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Using Procurement Auctions in the Department of Defense

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Summary

The Department of the Navy, and the federal government in general, have recently entered the electronic procurement auction marketplace. One prominent approach is the use of reverse auctions. In a reverse auction, a buyer solicits bids from a number of vendors for a product. These vendors submit bids specifying the price they will charge to provide the product. Lower bids are more likely to win the auction. Because sellers submit bids, the buyer acts as the auctioneer and lower prices are better bids than higher prices, the auction is "reversed" from the more familiar conventional or forward auction.

This paper addresses a number of questions associated with the use of reverse auctions.

- What savings can be expected from using reverse auctions?
- What should be auctioned, and how should the auction be conducted?
- What is the possibility of undesirable consequences, such as collusion or the erosion of the industrial base?

Auction savings: counterfactuals and estimates

Auction savings can be difficult to estimate because the true savings require knowledge of a counterfactual—the price that would have been paid if every other aspect of the transaction, including timing and quantity, were the same, but a different price-setting mechanism were used. The credibility of the estimate depends on the validity of the counterfactual.

Auctions are not likely to generate continuous cumulative price reductions with repeated use. Rather, auction prices are likely to fall from the traditional price when auctions are first introduced, and then vary around a new level with repeated auction use.

Navy and Army auctions

The Navy and the Army have conducted a number of auctions since May 2000. The counterfactual used for the estimates is typically the independent government estimate (IGE). The validity of the IGE varies. There is some evidence that the IGE is not always an accurate counterfactual. In addition, the Navy auction data, especially early auction data, have some notable inconsistencies.

Navy auctions have covered a wide variety of items, including commodities, services, and items produced to meet unique criteria. Army auctions have generally been for commodities. Using the IGE as the counterfactual, the Navy and Army estimates of the savings that have been realized in their auctions are as much as 25 percent of the expected cost.

We examined a limited set of Navy auction data where the Naval Audit Service found supporting data. In these 39 observations, we found little evidence that total value of the purchase affected the relative savings. We found savings in commodities, engineered items, and services, but because of the limited sample size, a few purchases with significantly above or below the expected cost had a significant effect on the magnitude of the savings.

Defense Supply Center Columbus

The Defense Supply Center Columbus (DSCC) automated a sealed-bid first-price auction mechanism that was intended to replace conventional procurements for selected items. The contracts could be awarded based on a number of criteria. The automated auction was then modified to be an open-bid, first-price procurement auction for a limited number of products.

The DSCC data provide a natural experiment in the effects of changing from a sealed-bid to an open-bid auction. Using the data, and controlling for quantity, product class price trends, and specific items, we estimate that publicly revealing bids reduces prices on average by 4.4 percent below the sealed-bid prices. The savings increase as the number of bidders increases. We used a rough calculation to estimate that implementing a sealed-bidding auction lowers prices by about 1 percent below the conventional best-value purchase.

Differences in estimated results

The Navy and Army auctions report savings that are much higher than those we found in the DIBBS auctions. We hypothesize that there are at least four possible reasons why the service and DSCC auction results are so different:

- First, the products that were selected for Navy and Army auctions might be from very different markets than those of the DSCC. If the DSCC markets are more competitive initially, the savings from the competition engendered by the reverse auction will be smaller.
- Second, the selection of products themselves might be very different. The DSCC products are not evaluated for particularly high prospective savings from auctions; if they meet certain criteria, such as not being a critical safety item and not being a high-priority purchase, they are auctioned. In contrast, each Navy and Army auction requires a conscious decision by a purchaser to use a reverse auction. We do not know the criteria used by individual buyers, but it is possible that they choose an auction when they expect savings from that choice.
- Third, the auction rules differ. The DSCC auctions allow the bidders more flexibility than do the Navy and Army auctions. In particular, DSCC auctions allow bidders to increase their bids. This rule might generate strategic behavior and potentially decrease the savings that the auction might generate.
- Fourth, the auction savings estimates are derived using different techniques. The Navy and Army auction savings are determined by comparing transaction price with the IGE in each auction. The DSCC auction savings are estimated by regression analysis which compares the prices of the same item under sealed-bid and open-bid auctions, while controlling for additional factors such as quantity. Because the DSCC auction savings are based on a large number of actual transaction prices,

rather than a small number of estimated prices, they may be more accurate.

Issues in using auctions

Auction candidates

Some characteristics of the types of items that are appropriate for auctions can be identified. These criteria indicate that using auctions indiscriminately to all purchases of an entire type of product might be inappropriate.

Good auction candidates are items that can be specified

Good auction candidates are items that can be fully specified. Because the auction generates competition on the basis of price, it is important that the prices compared be for essentially the same good. Thus, commodities, which are standardized items, are suitable for auctions. Services that can be well defined, and even items that must be produced to unique specifications, can also be suitable for auction.

Some auction candidates involve tradeoffs between features and cost

In some cases, excluding consideration of alternative quality-price combinations is undesirable. In these cases, auctions can still be part of the purchasing process. One way to do this is to specify the value of improved quality, so that bidders can compete for a fully specified item. Alternatively, the value of the non-price features can be unspecified, and after the auction, the product/price proposals of the vendors can be compared. However, in this case, the usefulness of the auction in stimulating price competition may not be as strong.

Commodities, engineered-items, and services are possible candidates

Commodities, engineered-items, and services can in many instances be fully specified, so procurement auctions might be appropriate for each of them. In some circumstances, however, even commodities are not ideal candidates. As noted, switching costs can be a limiting factor. Also, in some cases competitive commodity markets may have already made the posted prices nearly as low as possible. Auctions for uniquely specified engineered items and services can generate competition that leads to significant savings. However, some of these items might also involve tradeoffs in the features or quality that different vendors could provide, thus making auctions for some items less suitable for auctions.

Thus, a general statement of applicability of auctions to different items might lead to the inappropriate application of auctions.

Transaction costs and the costs of switching suppliers should be considered

The costs of switching suppliers should be incorporated into the auction decision. Because an auction initiates the possibility of switching suppliers, the costs of changing suppliers should be considered. Even switching commodity suppliers can have costs. For example, systems that streamline the purchasing process and delivery of a commodity may exist with one supplier and not another. Even though an auction may be appropriate for the item, these other transaction costs should also be considered, and weighed against the expected savings from an auction.

Also, the expected price savings from an auction should be weighed against the costs of conducting an auction. If the auction mechanism is especially efficient, or especially costly, the auction costs might drive the decision about whether or not to conduct an auction. For example, the Defense Supply Center Columbus' primary interest in auctions was streamlining the procurement process, rather than lowering purchase costs. In other cases, such as the full-service Navy auctions, the costs of the auction can be high, and are only justified for auctions with the potential to produce very large savings.

How auctions should be conducted

The rules for an auction are important. In particular, the rules may affect the savings by driving the bidding strategies of vendors. Unfortunately, the optimal auction depends on the specifics of the information available to the vendors and the nature of the market. Thus, one auction format is not always the best, but determining the auction environment can be difficult. In several circumstances, however, the open-bid auction is preferred to the sealed-bid auction because it reduces the risk of the winner's curse[1] and limits the ability of a single bidder to control the transaction price.

Collusion and industrial base issues

Collusion has been found to be a problem in some auctions, particularly in electromagnetic spectrum auctions, which were for very high stakes. The concern with collusion is that open-bid auctions provide the suppliers who are bidding with an opportunity to signal competitors legally. Although this is a possibility, there are a few reasons why collusion may be no more of a concern than in conventional procurements. First, collusion can only succeed only when there are a small number of bidders, and, in general, the items that are appropriate for auction have multiple potential suppliers. Second, collusive behavior can only be sustained if the same bidders are active in multiple auctions. In the spectrum example, several auctions were occurring simultaneously.

The concern with industrial base issues is that auctions might squeeze firms' profit margins, causing marginal firms to become unprofitable. This could lead to a consolidation of market power and ultimately reduce competition. However, this implies that the government is willing to tolerate inefficient suppliers who will pass on higher prices. Inefficient vendors may be forced out, but auctions are unlikely to create new barriers to entry that would inhibit competitive markets. However, if the market has significant barriers to entry, such consolidation could present problems.

1. The winner's curse is the problem that the auction winner might have overvalued the object being identified. In a reverse auction setting, the problem is that the auction winner might have significantly underestimated the cost of providing the good or service.

Introduction

Auctions have received considerable attention in recent years. One widely publicized example is the Federal Communications Commission (FCC) auctions for electromagnetic spectrum. Since 1994, the auctions have generated huge revenues—a single auction for multiple licenses ending in May 1996 yielded total revenues of over $9 billion [1]. Consumer Internet auction sites such as eBay, Yahoo, and Amazon, also gained wide publicity—eBay alone has nearly 50 million registered users, and the value of its transaction totaled more than $5 billion in 2000 [2]. And businesses, especially auction service providers, report dramatic savings that have been realized through their use of electronic reverse auctions. For example, FreeMarkets, an auction service provider, reports that its online auctions have saved its customers $9 billion since 1995, and GE Global Exchange Services claims that its customers have reduced their costs by 7 to 39 percent, resulting in savings of more than $200 million in the first quarter of 2002 [3, 4].

The Department of Defense is also participating in the electronic reverse auction marketplace. Naval Inventory Control Point Philadelphia (NAVICP) conducted the first government reverse auction in May 2000, and has established a reverse auction program using commercial providers. The Army's Communications and Electronics Command has conducted a number of reverse auctions using a commercial provider, and the Defense Supply Center Columbus has implemented reverse auctions using its own program.

The highly publicized success of recent auctions has generated speculation on the savings that could be realized in the Department of the Navy if the use of reverse auctions were more widespread. This paper is intended to help Navy decision-makers make informed decisions. To establish a foundation for our discussion of auctions, we begin with a definition of terms, and a review of key theoretical and empirical results from the economics literature. We then review and analyze auction data that we obtained. We conclude with a discussion of some concerns that arise when auction use is considered.

Auctions: Literature review

Auctions have been used to establish the trading price of items for thousands of years.[2] Auctions often bring to mind the picture of a fast-talking, gavel-wielding auctioneer and a room full of potential buyers. As the item, perhaps livestock or an antique, is presented to the buyers, the auctioneer starts calling out prices. When someone offers to buy the good at that price, the auctioneer seeks anyone who will bid a higher price. Buyers continue to bid until one buyer establishes a price no other buyer will top, and the auction concludes with the traditional "going, going, gone—sold to the gentleman in the third row."

