompetitive contracts, we classify participants based on their decisions to opt in or out into three categories: (1) those who make the same decision every time,[19] (2) those who start out opting in and at some point start opting out, and (3) the rest of the participants who switch between opting in and out (see Appendix A-3 for a detailed breakdown by individual). Category (1) is consistent with maximizing expected profit, when the decision is to always opt in, as well as with all standard models of risk aversion (Holt and Laury 2002). Category (2) is consistent with the model of decreasing relative risk aversion under the assumption that some wealth effects are present (see Cox and Sadiraj 2006, Heinemann 2005) as well as with Prospect Theory (Kahneman and Tversky 1979),[20] and category (3) behavior is consistent with various forms of the "gambler's fallacy" (see, for example, Hogarth 1987).[21]

Of the 36 subjects, the majority (19 people; 53%) fall into category 1 (labeled as (1) in Appendix A-3). Of the 19 participants in this category, 18 always accept the contract and one rejects it 9 times. Five participants (14%) fall into category 2, and the other 12 (33%)

[19] We also include in this category participants who make a single inconsistent decision because the single deviation can plausibly be counted as an error.

[20] Prospect theory implies that participants are risk averse over gains and risk seeking over losses, relative to some reference point.

[21] See Camerer (1995) and references therein for an excellent review of the gambler's fallacy and other related behavioral biases that have been documented in the psychology and experimental economics literature.

fall into category 3. Note that because we have no way of observing participants' beliefs, almost any behavior that changes over time is consistent with gambler's fallacy. This is behavior in which participants act as if they do not understand (or do not believe in) the independence of random draws, and they appear to try to "overcome" randomly drawn costs by inferring from the past draws to the future draws. The "gambler's fallacy" behavior is likely to be more common in the laboratory than in practice, because in practice neither costs nor prices are random—they are likely to be correlated. Therefore the 30% rejection rates in the laboratory probably overestimate the expected rejection rates in practice, however, because suppliers in practice are also likely to have more information about costs and prices than the participants in our experiment, the practical settings of interest may resemble one of the settings in which suppliers have more information. Therefore the results of our experiment should be interpreted as a baseline test of the theory and a first (not the final) step in testing the models of hybrid procurement mechanisms.

### 4.2. Bidding Behavior

The second presumption of the theory is that bidders follow the dominant bidding strategy in the auction. It has been well established that participants can learn to bid close to the dominant strategy in ascending auctions (see Kagel 1995 and references therein). Our experiment differs from the standard setting because we use the reverse auction frame, and in that (in the AU treatment), two units are being auctioned.

Despite the differences between our setting and the standard experimental setting, the bidding behavior is very close the dominant strategy in both treatments. Overall, 66% of the bids exactly equal cost (68% in the AU treatment and 65% in the NC treatment), and 89% of the bids are within five tokens of cost (87% in the AU treatment and 90% in the NC treatment). About 9.5% of the bids are more than five tokens above cost (10.9% in the AU treatment and 8% in the NC treatment), and about 2% of the bids are more than five tokens below cost (1.7% in the AU treatment and 2.3% in the NC treatment).

Because a bid that is below cost might result in a loss, bids below cost are clearly errors, and we see very few of them (only 2%). The vast majority of bids that are slightly above cost occur when bidders have very high costs (in other words, bidders had a very small chance of winning). These bids indicate that a bidder dropped out before the price reached the cost, so those bids can potentially result in foregoing an opportunity to win the auction, but because most of the instances happen when costs are high, the actual foregone opportunity to win is quite small.[22] This tendency indicates that actual auction prices are slightly above those predicted by the theory. However, because the tendency to drop out early is small, and is approximately the same in both treatments, it does not have a significant effect on the differences in total costs between the two treatments.

### 4.3. Efficiency Comparisons

In theory, the AU mechanism is 100% efficient, and the NC mechanism is only 67% efficient, because when the high-cost supplier is selected for the noncompetitive contract, the mechanism must result in an inefficient allocation. In the experiment, about 91% of the auctions resulted in the efficient allocation in the AU treatment, but only 48% in the NC treatment.