Although current auction practices can be quite different, this example of a traditional auction provides a common ground for developing the concepts and features of different auctions. In this section, we will introduce different rules for auctions and then discuss different information environments in which auctions take place. After laying this foundation, we will present some of the significant results in the economics literature on auctions.

Defining auction terms

Forward and reverse auctions

The scenario described above is a forward auction, commonly referred to as simply an auction. In a forward auction, the bidders seek to purchase a good or service from the auctioneer of an item or

2. Several articles cite Herodutus' report of Babylonian auctions for women of marriageable age in the 5th century BC. (See for example [5]). The sale of the Roman Empire by ascending auction in AD 193 is another noteworthy example [6].

items.[3] (The actual owner of the items could be someone other than the auctioneer, but we assume that the auctioneer acts on the owner's behalf.) The objective of the auctioneer is to obtain the highest price for the good being sold. The bidders want to pay the lowest price they can to obtain the good, but they must compete with other bidders for that good.

In contrast, a reverse auction involves an auctioneer who wants to purchase a good or service from one of several potential suppliers. Hence, the auctioneer's goal is to obtain the lowest price. The bidders' goal is to sell the product at the highest price, but they must compete with other bidders who are also trying to sell the product or service. Thus, the bidding will likely start at a high price, and as the bidders compete, successively lower prices are submitted until a price is submitted below which no other sellers are willing to go.

Four common auction formats

Every auction must specify how to submit bids, how the winning bidder is selected, and what the transaction price will be. In addition to these essential requirements, the auctioneer can impose a number of additional conditions, and these rules can have a significant impact on the auction outcomes.[4] Different auction formats developed to meet the needs of the auctioneers. In some cases, the rules were designed to influence the speed of the auction. In other cases, the rules were designed to encourage more aggressive bidding.

In this section, we discuss some of the more common auction formats, to provide background for readers. After defining auction types and other characteristics of the auction environment, we will discuss how those rules and characteristics affect the auction outcomes. We will

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3. It is not necessary that the final transaction involve only one seller and one buyer. Auctions can be designed to allocate goods from multiple sellers to multiple buyers. For simplicity, we will not focus on such auctions in this paper.

4. Reference [7] provides numerous examples where auction rules inadvertently led to unintended (and undesirable from at least one party's perspective) outcomes.

use the reverse auction as the context for describing the formats. (A forward auction analogy exists for each format.) Thus, lower bids are more likely to win than higher bids.

The scenario that introduced this section is an **English** (or English open outcry) auction. A reverse auction version involves suppliers who submit successively decreasing bids until no other bidder will announce a lower bid. The history of bids and the bidder's identity is known to all bidders. The winning supplier is the bidder who makes the last (lowest) bid. The contract price is the winner's bid. Unique items, such as art work, antiques, and livestock are common examples of items sold by English auction.[5]

In a **sealed-bid, first-price** reverse auction, each vendor/bidder submits only one bid. The bids are not revealed to competing bidders. The winning bidder is the one who submits the lowest bid, and the contract price is the amount of the winning (lowest) bid. Sealed-bid, first-price auctions are frequently used for purchasing items. Government procurements have often been sealed-bid, first-price auctions.

In a reverse **Dutch** auction, the buyer/auctioneer initiates the auction by announcing an extraordinarily low transaction price. He then announces successively increasing prices until some provider/bidder stops the bidding. The winning bidder is the first one to stop the auctioneer, and the price paid is the last price announced by the auctioneer. The Dutch auction is so named because the forward Dutch auction is used in the wholesale flower market in the Netherlands. It is also used in fish markets in Israel and tobacco markets in Canada [6].

In a **sealed-bid, second-price** (also called Vickrey) auction, each bidder submits only one bid. The winner is the one with the lowest

5. A variant on the English auction is the **Japanese** (also called English-descending-clock or open-exit) auction. In the reverse auction version, the auctioneer announces successively decreasing prices. All vendors are initially in the auction. As the price falls, bidders must choose the price at which to withdraw (publicly) from the auction. The last vendor remaining is the winner, and the contract price is the price at which the next-to-last bidder withdrew.

bid, and the contract price is the amount of the next-lowest bid. A multi-unit version of the sealed-bid, second-price auction has been used to sell U.S. Treasury securities since 1997 (the single-price auction described below). This format was designed to lead bidders to bid their actual valuations.

Variations

Multiple-item auctions

The auctions we just described establish rules for setting the price and completing the transaction between a seller and a single buyer. (The good can be a “lot” or bundle of items, but it is sold as a single entity.) However, in some instances, an auctioneer may want to purchase identical items from several different vendors, and if so, the auction rules must specify how the multiple vendors are to be selected, the price each vendor will receive, and the quantity each vendor will provide.

Multiple-price auctions are one alternative. In a multiple-price reverse auction, the vendors each submit a bid with a quantity and price. The auctioneer then orders the bids by price, and awards quantities to the lowest bidders until the full quantity is allocated. The transaction price for each bidder is the bid. For example, suppose the Navy wanted to purchase 1,000 life jackets, and the vendors’ bids were those listed in table 1. Vendors A, B, and C would each provide the quantities they bid, at their bid price. Vendor D would only provide 200 units, at price 16, because that satisfies the entire purchase quantity. Before 1998, most Treasury auctions were multiple-price auctions.

Table 1. Hypothetical multiple-item auction bids

Vendor	Bid quantity	Bid price
A	200	10
B	100	12
C	500	15
D	400	16
E	700	18

Single-price auctions are similar to multiple-price auctions. The difference is that all bidders who provide any quantity do so at the same price. This price can be the highest bid price that provides any of the good. In the example, the quantities remain the same, but each vendor receives 16 per unit. Alternatively, the price can be the lowest of any vendor not winning a quantity. Because the price is not set at the actual bid for most vendors, the single-price auction is similar to the second-price auction introduced earlier.

Additional rules

Auction formats may include additional features. For example, **reserve prices** can be used to establish a ceiling in a reverse auction above which the auctioneer will not purchase the good from any bidder. Reserve prices can be hidden or open. **Minimum-bid increments** can be required in open auctions; this forces one bidder to exceed the current best bid by at least the minimum increment. These minimums can speed up the auction process by eliminating trivial bidding increments. An auctioneer can specify **fixed auction periods** that require all bids to be submitted within a given period. **Entrance fees** can also be established. **Proxy bidding** has been used by some on-line auctioneers, such as E-bay. In a proxy bid, the bidder states the maximum he is willing to pay for an item. This maximum is compared against the current best bid, and if the maximum exceeds that bid, a bid of the current best bid plus the minimum increment is entered. Proxy bidding requires a third party to act as the auctioneer. **Anonymous bidding** can be incorporated into different auction formats. Internet-based bidding has greatly facilitated anonymous bidding in English auctions. Anonymity in sealed-bid auctions has always been easy to arrange. **Rank-order bidding,** where bidders do not know the values of the other bids, but only how their own bids rank relative to the others, are similar to English auctions. Many commercial online auction websites have experimented with additional features, as detailed in [8].

Optimal mechanism design

Economists have devoted significant effort to developing auction rules that guarantee efficiency, which is the condition that the bidder with the highest valuation will win the auction assuming everyone plays optimally.[6] However, most of these rules become very complicated or cumbersome.[7]

One variant that seems reasonable is a hybrid between the English auction and the sealed-bid auction. Klemperer (1998) suggests that the reverse auction should start with open bidding, with the price falling until all but two bidders have dropped out. Then the two remaining vendors should each submit a "best-and-final" sealed-bid offer that is no higher than the last open bid. The winner is the vendor with the lowest bid, and that bid is the transaction price [10].

Auction information environments

A key feature in every auction is the bidders' information about the value of the auctioned item. That value may be known precisely to each bidder, or may be unknown, although some signals of the value are available to each bidder. The information structures influence bidding behavior and outcomes. Different types of auctions will aggregate these diverse bits of available, but privately held, information about the actual value of an item up for bid. This section describes the different information environments.

Economists typically model valuations as the result of draws from a random distribution. Thus, the information environment is characterized by how the draws affect the valuation, and how the draws of the different bidders are related.

Private values

The private value environment exists when each bidder's valuation of the auctioned item is known to himself, but each bidder does not

6. Intuitively, "optimal" play means that each bidder rationally bids in his own best interest. Technically, it means each bidder follows his dominant bidding strategy.

7. For example, one proposed auction design requires every bidder to submit a sealed "bidding schedule" of his bid responding to every other possible bid by other bidders [9]. Although the auction has desirable properties, it seems unlikely that vendors would be willing to participate in such a complex auction.

know the other bidders' valuations. Thus, in a private values environment, knowing other bidders' information does not affect any one bidder's valuation of the auctioned item. In other words, if a bidder knew all the private information that other bidders hold, his valuation of the auctioned item would not change (though the bidding strategy could change). With private values, the valuations are modeled as independent draws from continuous distributions [11].

A simple private value example might be an auction for a bottle of wine. Each bidder assesses the qualities of the specific vintage and has a personal valuation of those qualities. If each bidder's assessment and valuation do not depend on other bidders' quality assessments, then a private values environment exists. In a reverse auction context, a private values environment exists if a bidder's estimate of the cost of producing the item up for bid cannot be improved by knowing other bidders' information. This may hold when the product in the reverse auction is produced on a repetitive basis. The private values assumption is most likely to hold in forward auctions for nondurable consumer goods [11].

Common values

By contrast, a common values environment exists when one bidder's information is useful to another bidder. In the "pure common values" case, the value of the auctioned item is the same to each bidder, but each bidder's information about that value differs. If a bidder knew the information that the other bidders had, he could form a different, and presumably more accurate, valuation of the auctioned item.

Milgrom provides an example of a common values environment [12]. Suppose several painters are equally capable of doing a job at the same real cost of C. However, they each estimate the cost as $C+e$, where e is an error that is independent from painter to painter and has a mean of 0. The error e represents the over- or under-estimate of the time and materials that the job will require. The average of the bidders' estimates should then be accurate, but each bidder's valuation individually will be inaccurate. Thus, knowing the estimates of other bidders will allow any bidder to change his own valuation of the auctioned item. In this example, the valuations are the sum of a random draw *C* and the error term *e*. Even though the errors are independent, the valuations are correlated because of the common term *C*.

An **affiliated values** environment allows the valuation to depend on both a common element and a private element. An example might be a bid for a large, technically-demanding design project. In this case, there is a common value because the technical challenges and material costs are uncertain but would be the same for all bidders. However, there are also private values because the production process and the skills and wages of the engineers and production staff might differ. The affiliated values environment includes the pure common values and private values models as special cases.[8]

The winner's curse—a common values problem

The winner's curse is a problem associated with the common values environment. Suppose each bidder's estimate of the value is based on the imperfect signal that he receives, and the bidder submits that value as his bid. Then the winning bid will be the greatest overestimate of the item's value. Thus, the winning bidder is "cursed" by winning because he will over-pay for the auctioned item.

Knowledge of the winner's curse causes some bidders to alter their bidding strategies, which in turn affects the final outcome of the auction. One issue in conducting auctions is knowing how the auction rules affect the bidders' ability to avoid the winner's curse.

Symmetric and asymmetric bidders

A second important feature of the auction environment is the similarity between bidders. Bidders can be **symmetric**, meaning that the bidder's valuations and signals are drawn from the same distribution. The implication is that the bidders each treat a given set of information in the same manner, including the information they have gathered and the information from other bids [11]. Thus, bidding

8. The definition of affiliated values can be interpreted as "large values for some of the variables make other variables more likely to be large than small." The formal definition and interpretation of affiliated values are provided in [11].

strategies are the same; that is, given the same set of information, each bidder will bid the same. Alternatively, bidders can be **asymmetric**. In this case, the bidder's valuations are based on draws from different distributions, although the distributions themselves are common knowledge. Asymmetric bidders are fundamentally different. In a reverse auction, for example, the item up for bid might be related to an item already being produced by only one bidder. Having already established a production line, that bidder might be able to produce the new item for bid at lower cost. This creates an asymmetry—one firm has an advantage. Bidding strategies and auction outcomes depend on whether the bidders are symmetric or asymmetric.

Efficiency

An efficient auction mechanism has the property that, given optimal behavior by the participants, the winner is always the bidder with the highest valuation. Efficiency generally varies across auction types and depends on several characteristics of the underlying information environment. An auctioneer is not always interested in an efficient mechanism. In particular, in a procurement auction, the purchase-price-minimizing auction allocates the item to the bidder with the lowest marginal cost. This is not necessarily the bidder with the highest valuation [6]. Thus, efficiency is not our primary concern.

Theoretical results in the auctions literature

The auction theory literature dates to at least 1961, when William Vickrey published "Counterspeculation, Auctions, and Competitive Sealed Tenders" in the *Journal of Finance* [13].[9] Since the early 1980s, the field has expanded rapidly—the *Journal of Economic Literature* lists 25 articles on auctions published in major economics journals between May and September 2002 [14].

The results on the types of auctions that result in the best outcome for the auctioneer in different environments might be useful to the Navy when deciding which auction rules to use in a given setting.

9. Vickrey's contributions to theory of information economics were recognized with the 1996 Nobel Prize in Economics.

Though the magnitude of the difference has not been quantified in the literature, even a marginal price improvement from appropriately structuring an auction on a high value purchase could yield significant savings.

We summarize here only a small selection of the most applicable results. We will focus on the effects of different auction environments and rules on the transaction price.

Auctions with private values and symmetric bidders[10]

A single-item, private values auction with symmetric bidders is the easiest type of auction to analyze. In such an auction, the bidding strategies can be easily deduced. For example, in an English open auction, a dominant strategy is for a bidder to bid the minimum amount over anyone else until his valuation is reached, and then to drop out. Because all bidders will follow this strategy, the bidder with the highest valuation will win the auction with a bid that just exceeds the second highest valuation. Theoretically, we assume that "just exceeds" is negligible, so that the transaction price is the second highest valuation.

In a second-price, sealed-bid auction, the dominant strategy is for a bidder to bid his actual valuation. Because the transaction price when he wins is set by someone else's bid, he has no incentive to shade his bid. For example, suppose he bids his valuation. In this case, he either has the highest bid and wins, but pays less than his valuation, or someone else has the highest bid and he is just as well off as he was before. However, suppose he bids less than his valuation. Then he could lose the auction to someone else who bid more than he did, but still less than his actual value, so he is worse off than if he had bid his valuation. Bidding more than his valuation could mean he wins. If the second highest bid was below his valuation, the outcome (both winner and transaction price) is the same as if he had bid his valuation. However, if the second highest bid is more than his valuation, he wins but has to pay more than his value and he is worse off. Thus, the

10. The results in this summary can be found in numerous articles. They are nicely summarized in [11].

optimal bid for each bidder is the actual valuation. Given this strategy, the winning bidder is the one with the highest valuation, and the price is the second highest bidder's valuation.

Note that the outcomes of the first-price, open-bid auction and the second-price sealed-bid auction are the same. Given the restrictive assumptions of private values and symmetric bidders, the auctions are equivalent.

In the Dutch auction, the bidder must decide at what point he will stop the auction if no other bidder has claimed the item. In the first-price sealed-bid auction, the bidder faces the same decision problem—he must bid the value at which he is willing to claim the prize. The actual choice of the bid represents a tradeoff for the bidder between the probability of winning and the value of winning. In a reverse auction, bidding low makes it more likely that the bid is the lowest received and thus the winning value, but it also reduces the profit from winning. Conversely, a high bid means that the vendor is unlikely to win, but the profit from winning is very high. The bid is selected to maximize the expected payoff, considering both the probability and value of winning. Note, however, that the auctioneer obtains more information from nonwinning bidders (namely their bids) under the sealed-bid first-price auction than under the Dutch auction.

The **revenue equivalence theorem** is a significant result in the auctions literature. This theorem states that, given private values, risk-neutral symmetric bidders, and the same set of bidders' valuations, the expected winning bid in an English, first-price sealed-bid, second-price sealed-bid, or Dutch auction in a private-value, symmetric auction is the same. In other words, the optimal tradeoff between winning and the payoff to winning in the Dutch and first-price sealed-bid auctions results in the expected value of the winning bid being equal to the second highest bidder's valuation.[11]

11. Technically, the theorem requires that the auction rules result in an efficient outcome and that the bidder with the lowest possible valuation expects zero surplus, that is, he expects to be exactly as well off after the auction as before. The revenue equivalence theorem has multiple proofs. For readable summaries, see [6].

Auctions with affiliated values and symmetric bidders

Bidding strategies in auctions with affiliated values are much more complicated, because a bidder is uncertain of the value of the item being auctioned and other bids provide information about the signals that other bidders have observed. Thus, a bidder might adjust his valuation of an item as other bids are observed, and this adjustment leads to changes in bids. Because auction formats differ in how much information can be gathered and how that information can be used, more variation in outcomes can occur.

Milgrom and Weber established a number of relationships in the affiliated values environment that may pertain to the decisions regarding the use of auctions.[12] Their paper [11] demonstrates the following results for auctions in symmetric, affiliated values environments:

- From the auctioneer's perspective, the expected winning bid in the auction can be ranked from best to worst as
  - — Open-bid, first-price (English) auction
  - — Sealed-bid, second-price auction
  - — (Tie) sealed-bid, first-price auction and Dutch auction
- If the auctioneer has information, even imperfect information, about the valuation of the item, his best policy is to truthfully reveal it.

The intuition for the ranking of auctions is that the auction formats differ in how much information the bidders can infer from bids, and how much control the winning bidder has in setting the transaction price. The more the price depends on private information, the more the vendors will hedge their bids and bid a price above their cost. Thus, bidders most prefer, and auctioneers least prefer, the first-price, sealed-bid auction, because the final price is based on the winning bidder's price alone, and there is no additional information

12. The results incorporate the assumption of risk-neutrality among the bidders. Firms are generally assumed to be risk-neutral, so this assumption seems innocuous. For a review of experiments and theory related to risk-averse bidders, see [15].

from the auction to cause bidders to bid more aggressively. In the second-price auction, there is less hedging because the price depends on a second bidder's information, which will be correlated with the first bidder's valuation because the valuations are affiliated. In the English auction, the price depends on several bids as each bidder incorporates other bidders' actions as signals of their information, so that the price depends even less on private information [6, 12].

Auctions with private values and asymmetric bidders

Research in auctions with asymmetric bidders is close to the cutting edge in auction theory. Asymmetric bidders exist when it is common knowledge that the valuation distributions vary among bidders. Maskin and Riley have studied the outcomes when two different bidders are in the auctions [16]. They characterize the differences between the bidders as:

- The "strong" bidder's valuations are drawn from a distribution shifted to higher valuations, either by extending the upper limit on the valuations, or by shifting both the upper and lower limits to higher valuations.
- The "weak" and "strong" bidders' valuations are drawn from the same range of values, but the strong bidder is more likely to have high valuations.

They consider the sealed-bid, first-price, and English auction (which is equivalent to the sealed-bid, second-price auction) and derive the preferences of the types of bidders and the revenue-generating potential of the auctions. Table 2 summarizes the results.

Table 2. Summary of asymmetric auction revenue theory [16][a]

Result	Strong bidder valuation drawn from distribution with supports shifted or stretched to higher valuations than weak bidder's	Strong bidder valuation distribution drawn from distribution with same supports, but higher probabilities of higher valuations
Strong bidder's auction preference	English[b]	English
Weak bidder's auction preference	Sealed-bid, first-price	Sealed-bid, first-price
Auctioneer's preference	Sealed-bid, first-price	English

a. Assumes private values.
b. The English auction is also called an open auction, and is equivalent to a sealed-bid, second-price auction.

Klemperer offers a possible reason for this result. In a first-price auction, the optimal strategy is for a bidder whose value is drawn from the weaker distribution bids to bid closer to his actual valuation than the bidder who draws from a stronger distribution. Thus, the weak bidder has a higher probability of winning and prefers the sealed-bid, first-price auction to the English auction, which is won by the bidder with the higher distribution (and is thus favored by the strong bidder). The expected transaction price depends on how the asymmetry arises [6].

These results might help the Navy decide which type of auction to use in a given procurement. For example, if potential bidders for a given procurement all use the same production process, but one consistently achieves lower production costs, then the situation from the second column of table 2 exists—the strong bidder's valuation is from the same range, but the strong bidder is more likely to get the lower cost. In this case, the Navy would find an open-bid first-price auction preferable to the sealed-bid first-price auction. Conversely, if one bidder uses a different technology that is more likely to produce at a lower cost, the Navy would prefer the sealed-bid first-price auction. Though the magnitude of the difference was not quantified in the literature, even a marginal improvement from appropriately structuring an auction on a high-value purchase could yield significant savings.