The auction outcome itself is not 100% efficient because bidders occasionally stop bidding short of their costs, and this causes 31 out of 360 auctions (about 9%) in the AU treatment to result in inefficient allocations. In the NC treatment, only 10 out of 360 auctions result in inefficient auction allocations (about 3%), but the two major sources of inefficiency are (1) the high-cost supplier being chosen for the noncompetitive contract (which, by design, happened in about 33% of the auctions) and (2) a low-cost supplier was chosen for the noncompetitive contract, but rejected the contract (this happened in 57 out of 360 auctions—about 16%).[23]

### 4.4. Buyer Cost Comparison

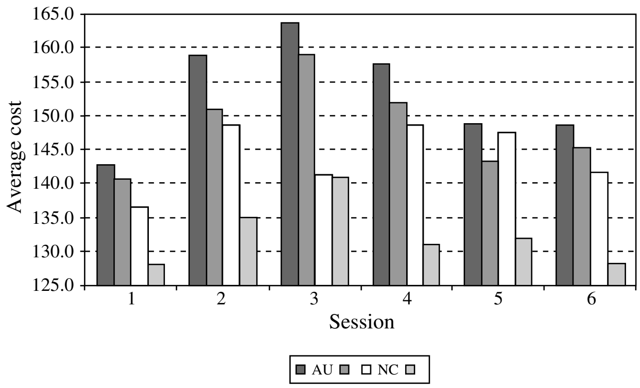
We display the actual and predicted buyer costs for the last 20 periods graphically in Figure 3. Recall that acceptance rates in the NC treatment have settled at approximately 70% in the last 20 periods, and therefore we confine the analysis comparing buyer costs in the two treatments to the last 20 periods.

We use the Mann-Whitney U test (also referred to as a Wilcoxon test, see Seigel 1965, p. 116) to compare the costs in the two treatments and the average predicted and actual costs in each treatment in the last 20 periods. The test reveals all the differences to be statistically significant, with the exception of the dif-

[22] Kwasnica and Katok (2006) report on behavior in English (forward) auctions with high opportunity cost of time induced, and find that stopping short of value is consistent with equilibrium theory when bidder impatience is a factor, and is commonly observed in the laboratory. Bidder impatience has also been found to affect behavior in descending clock (Dutch) auctions (see Katok and Kwasnica 2004).

[23] We count this latter case as an inefficiency, although in practice a supplier who rejected a noncompetitive contract may have some more attractive outside options, and therefore the actual outcome may not be inefficient.

**Figure 3** **Actual and Predicted Average Costs for the Last 20 Periods (Periods 21–40 in the Study), Broken Out by Sessions**




**Average costs**

AU:

| | |
|---|---|
| Predicted: | 148.5 |
| Actual: | 153.4 |
| Difference: | 5.0 (3.25%) |
| *p*-value: | 0.2356 |

NC:

| | |
|---|---|
| Predicted: | 132.6 |
| Actual: | 144.1 |
| Difference: | 11.6 (8.05%) |
| *p*-value: | 0.0021 |

Difference between AU and NC:

| | |
|---|---|
| Predicted: | 16.0 (10.7%) |
| *p*-value: | 0.0026 |
| Actual: | 9.3 (6.1%) |
| *p*-value: | 0.0153 |

*Note.* The $p$-values refer to one-sided Mann-Whitney U test (Wilcoxon test) with the null hypothesis of MC $<$ AU and Predicted $<$ Actual.

ference between the actual and predicted costs in the AU treatment.[24] We note the following regularities:

- Actual costs in both treatments are higher than the predicted costs. These differences are not very significant economically but are statistically significant for the last 20 periods in the NC treatment, as well as for all 30 periods in the AU treatment (Mann-Whitney $p$-value is 0.0026). These differences are caused by the tendency of about 10% of the bids to be more than five tokens above costs.
- The actual differences in costs between the AU and the NC treatments are statistically significant, although slightly below predicted differences (actual difference in cost for the last 20 periods is 9.3 tokens or 6.1%, which is slightly smaller than the predicted difference of 16 tokens or 10.7%). The actual differences are below predicted differences primarily because not 100% of noncompetitive suppliers accept the contract (see detailed discussion in the previous section). Because only 70% of the suppliers accept the contract (in the last 20 periods), buyer costs are calculated under the assumption that the buyer exercises her outside option to purchase one unit at 100 when the noncompetitive supplier rejects the contract. This happens in about 30% of the auctions, driving the actual costs above the predicted costs in the NC treatments.

In short, consistent with our theory, the noncompetitive sales mechanism reduces costs. The reduction is smaller than the theory suggests primarily because noncompetitive suppliers sometimes decide not to participate.