Common values and asymmetric bidders

Results in common values and asymmetric bidders are not well developed, in part because the results depend on the particular specification of the asymmetry. It has been demonstrated that a small advantage in an almost common value auction (one where the private values are relatively small compared to the common value) can significantly tilt the auction toward the stronger bidder. This small advantage in the private value enables the bidder to bid a little more aggressively. Such a bid means that a weaker bidder who wins is more likely to suffer from a winner's curse, and thus the weaker bidder must hedge the bid a bit more [6]. Thus, even a small advantage can have a dramatic impact.

The effect of more bidders

Generally, more bidders are better for the auctioneer. In a private-values, symmetric environment, additional bidders will improve the price the auctioneer receives. Consider, for example, a sealed-bid, second-price procurement auction with private values. The dominant strategy is for each bidder to bid his own valuation. In a reverse auction, the additional vendor can bid above the second-lowest bid, between the lowest and second-lowest bid, or below the lowest bid. In the first case, the transaction price is not changed. In the second case, the transaction price is lower because the new second-lowest bid is below the old second-lowest bid. In the last case, the transaction price is also lower because the old lowest bid becomes the second-lowest bid. The additional bidder can only improve the price received by the auctioneer.

Bulow and Klemperer studied the effect of adding one bidder to an auction. They first establish that the optimal mechanism for the auctioneer in an affiliated-values environment is an English auction followed by a take-it-or-leave-it offer to the last remaining bidder. This ultimatum exploits the auctioneer's monopolist/monopsonist position. They then show that the expected price in such an auction is not as good for the auctioneer as an English auction with just one more bidder. Because the take-it-or-leave-it approach is optimal given a set number of bidders, this implies that any other rules the auctioneer can use to improve his expected price, such as reserve prices, are not as valuable as attracting an additional bidder [17]. Also, additional bidders reduce the potential for collusion.

Empirical results in the auctions literature

Auction formats and revenue

The empirical research of auctions is not as developed as the theoretical research. One recent paper reports the results of an experiment auctioning collectible cards on the Internet using different auction formats. The experiment involved selling matched sets of cards using the English and second-price, sealed-bid auctions, and another matched set of cards using both the Dutch and first-price, sealed-bid auctions. The experiments were performed twice, so that each of the auction formats would be first once. In the English and second-price experiment, the English auction had significantly higher revenue when it was second, and the second-price had statistically insignificant higher revenue when it was second. The pooled results found no statistical difference, controlling for order. Under symmetric private-values auctions, theory indicates that the revenue should be the same. Under symmetric affiliated-values auctions, English auctions should have higher revenue. Because the environment is not known, these results do not conclusively support or contradict theory.

The Dutch auctions were statistically significantly higher than the English auctions regardless of ordering. Under symmetric private-values or affiliated-values auctions, theory indicates that the Dutch auction and first-price auction should have the same revenue. Thus, the results contradict theory. However, the Dutch auction resulted in more bidder participation than did the first-price auction, possibly altering bidding results [18].

A study of Forest Service timber auctions found that English and first-price sealed-bid auctions did not result in statistically different revenues [19].

Effects of additional competition

Experimental results indicate that the number of bidders improves the transaction price for the auctioneer. A recent experimental study found that the number of bidders in first-price auctions led to better prices for the auctioneer [20]. Simulation results demonstrated that the magnitude of an additional bidder's effect declines as the number of bidders increases in both sealed-bid first and second-price auctions [21].

The effect of additional bidders improving the outcome for the auctioneer is well supported with empirical evidence. One analysis examined the effect of more bidders in bond auctions, oil lease auctions, and timer auctions. In every case, the auctioneer's price improved as the number of bidders increased. The auctions studied encompass both private-value and common-value examples, indicating that more competition is better in both environments. The effect of additional bidders is most pronounced at lower numbers of bidders. As the number of bidders increase, the additional impact decreases [22].

The effect of open-bid auctions: evidence from DIBBS

Our richest source of procurement auction data was the data we obtained from the Defense Supply Center Columbus (DSCC) Internet Bid Board System (DIBBS). In August 2000, DSCC converted a sealed-bid, first-price auction program into an open-bid, first-price auction program. This conversion was the result of a change in the Federal Acquisition Regulations and not related to any changes in the product markets or purchases.[13] This provides a convenient natural experiment that can be used to evaluate the price effects of conducting open auctions.

DIBBS auction history and rules

In August 1999, DSCC implemented an automated system for soliciting, evaluating, and selecting bids, called Procurement Automated Contract Evaluation (PACE). Procurements under $25,000 (the threshold was later raised to $100,000) that met the criteria for routine purchases were processed through PACE.[14] PACE solicitations are posted to DIBBS, and registered suppliers respond with their bids. Bidders can submit bids that deviate from the solicitation, but these bids will be considered only if the best bid does not meet solicitation criteria. When the solicitation closes, PACE discards bids that are not eligible for automated awards and evaluates the bids that are

13. For a summary of the legal issues, see [5].

14. Among the criteria that disqualify an item for a PACE purchase are items requiring first article inspection, critical safety items, high-priority purchases, and items using government-furnished material.

in accordance with the solicitation criteria.[15] The evaluation includes price adjustments for surplus materials and inspection at origin rather than destination, and applies a price-reasonableness algorithm to the lowest bid. If the lowest bid satisfies the price-reasonableness algorithm and final automated checks for contractor responsibility, the vendor is automatically selected, notified, and sent a contract. If the lowest resulting bid fails the algorithm or final checks, then PACE does not make a selection and a manual selection process is used. PACE does not apply best-value criteria, though these criteria may be used in the manual selection process. Essentially, PACE implemented and automated the sealed-bid, first-price auction for selected items.

In August 2000, DSCC modified the PACE program to conduct first-price, open-bid procurement auctions on DIBBS. These auctions modified the same procedures of the PACE procurements that had already been initiated. Specifically, they notified the vendors that the purchase would be an auction, and the vendors had to agree to let their bids be published, anonymously, on the DIBBS website. At the end of the bidding period, PACE applied the same evaluation and selection criteria.

This implementation of open-bid auctions resulted in a set of rules that differs significantly from those of most commercial auctions, including those used by the Navy and Army. DIBBS auctions typically last 14 days and have a firm closing time, whereas most Navy and Army auctions are initially restricted to as little as half an hour, although extensions are allowed if bids are received just before closing time.[16] For each auction, not only are price quotes published for DIBBS auctions, but other factors that affect price-related evaluation,

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15. Bids that are not eligible are alternate bids and bids with exceptions, which include deviations from the solicitation's item description, packaging, freight on-board or required quantity. However, quoting delivery that is different from the required delivery days or quoting origin inspection when the solicitation specifies destination inspection are not exceptions that make the bid ineligible. See DSCC Master Solicitation.

16. DIBBS auction start and end times are specified in the solicitation [23]. The effects of open-ended and fixed bidding periods has been studied by [24].

such as Buy American status, are published as well. DIBBS allows the submission of quotes that are higher than the minimum bid (thus, there is no minimum bid increment) and allows bids to be revised upward and to be withdrawn. The possibility that PACE will reject the lowest bid and revert to a manual vender selection process that may involve best value criteria, rather than the lowest evaluated price criterion, encourages bidders to submit bids above the lowest bid.

DSCC has limited DIBBS auctions primarily to Federal Stock Classes 2530 (vehicle brake, steering, and wheel parts) and 5961 (semiconductors and related equipment). In September and October 2000, two additional FSCs—4730 (fittings for hoses, pipes, tube, lubrication, and railings) and 5930 (switches)—were included in the reverse auctions. DSCC stopped reverse auctions on these items because the cumulative demands on the computer systems were overtaxing the systems. The FSCs were selected because DSCC thought that they had promise for reasonable returns from implementing auctions, though they did not inform us of any specific studies that indicated these FSCs would have abnormally high returns. Within theses FSCs, any item that meets the criteria for a PACE award is issued as an auction solicitation.

In October 2000, DSCC further modified its automated procurement system by implementing a fast award feature for purchases below $2500. In a fast purchase, bids are evaluated each day, and the first bid that meets price reasonableness criteria is selected. Thus, the closing date for the item is not fixed. Fast bids are not publicly displayed.

DIBBS auction data

The DIBBS auction data used in this analysis consist of the results of the sealed-bid and open-bid auctions conducted from inception in 1999 through August 8, 2002. The sealed-bid data consist of 2,019 contracts for 1,090 items totaling $11.0 million.[17] The open-bid data

17. An item is defined by a National Stock Number (NSN). The value of the awards has been adjusted to January 2002 values using the Bureau of Labor Statistics' Producer Price Index (PPI) for all manufacturing industries (Series PCUOMFG#). The number of auctions in our data set is fewer than the actual number conducted because we omit auctions that reverted to the manual selection process.

consist of 3,345 contracts for 2,413 different items, totaling $26.8 million in awards.[18] In addition to price and quantity, each participating vendor's final bid and the date of that final bid are available. The DIBBS data include not only the purchases made using reverse auctions, but also purchases made using conventional procurement practices both before and after auctioning and the PACE awards made before auctions were implemented. These awards provide a valuable data set for investigating the price effects of reverse auctioning.

Conventional procurements in the FSCs selected for auctions occurred when one of the criteria for an automated purchase did not hold. Thus, some NSNs would never be auctioned—critical safety items, for example. Some NSNs were purchased using either auctions, conventional procurements, or fast purchases, depending on the circumstances of the purchase. Unfortunately, the data do not reveal the circumstances of the purchase. However, the only criteria that would normally change for an item that was once auctioned would be the priority of the item or the cost of the purchase. Thus, if high-priority purchases include a price premium, comparisons of conventional purchases with auction purchases would lead to an overstatement of auction savings. This would apply to both conventional purchases made once auctions were initiated and to conventional purchases made before the auctions were initiated because the purchases include an unknown mix of both high-priority and routine purchases. However, PACE purchases before the implementation of open auctions applied the same criteria to the purchases that are applied to the auction. Thus, comparisons of prices resulting from PACE sealed-bid purchases and PACE open-bid auction purchases provide an estimate of the effect of using open auctions.

Table 3 provides summary statistics on the number and value of DIBBS reverse auctions, both for sealed- and open-bid auctions. Sample sizes for both types of reverse auctions are relatively large, enabling statistical analysis. FSCs 4730 and 5930 have smaller auction

18. For this analysis, we omit 1,002 open-bid observations where the bids did not meet the PACE pricing algorithm and were awarded manually. This provides a comparable data set to the sealed-bid data, where we can only tell whether the item was automatically awarded.

samples because they were used less frequently. Table 4 provides summary statistics on prices and quantities in PACE open-bid auctions and PACE closed-bid auctions. The similarity in mean and median quantities and values suggests that the two samples are comparable. Both the open- and sealed-bid auctions have a large amount of variation in price and quantity. This variation reflects the diversity of items within the sample, which includes diodes and brake sets.

Table 3. DIBBS auctions: number and value of awards

		PACE open-bid auctions[a]		PACE sealed-bid auctions	
	FSC	Number of awards	Total value of awards ($ million)	Number of awards	Total value of awards ($ million)
2530	Brake, steering, axle, and wheel components	1,592	10.3	614	3.2
4730	Hose, pipe, tube, lube, and railing fittings	613	1.6	752	3.8
5930	Switches	299	1.2	436	2.9
5961	Semiconductor devices and associated hardware	841	3.7	217	1.1
	Total	3,345	16.8	2,019	11.0

a. Some auctions fail the PACE evaluation criteria and are awarded after buyer intervention. To maintain comparable data, we omitted these auctions from the table.

Table 4. Summary statistics on DIBBS auctions

	PACE open-bid auctions	PACE sealed-bid auctions
Mean value of award	5,017	5,464
Mean quantity	201	276
St dev quantity	1,180	2,388
Mean price	318	292
St dev price	882	562
Median value of awards	3,192	4,269
Median quantity	31	34
Median price	90	122

The auctions also vary widely in the number of vendors they attract. Table 5 gives a breakdown of the number of bidders that participated in open-bid auction. The median number of bidders is 5 and the maximum is 30.

Table 5. Number of bidders in open-bid auctions

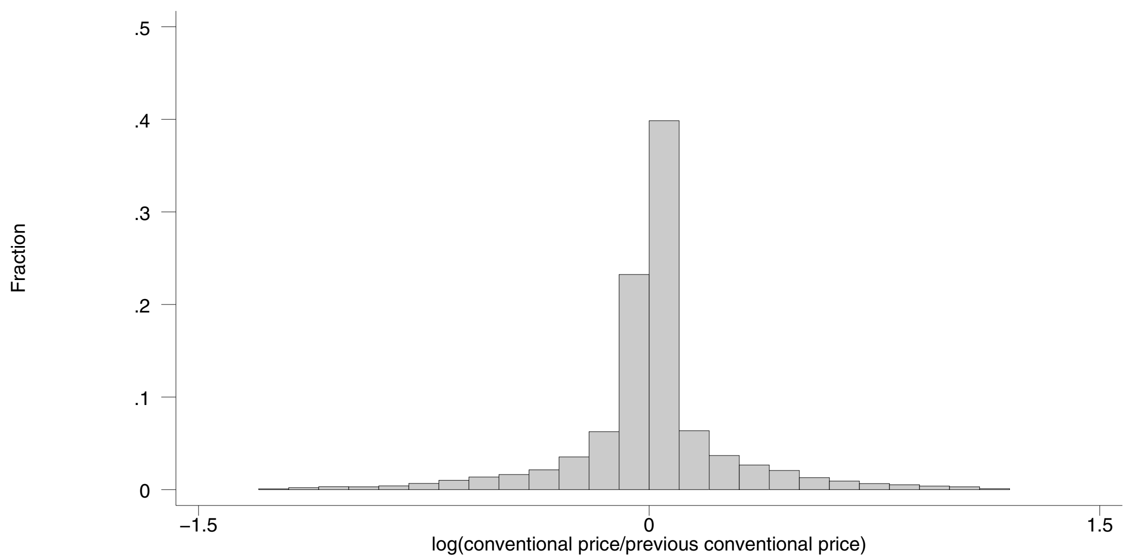
Number of bidders	Number of open-bid PACE auctions
1	294
2	370
3	360
4	375
5	330
6	309
7	266
8	228
9	205
10	137
11	124
12	81
13	66
14	63
15 or more	137

Analysis of DIBBS auction results

DIBBS auction savings: simple comparisons

The DIBBS data reveal purchase prices through a sequence of procurement practices. A simple estimate of the savings compares the unit price received using one purchase practice with the last price paid under a different purchase practice for the same good. If the procurement technique changed from one purchase to another, the change in price provides a crude estimate of the effect of changing practices. However, prices are quite volatile even without a change in purchasing practices. Figure 1 illustrates the ratio of the price of an NSN to the previous purchase of that NSN for all NSNs in our data with conventional purchases from 1996 until PACE was implemented in August 1999. For convenience, we convert the ratio to the natural log of the ratio.[19] If the price is constant, the log of the ratio is zero; if the newer price is lower than the earlier price, the log of the ratio is negative. The conventional purchases were made by a buyer who should apply a best-value criterion. These data do not distinguish between high-priority and routine purchases. We also note that these histograms do not control for quantities, which might have a significant effect on prices. Note that there is a wide spread in ratios. However, the average of the log of the ratio is 0.0027, or an increase of about one-quarter of 1 percent above inflation.[20]

Figure 1. Histogram of log of ratio of prices in consecutive conventional purchases of the same NSN in selected FSCs, 1996–1999



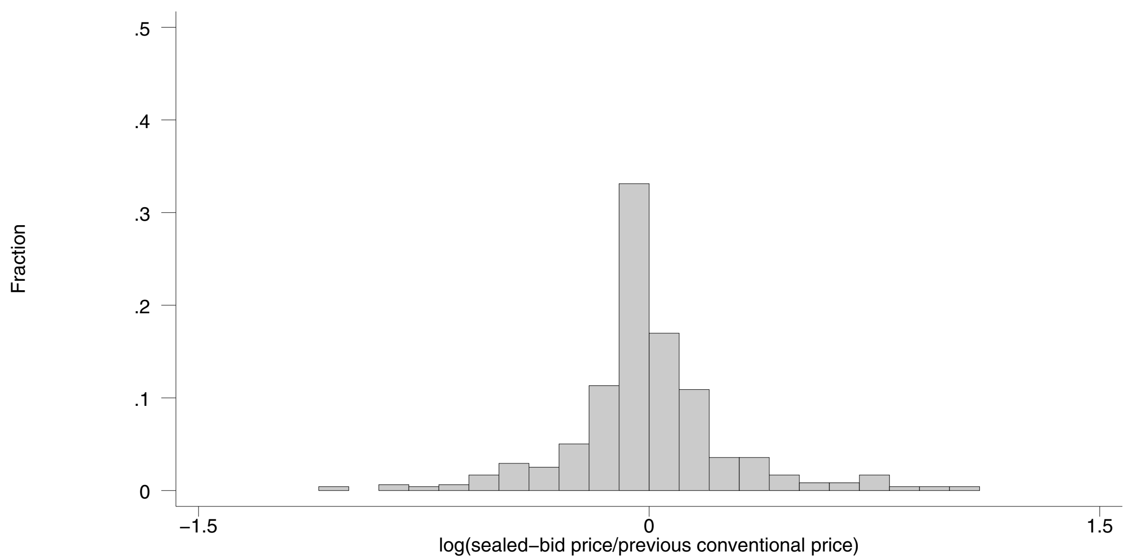
In figure 2, we present the distribution of the ratios of the price in the first PACE sealed-bid auction with the preceding conventional

19. We use the natural logarithm to make a doubling in price comparable graphically to halving the price. A negative number in the graph indicates a decrease in price. For ratios near 1, the log of the ratio is roughly equal to the percent change in price.

20. We trimmed outliers for the histograms by omitting the largest 1 percent and smallest 1 percent of observations in each price ratio. We also inflated all prices to constant January 2002 dollars using the PPI.

purchase for that NSN. The distribution is somewhat different. The weight of the distribution is below zero, with a median of -0.005. This suggests that the use of PACE, which is a rigorous first-price, sealed-bid auction, led to slightly lower prices. However, there are also a large number of significant increases.

Figure 2. Histogram of the log of the ratio of sealed-bid auction price to previous conventional purchase price of the same NSN in selected FSCs



Similarly, DSCC transitioned from PACE awards, which are sealed-bid auctions, to open-bid reverse auctions for the given FSCs. The log of the ratio of the first open-bid auction price to the previous sealed-bid auction price is shown in figure 3. This distribution is much tighter than the previous two, but it is still more heavily weighted toward the negative side, with a mean of -0.057. This also suggests that open bidding was associated with an overall decrease in prices from sealed bidding. In both the sealed-bid and open-bid cases, however, price increased in numerous instances.[21]

21. Additional distributions of possible interest are provided in an appendix. In particular, we provide comparisons of the price from purchase to purchase within a procurement practice. The interesting result is that sealed bidding has the smallest variation in price changes between consecutive purchases.

Figure 3. Histogram of the log of ratio of the open-bid auction price to previous sealed-bid auction price of the same NSN in selected FSCs

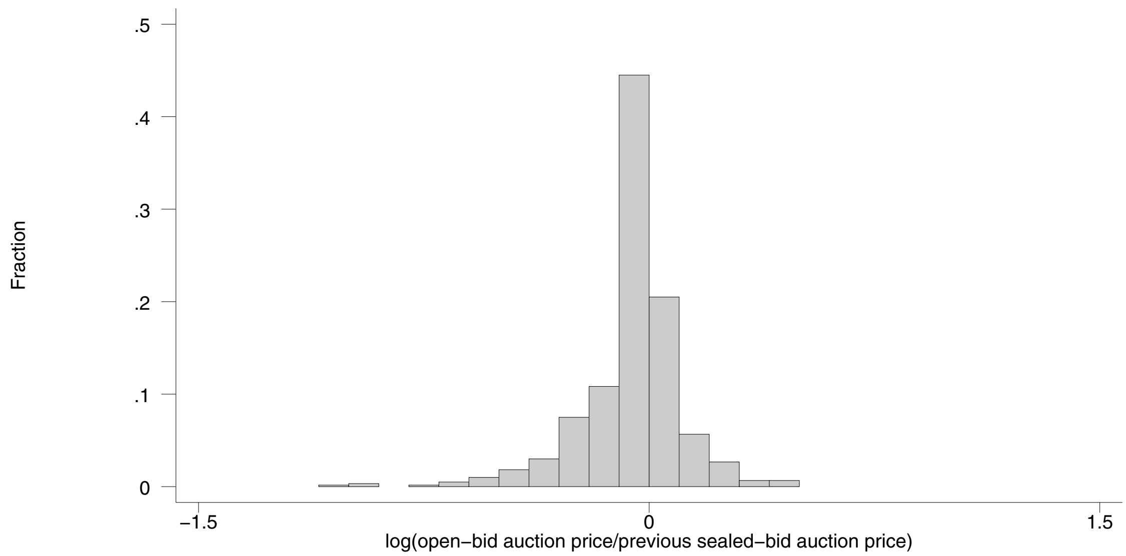


Table 6 lists the number of observations, means, standard deviations, and medians for each of these distributions.