[24] Sign test yields the similar results, except that the difference between the actual and predicted costs in the AU treatment is also significant. The sign test $p$-values are 0.0156 in all cases.

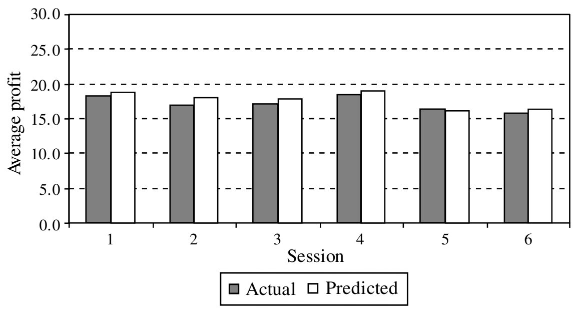
### 4.5. Supplier Profit Comparisons

Next, we look at the actual and predicted supplier profit under the two mechanisms. Figure 4 shows the average profit in the last 20 periods, separated by session. The differences between the averages of actual and predicted profits from auctions are extremely small and not statistically significant (Mann-Whitney test one-sided $p$-values are 0.4364 for AU and 0.2609 for NC). Actual profits of the noncompetitive suppliers are lower than predicted and the differences are weakly significant (Mann-Whitney test one-sided $p$-values is 0.0868), and are substantially more variable than the profit of auction participants. The differences are because of the fact that only 70% of suppliers accept noncompetitive contracts. The average profit in the last 20 periods for noncompetitive suppliers who accept the contracts is 17.0—exactly matching the predicted profit. Profit differences between treatments are significant, both economically and statistically. Suppliers in the AU treatment make on average 35% more than the auction participants in the NC treatment and 53% higher gains than noncompetitive suppliers in the NC treatment (the latter higher difference is again because of the fact that only 70% of the noncompetitive suppliers choose to participate).

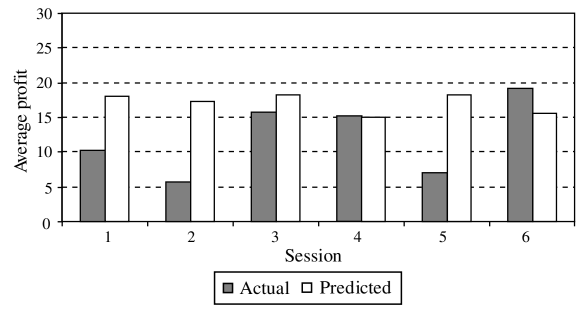
## 5. Summary and Discussion

In practice, reverse auctions are often combined with noncompetitive mechanisms when used for procurement. These combined (or hybrid) mechanisms are used as a way to capture the benefits of auctions (competition) while at the same time allowing the buyer control over whom to do business with. Our work is a first step toward gaining analytical and empirical insights into the performance of these

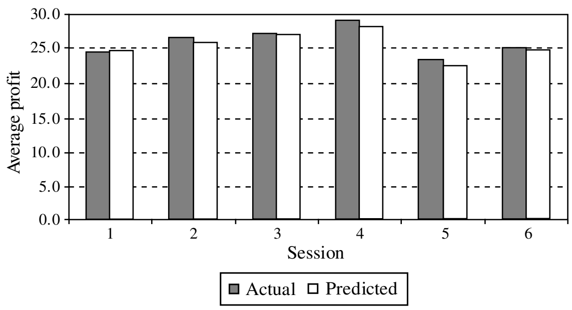
**Figure 4 Profit Comparisons in the Last 20 Periods**




(a) NC Treatment: Suppliers in the auction




(b) NC Treatment: Noncompetitive suppliers




(c) AU Treatment

*Average Profits*:

| NC (Noncompetitive Suppliers) | | NC (Auction) | |
|---|---|---|---|
| Actual: | 12.2 | Actual: | 17.1 |
| Predicted: | 17.0 | Predicted: | 17.7 |
| *p*-value: | 0. 0868 | *p*-value: | 0.2609 |

| AU | |
|---|---|
| Actual: | 25.9 |
| Predicted: | 25.4 |
| *p*-value: | 0.4364 |

hybrid mechanisms. We investigate a simple mechanism that combines an auction with a noncompetitive sales contract. Specifically, we develop an analytical model of the new mechanism and test this model in the laboratory. Our results show that using the hybrid mechanism decreases the buyers' costs relative to a stand-alone auction, even without considering any potential benefits a buyer may gain by dealing with specific suppliers. This finding is a critical first step in studying more complex and realistic procurement mechanisms.