Table 6. Summary statistics of purchase-to-purchase price ratios

Log of	Observations	Mean	SD	Median
Conventional/previous conventional	5942	.0027	.265	0.000
Purchase first sealed-bid PACE/previous conventional	477	-.005	.272	-0.027
Open-bid PACE auction/sealed-bid PACE auction	600	-.059	.169	-0.029

Open-bid auction savings relative to sealed-bid

The histograms in figures 1, 2, and 3 suggest that reverse auctions can reduce the purchase prices. However, the histograms fail to incorporate several significant features of the purchase. In particular, they do not consider the quantity purchased, and they do not consider potential price trends beyond the PPI. In addition, they do not consider the potential effects of the price-reasonableness algorithm in determining whether an item was a PACE or a manual purchase, and thus the effects on the savings estimates. In this section, we ignore the potential selection effects, and incorporate quantity and time trend effects by estimating an econometric model of how the purchase price is associated with different auction mechanisms.

We estimate the effect of reverse auctions on prices by modeling price as a function of the quantity purchased, the use of a reverse auction, and time (to control for time trends in price not captured by the PPI). Specifically, we estimate the equation

$$\ln(p_{it}) = \beta_0 + \beta_1 \ln(q_{it}) + \beta_2 1_{RA} + \beta_3 1_{FAST} + \beta_4 t + \beta_5 t^2 + v_i + e_{it}$$

where p_{it} is the real price of good i at time t, q_{it} is the quantity of good i purchased at time t, v_i is a fixed effect for each NSN, 1_{RA} is an indicator equal to one when a reverse auction was used for the purchase and zero otherwise, 1_{FAST} is an indicator equal to one when a fast PACE procedure was used for the purchase and zero otherwise, and e_{it} is an error term. By using this log specification, the coefficient on the reverse auction indicator can be interpreted as the percent price change resulting from a change in the variable. Using the fixed effect term v_i controls for the average price of each product. This assumes that the quantity discount and the effect of time are the same on all prices.[22]

We estimate this equation on the sample of PACE purchases. This restricts us to a sample of 2,668 different NSNs, covering 6,464 open-bid and sealed-bid auctions. We restrict the sample to these purchases because it captures most completely the natural experiment. The only change in the procurement practice is that open bidding was employed in place of sealed bids. By restricting the choice to PACE purchases, we omit data from both the PACE period and the auction period where the item either did not qualify for PACE initially, or the bids did not satisfy the PACE post-bidding criteria. We can distinguish between the two in the open-bid auction data but not in the sealed-bid auction data.[23]

The results of estimating this equation are listed in column 1 of table 7.[24] The effect of switching from sealed bids to open bids was to lower prices by a statistically significant 3.8 percent. The regression also indicates that a 1-percent increase in the quantity purchased decreases the unit price by .2 percent. The time trend variables are insignificant. This is not surprising because the model assumes that the price trend is the same for the four FSCs in the sample. Because the FSCs represent very different classes of products, allowing price trends to vary within an FSC might be more reasonable. Column 2 of table 7 presents estimates with a separate quadratic time trend for each FSC. These time trends are significant for each of the FSCs. The estimated effect of the reverse auction is to decrease prices by a statistically significant 4.4 percent.

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22. This model incorporates quantity as an independent explanatory variable. Although quantity and price are endogenous in many settings, which would make the hypothesized model inappropriate, in the DIBBS environment, the quantity is exogenous. Two mechanisms generate the decision to buy an item, and the quantity of that item. If the item is for DSCC stock, the decision is generated by an algorithm that incorporates the stocking level desired and the consumption rate, but not the current expected price.

    If the item is for a specific customer, the customer provides the quantity. Several reasons make it unlikely that a DSCC customer's choice of quantity is influenced by price. First, the quantity must be specified before the transaction price is known; thus, buying additional quantities given a low bid is not possible. Second, because the customer by definition is not a buyer in the market—that is DSCC's role—the customer may be unaware of market price movements. Third, the time it takes to complete an auction (from initial interest to purchase) is sufficiently long that customers would not be able to take advantage of short-lived price drops. Fourth, the customer's cost of having surplus inventory due to over-buying may be greater than the value of the marginal savings from buying more when price is low. Fifth, because DSCC is a working-capital-fund activity, the price paid to DSCC by the customer is fixed for the current budget cycle, so the customer's immediate price and budget do not benefit from a lower auction price. Sixth, the risk of equipment downtime associated with delaying spare parts purchases until prices fall may be greater than the value of marginal savings.

23. An alternative restriction is to limit the data only to those NSNs that had both a PACE sealed-bid and a PACE open-bid auction. This restricts the sample to 3,489 purchases in 933 NSNs. The results are very similar. We use the larger sample size because it utilizes more information on the quantity discount and time trends.

24. Again, the price data are inflated using the PPI to January 2002 dollars.

Table 7. Fixed-effects estimates of open-bid auctions, compared to sealed-bid auctions[a]

Dependent variable	(1) logprice	(2) logprice (adds FSC time trend)	(3) logprice (adds number of bidders terms)	(4) logprice (adds term for multiple auctions)
Ln(quantity)	-0.197	-0.196	-0.194	-0.196
	(34.91)**	(34.70)**	(34.46)**	(34.70)**
Open-bid auction indicator	-0.038	-0.044	0.034	-0.045
	(3.90)**	(4.33)**	(1.91)	(4.34)**
Award date	0.000	0.015	0.014	0.015
	(0.06)	(4.17)**	(3.93)**	(4.20)**
Award date squared	-0.000	-0.000	-0.000	-0.000
	(0.05)	(4.19)**	(3.94)**	(4.22)**
Fast purchase	-0.142	-0.137	-0.136	-0.137
	(10.11)**	(9.70)**	(9.64)**	(9.68)**
Number of bids			-0.019	
			(4.66)**	
Number of bids squared			0.001	
			(3.30)**	
Fifth or greater auction for NSN				0.025
				(0.74)
Constant	4.228	-4.680	-3.327	-5.639
	(0.37)	(0.41)	(0.29)	(0.49)
Includes FSC specific time trends[b]	no	yes	yes	yes
Number of observations	6,464	6,464	6,464	6,464
Number of NSNs	2,668	2,668	2,668	2,668
R-squared	0.27	0.28	0.29	0.28

a. Absolute value of *t*-statistics in parentheses. * Significant at 5 percent; ** Significant at 1 percent
b. These coefficients are reported in the appendix.

Open-bid auctions allow bidders to infer information from other firms' bids. Thus, final bids are not based solely on the bidder's private information, but also on information that other bidders have. This means that unusually low bids are less likely in open auctions—firms that would have made such a bid are likely to adjust their bid after observing others bid. Further, an open-bid auction that appears likely to go to an unusually high bid may draw additional interest from another firm. This suggests that the resulting open-auction winning bids should have a tighter distribution than those in sealed-bid auctions. The data support this observation. Figure 4 plots the smoothed residuals of the estimation of column 2 above. The residuals of the winning bid represent a relative deviation from an expected price given the auction mechanism, product, quantity, and date. The sealed-bid auction data have a broader distribution than do the open-bid auction residuals.

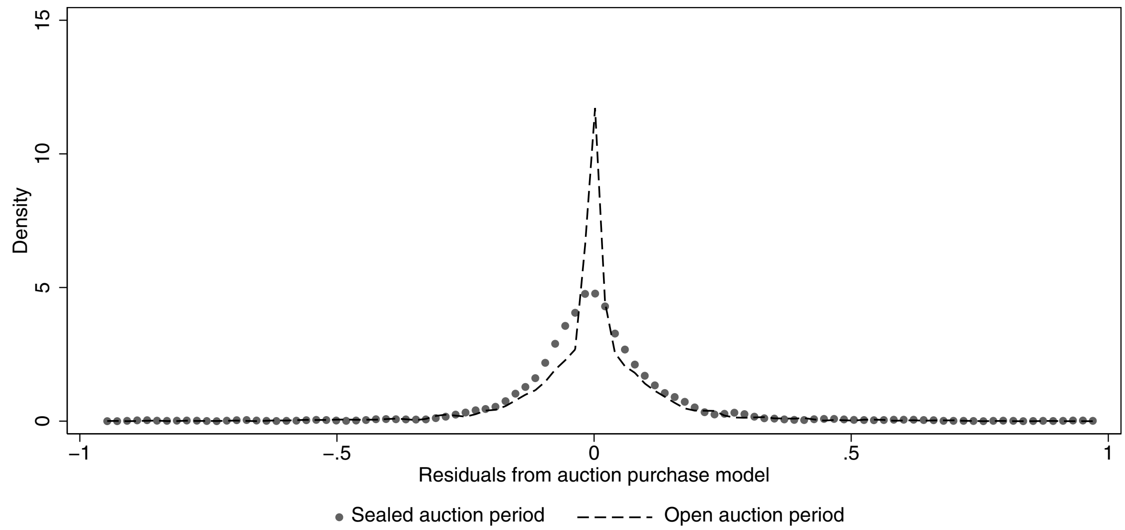
Investigating potential sample selection issues

As we noted previously, the above estimated effect ignores potential sample selection issues. Sample selection occurs when characteristics that might affect the outcome variable of interest are used to determine whether an observation is included or excluded in a sample. The resulting problem is that the sample includes only observations where the results are likely to be higher or lower than would be expected for a random observation.[25] This difference in the selection process can lead to an over- or under-estimate in the savings associated with open-bid auctions. In this section, we investigate the potential for selection bias problems. [26]

25. Sample selection problems are common in econometric studies, and several techniques have been developed to address the problem. The most prominent are the Heckman sample selection model and, more recently, semiparametric sample selection models. However, these models use an auxiliary regression of the probability of selection into the sample. This requires variables that affect selection but not the outcome of interest. Unfortunately, such information that is exogenous to our model is unavailable. Thus, we approach the problem by examining the actual data.

26. If selection bias exists, theory does not indicate whether it leads to over- or under-estimates of the savings. We discuss the possible potential bias effects in the appendix.

Figure 4. Distribution of residuals from the auction purchase model



Possible selection bias source

DIBBS applies a selection process to determine whether an item is an automated auction or a manual procurement—the procurement and bids must satisfy several criteria. The estimated open-bid auction effect is therefore the effect given that the criteria are met. The selection process only introduces a bias in the estimate if it affects the open- and sealed-bid auction samples differently. In other words, if the selection rule resulted in a purchase in the open-bid auction period being selected into the automated/manual sample the same as it would have been in the sealed-bid period, then a bias is not introduced.