Our model, and the laboratory setting we use to test this model, is stylized relative to e-sourcing settings observed in practice, and yet it helps us to draw useful conclusions for e-sourcing. In practice, we observe that suppliers prefer hybrid mechanisms to pure auctions (Jap 2002). But it is up to the buyers to design the rules for these mechanisms. We demonstrate that it is possible to design hybrid mechanisms that generate costs that are as low, or lower, than reverse auctions. In practice, price is not the only dimension used to generate value for the buyer, and because hybrid mechanisms leave more room for communication, suppliers may perceive them as more attractive than stand-alone auctions. For example, a supplier who is offered a noncompetitive contract might be a long-term supplier with a proven track record for quality and delivery reliability. The auction is used to establish a baseline price that could then be adjusted for the noncompetitive supplier to properly account for the higher quality of this supplier's product. A small part of the business could be auctioned off to establish the baseline price and also discover new potential suppliers. Auction winners get an opportunity to prove themselves to enter into a longer term contract in the future.

Finally, we suggest several directions for future research. One interesting direction is to investigate what happens when suppliers are offered endogenous choice. Engelbrecht-Wiggans (1996) showed that if there is a cost to bidding in an auction and this cost can be avoided by accepting a noncompetitive contract, there are situations in which some suppliers will voluntarily choose the auction, while others choose the noncompetitive contract. Our results at the end of §2 indicate that there are settings in which the buyer can save money by using a hybrid mechanism even when the noncompetitive supplier has full information about his own cost and the auction price. In this full information setting, the buyer still benefits at the expense of suppliers, but the question of whether suppliers might not prefer such a mechanism to an auction is ultimately an empirical one.

Another potentially fruitful direction that can bring our model closer to reality is to investigate how to combine noncompetitive contracts with auctions in which a bidder may provide more than one unit. When bidders may supply multiple units, several new issues arise: the *demand reduction*, the *exposure*, and the *free-riding* problems.[25] It has been shown analytically that when bidders with linear preferences bid on multiple units, demand reduction may hinder competition.[26] Some of these analytical findings have also found support in the field.[27]

When bidders have synergies, two potential problems arise. The exposure problem happens when bidders with synergies are not guaranteed all the units they want, and therefore they risk losing money. The free-riding problem happens when the efficient allocation requires bidders without synergies to combine to outbid a bidder with synergies (see Milgrom 2004 and references therein).[28]

Combining noncompetitive sales with multiunit auctions may alleviate these problems. Suppliers who have synergies may have an additional incentive to prefer noncompetitive contracts, because those contracts remove the uncertainty associated with the production quantity. Buyers may have an additional incentive to offer noncompetitive contracts to bidders with synergies because those bidders, fearing the exposure problem, may be unwilling to compete aggressively in auctions. Therefore, an area for future research is to investigate what happens if suppliers may provide multiple units, the effect that combining noncompetitive contracts with auctions has on the free-riding and exposure problems, and the managerial question of, for example, if only some suppliers can provide multiple units, is it better to offer these suppliers the noncompetitive contracts or to make them bid in the auction?

An online appendix to this paper is available on the *Management Science* website at http://mansci.pubs.informs.org/ecompanion.html.

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[25] *Demand reduction* means that bidders bid below their true valuation on some of the units (in other words, they reduce the demand for the unit).

[26] See Ausubel and Crampton (1998) and Engelbrecht-Wiggans and Kahn (1998a, b). Engelbrecht-Wiggans (1999) characterizes the equilibria to uniform price auctions when bidders have uniformly distributed flat demands.

[27] See List and Lucking-Reiley (2000), Engelbrecht-Wiggans et al. (2006), and Kagel and Levin (2001).

[28] Krishna and Rosenthal (1996) examine simultaneous ascending auctions with synergies and heterogeneous bidders, and find that when bidders who exhibit economies of scale (synergies) are present, the bidding is less aggressive. Katok and Roth (2004) compare the descending-bid Dutch auction and the ascending-bid uniform-price auction for homogeneous goods in an environment with synergies and find that the descending auction generates higher revenues and more efficient allocations in a variety of environments.

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