We examined the reasons that items are selected out of the automated procurement. During the open-auction period, we can separate the data into different groups:

- Purchases that were auctions. These are procurements where all the criteria, both pre-bidding and post-bidding, for an auction purchase were satisfied. In the open-auction period for these FSCs, this is 3,345 procurements or 50 percent of the open-auction period purchases. In the sealed-auction period, this is 2,019 procurements, or 34 percent of the purchases.

- Purchases that were not auction candidates. These are procurements where the initial criteria precluded an auction. Examples are high-priority purchases and long-term contracts. These criteria did not change when the purchases changed between sealed- and open-bid auctions. These criteria do not introduce selection bias, because the selection is made exogenous to the process that determines the price. In the open-auction period, this is 1,984 procurements, or 29 percent of the open-auction period purchases.

- Purchases that were auction candidates but became manual purchases. These are the procurements where the bid or bidder criteria were not satisfied. Examples are that the low bidder did not meet contractor responsibility criteria (and was thus reviewed by a buyer), or that the low bid did not meet a price reasonableness criterion. The second of these particularly has the potential to introduce selection bias. Ideally, we could adjust the estimates to reflect this censoring. However, the censoring point moves over time in ways that are not directly observable by us. In the open-auction period, this is 795 procurements, or 12 percent of the open-auction period purchases.

The proportions of observations in these categories are provided in table 8. In addition, we have the proportions of observations from the sealed-bid period that are in parallel categories. About 50 percent of the open-auction period procurements were auctions, whereas about 34 percent of the sealed- auction period procurements were auctions.

Table 8. Purchase mechanism by period

Open-auction period			Sealed-auction period		
	Number	Percent		Number	Percent
PACE auction	3,345	50	PACE auction	2,019	34
Initially auction, but converted to manual	795	12	Manual (either converted during Auction, or not candidate)	3,059	56
Not auction candidate	1,984	29			
Fast purchases	578	9	Fast purchases	522	10

These numbers only indicate that the auction/manual mix was somewhat different between these two time regimes. In itself, it presents little evidence that selection bias is a problem.

Examining the data for selection bias

To examine whether the excluded purchases changed significantly between the open- and sealed-auction periods, we examine the residuals from a regression of the excluded purchases. We obtain the residuals from the regression

$$\ln(p_{it}) = \beta_0 + \beta_1 \ln(q_{it}) + \beta_2 t + \beta_3 t^2 + \Sigma_j\left((\gamma_j 1_{FSC_i = j} t) + \delta_j 1_{FSC_i = j} t^2\right) + v_i + e_{it}$$

where the summation is taken over the four different FSCs in the sample, and $1_{FSC_i = j}$ is an indicator that the NSN for purchase i belongs to the FSC j. This regression assumes that the underlying price distribution of the manual purchases in the sealed- and open-auction periods is the same, given the quantity, time-trend effects, and products. We note that two FSCs had very short open-auction periods, and then reverted to sealed auctions. This results in time trends that do not proxy the effects of switching auction types. This regression is similar to the regression used for column 2 of table 7. The difference is that in this regression, we only use the subsample of manual purchases, and we omit the explanatory variable for open auctions.

After controlling for these effects in a regression of the manual purchases during the sealed- and open-auction periods, we examine the residuals by the different types of auctions that would have been used if the purchase had qualified for an auction purchase. If the residuals of the open-auction period are different from those of the sealed-auction period, it would suggest that the process that led to manual purchases during the open-auction period affected the purchases differently than did the process in the sealed-auction period, and a selection bias was introduced. Conversely, if the residuals are similar, it is less likely that such a bias was introduced.

We present several alternatives to evaluate the data for selection bias:

- Graphical evidence. Obvious differences in the distributions can be observed by simple examination of the distribution of the errors. We present the distribution using histograms in figure 5.[27] The histograms are similar but not identical. The open-auction period manual purchases have a higher peak in the density near zero. An alternative visual representation is a non-parametrically smoothed plot of the density, presented in figure 6. This shows the densities of the residuals from the two periods in a single plot. These plots suggest that the subsamples are similar but not identical. They do not indicate whether the observed differences are due to random variation or fundamental differences.

- Statistical tests of the distributions.

  — A test of the equality of the medians of the two subsamples is one approach. The test statistic on the trimmed data has a p-value of .907. Without trimming, the test statistic has a p-value of .768.[28] The median test suggests that the subsamples were drawn from distributions with the same median. A t-test of the equality of the means on the trimmed data has a test statistic of 1.9374, which has a p-value of .0527. This rejects equality but not at a stringent significance level. The untrimmed data test statistic is .8042, which has a p-value of .4213, and thus does not reject equality.

  — The Wilcoxon rank-sum test of whether the two samples are from the same distribution is an alternative approach. This test statistic also does not reject the hypothesis that the samples are from the same distribution; the p-value of the test statistic is .6306. Without trimming, the Wilcoxon rank-sum test has a p-value of .8495. This test evaluates only whether a disproportionate number of the observations from a

27. These plots trim residuals with absolute value greater than 1, reducing the sample size from 5,837 to 5,772 observations. We trim the residuals to improve the visibility of the plots in the area where the data are concentrated.

28. Trimming reduces the variance of the residuals, thus providing stricter tests of equality.

Figure 5. Comparison of residuals from the manual purchase model in open- and sealed-auction periods

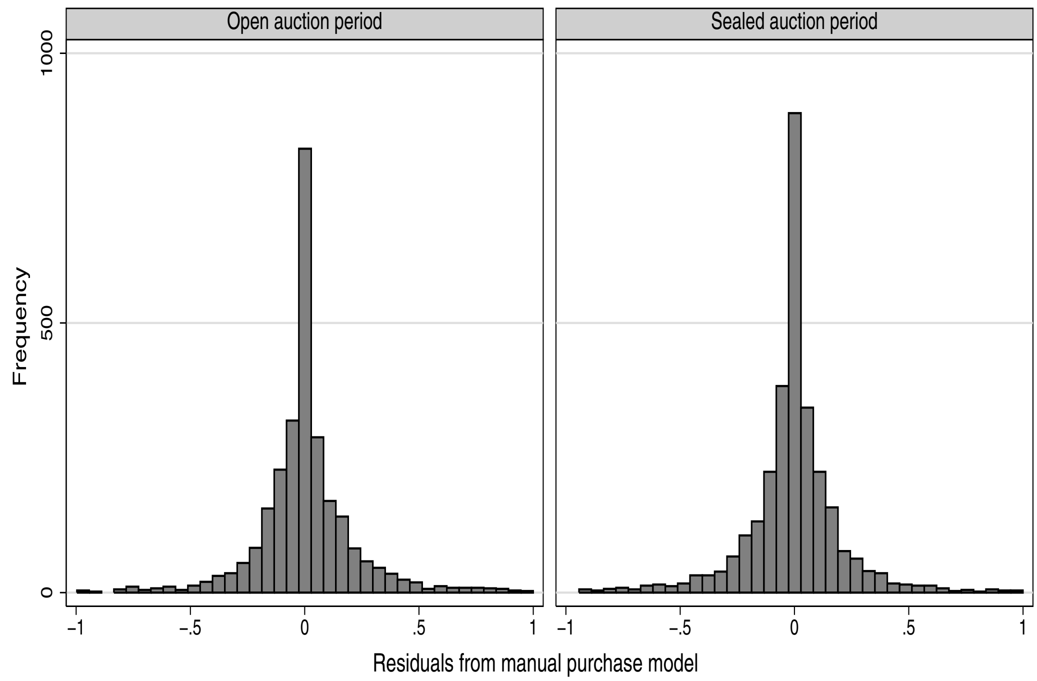
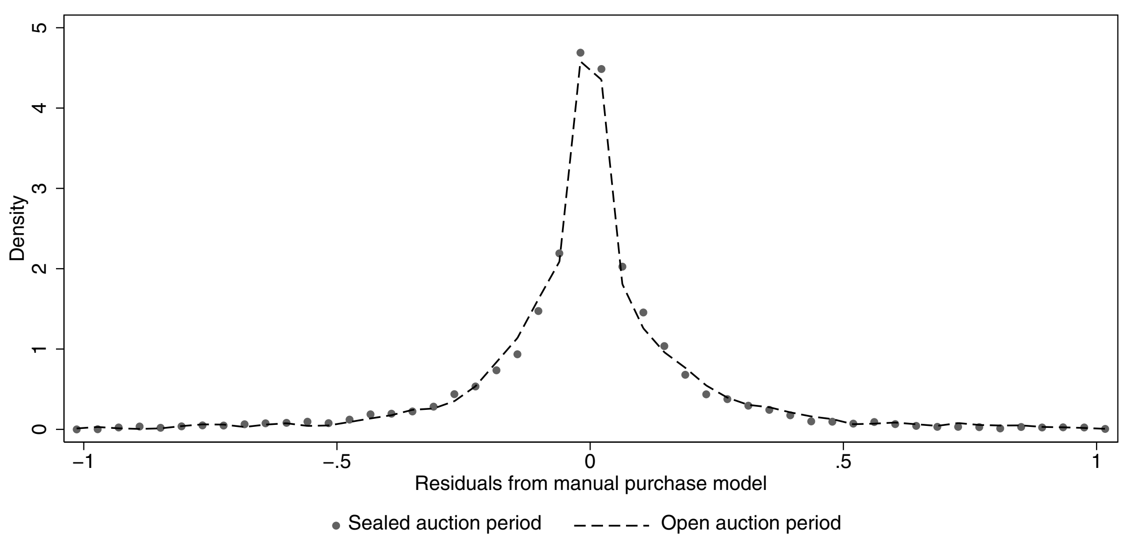


Figure 6. Smoothed density plot of residuals from the manual purchase model



subsample are larger than the other sample; the magnitude of a difference does not influence the test.

— A Kolmogorov-Smirnov test of equality of distributions has a p-value of .232. Without trimming, the Kolmogorov-Smirnov test has a p-value of .347. Thus, the Kolmogorov-Smirnov test does not reject the hypothesis that the distributions are the same. This test is based on the maximum of the differences between the two distribution functions; it is powerful against "lumpiness" or "clustering" of the data, but not against tails [25].

— Finally, in 1996 Li proposed a test of the closeness of the distributions of samples drawn from two unknown distribution functions [26]. The test is essentially the normalized square of the area between two smoothed distribution curves, such as those in figure 6. Thus, it incorporates both how often the curves differ and how big this difference is. The Li test rejects the hypothesis of equal distributions.[29] Given our sample size (about 3,000 observations for both subsamples), it may be that we find statistical significance, though the differences are not economically significant. With large sample sizes, the differences at the peak and in the neighborhoods of .1 and -.1 might lead to a conclusion that the distributions differ, though the amount of the difference might be inconsequential.[30]

Nevertheless, the rejection suggests caution should be used in interpreting the estimated savings from open-bid auctions, because of the possibility of sample selection bias.

29. The test statistic is 6.1, which rejects the hypothesis of same distributions at the .01 significance level.

30. This would be analogous to saying that an item priced at $100.01 is more than an item priced at $100.00. We can say with certainty that the former is more expensive, but that the magnitude is inconsequential.

DIBBS auction savings: number of bidders effects

The results in columns 1 and 2 of table 7 represent the average outcomes for the open-bid reverse auctions. However, the number of bidders may affect the degree of price competition and thus influence the price dynamics in the auction, particularly in DIBBS auctions where there is no minimum number of bidders and bidders can increase their prices later. To investigate these effects, we include the number of bidders and the number of bidders squared in the regression. We include the quadratic term because the effect of an additional bidder is likely to decrease as the number of bidders increases. (For example, significant price reductions might be associated with going from 1 to 2 bidders, but little change might be associated with going from 10 to 11 bidders.)[31]

Column 3 lists the results of the regression with the number of bidders included. The coefficient on the number of bids is negative and significant, whereas the coefficient on the number of bids squared is positive and significant, while the coefficient on the indicator for auctions is positive. The coefficients imply that an auction with only one bidder will result in an increase of about 1.7 percent from the price in a sealed-bid auction. This result may be biased because the PACE program applies a price reasonableness criterion to the bids. In fact,

31. In general, the equilibrium number of bidders can be influenced by the auction format. In particular, if it's true that the expected price is lower in open-bid auctions (for the same number of bidders), this means expected profit is lower in open-bid auctions. If we allow the number of bidders to adjust, we'd expect more bidders under the sealed-bid format (enough to achieve equality in expected prices between the two auction formats).

    Our analysis assumes the number of bidders is exogenous. (Because we do not observe the number of bidders in the sealed-bid DIBBS auctions, we are unable to test this assumption empirically.) In the DIBBS context, the bidders never know the exact number of other bidders in any given auction (sealed or open). Instead, it is likely they know the number of potential competitors in the marketplace and may reasonably assume they will all be potential bidders, regardless of the auction format, especially because the cost to participate is almost negligible.

42 percent of the auctions with one bidder failed the PACE screening. Thus, the price increase in an open-bid auction is likely to be more than the model estimates. Adding a second bidder suggests that the price is about the same as in a sealed-bid auction, and additional bidders lead to reduced prices. At five bidders (the median number of bidders), savings are about 4.1 percent. The coefficients imply that savings continue to increase through 13 bidders and then begin to decline, but because we have relatively few auctions with more than 12 bidders and we use a quadratic specification, the predicted effect of very large numbers of bidders is unreliable. These results suggest that reverse auctions are best applied when the auction will generate a fair amount of interest from potential suppliers.

Other effects of DIBBS auctions

Effect on competition and supplier base

One frequently cited concern is that auctions might provide savings in the short run as firms compete for business, but that the competition could lead to a reduced supplier base, and ultimately to higher prices as competition wanes. To investigate this possibility, we included an indicator variable for open-bid auctions for NSNs that had five or more open-bid auctions. The result is in column 4 of table 7.

This variable was insignificant. This means that the repeated auction had not caused prices to increase. Our data cover only about 2 years of open-bid auctions, so if the shakeout effects take longer than 2 years, we would not see them.

Sealed-bid auction savings relative to conventional purchase

In addition to the effect of moving from sealed bids to open bids, we can indirectly estimate the effect of moving from conventional purchases to sealed-bid auctions. Our estimate of the effect of the open-bid auction relative to the sealed-bid auction relies on open- and sealed-bid period samples that have roughly the same selection criteria. We cannot create a set of conventional purchases prior to the introduction of the PACE program as a control group. The problem is that there is nothing in the data to indicate which purchases prior to PACE introduction would have passed the PACE criteria, and thus would have allowed a comparison.

Instead, we infer the sealed-bid effect using a regression that includes the entire data set—conventional, sealed-bid, and open-bid purchases. Table 9 provides the key results from this pooled regression. The regression indicates that the average purchase price, controlling for quantity and time trends, during the sealed-auction period was about .4 percent lower than before PACE was introduced. Note that this average includes both the auction purchases and those that did not meet the PACE criteria, for example high-priority or critical safety items. The regression also indicates that the average purchase price during the sealed-auction period was about 3 percent below the prices realized before PACE.

Table 9. Regression results, pooling manual and automated purchases[a]

Dependent variable	ln(price)
ln(quantity)	-0.160 (77.54)**
Sealed-bid auction period	-0.004 (0.37)
Open-bid auction period	-0.031 (2.45)**

a. Regression includes time, time-squared, and FSC-specific time trends.

Assuming that these differences were due to the use of the sealed- and open-bid auctions on a subset of purchases, and that the other purchases (after controlling for quantity, item, and time trends) had the same prices, we can infer an overall effect. During the sealed-bid period, 34 percent of the purchases were auction purchases. To have a .4 percent effect on the average sealed-bid period price requires the subsample of sealed-bid purchases to have a 1.2-percent effect. That is, if 34 percent of the purchase prices fell by 1.2 percent, the effect on the average prices would be .4 percent. Similarly, during the open-bid period, 49 percent of the purchases were auction purchases. A 3.1-percent average decline during the period requires a 6.3-percent decline in the auction subsample. Note that the difference between the sealed- and open-period purchases is 5.1 percent, which is reasonably close to the 4.4 percent we estimated directly.

A sealed-bid auction effect of 1.2 percent is relatively small. This is likely because the conventional purchase process is very similar to a sealed-bid auction. In a conventional purchase, vendors submit bids, which are then evaluated on the basis of price and other factors. If price is the dominant factor (as it likely is in the commodity purchases in this sample), a modest sealed-bid effect is to be expected.

DIBBS results and theory

The DIBBS auction data provide an excellent natural experiment to evaluate the effects of changing from a sealed-bid, first-price auction to an open-bid, first-price auction. Controlling for time trends, quantity, and specific items, the data indicate that the prices are reduced on average by 4.4 percent when an open-bid auction is used.

Recall that in a symmetric, affiliated-values environment, the auctioneer will be better off with an open-bid auction than a sealed-bid auction. If this describes the procurement environment, then the result supports theory. We cannot say with certainty what the environment is. It seems likely that the valuations of the goods are affiliated—there are likely both private and common values aspects. For example, the cost of producing the auctioned item depends in part on possibly unforeseen technical difficulties that are the same for all bidders, and uncertain input prices that all bidders would incur. However, each vendor may face idiosyncrasies that are not common but are related—local labor market conditions, for example—that inject private- and affiliated-values features. Thus, we could argue that the auction results match perfectly with theory on expected revenue in auctions.

In this environment, the data also support the theory on the number of bidders—that an additional bidder provides an advantage to the auctioneer.

At the same time, one could argue that the environment is an asymmetric environment because the vendors might be fundamentally different. The incumbent supplier may hold an advantage, or the vendors may have adopted different technologies that give them different valuations of winning the contract. If this is the case, the results will either support or reject the theory depending on the nature of the asymmetry. We cannot determine the nature of the asymmetry (if any) among the firms. Further, as we see in figure 3, the variation in the ratio of prices when changing from sealed- to open-bid auctions is significant. This variation could be due to randomness, or it could be due to differences in the nature of the symmetries and asymmetries in the bidders.

Navy and Army auctions

The Navy and Army each began using reverse auctions in 2000, and have some experience with auctions. The approaches of the two organizations were similar. They contracted with auction services providers and then allowed customer organizations to use the providers to purchase goods or services. This section describes the services' experience with auctions. We discuss the Army and Navy auction data, including concerns with the suitability of the data.

Navy auctions

History

The Department of the Navy conducted the first on-line reverse auction in the federal government on May 5, 2000, when it began a five-auction pilot project. The pilot project was conducted by Naval Inventory Control Point (NAVICP) Philadelphia between May and September 2000, and consisted of auctions for ejection-seat recovery sequencers, shipboard berthing, aircraft engine blades, MRI services, and CVN camels. These auctions were designed to test auctions as a price negotiation mechanism for source selection criteria and products, as shown in table 10. These on-line auctions were conducted using the services of Freemarkets, Inc., a commercial provider of on-line auction services.

Table 10. NAVICP Reverse Auction pilot project

Item	Evaluation criteria	Item type
Ejection seat components	Price only	Engineered item
Shipboard berthing	Technically acceptable low price	Engineered item
Aircraft engine blades	Price only	Engineered item
Mobile MRI services	Best value	Service
CVN camels	Best value	Engineered item

Following the pilot project, NAVICP implemented two contracts for reverse auction services. A contract with Procuri.com uses a "desktop" self-service approach—the buyer (or NAVICP) runs the auction, providing bidder accounts and passwords, establishing and disseminating auction rules and timing, and running the software itself. NAVICP allows the Navy and Marine Corps to use the contract for free and charges a nominal fee to non-DoN government agencies, though only the Air Force and the Coast Guard have used it.[32] The other contractor, eBreviate, provides a full-service hosted auction, even offering to provide sourcing and market research. The desktop approach has been used frequently for both small and large value auctions; the full-service approach has been used less often, and mostly for larger value auctions.

Navy auctions have covered a wide variety of products and services, including commodity products such as refrigerators, coveralls, and potatos; services such as drydock repairs and couriers; and equipment manufactured to Navy specifications, such as FLIR containers and components, E2C wheels, CVN camels, shipboard berthing, and FA–18 engines. The successful use of auctions for items that are not generally considered commercial off the shelf (COTS) is of particular interest. These auctions demonstrate that a well-established market for an item is not a requirement for a successful auction. Rather, the primary requirement is that the item being procured can be fully described through a set of specifications.

Most of the reverse auctions have been conducted for Navy and USMC organizations, though the Veteran's Administration, Defense Supply Center Philadelphia, and Air Force have also used the services. NAVICP's summary of the Navy's auction activity is presented in figures 7 and 8. Both NAVICP and the Fleet and Industrial Supply Centers (FISCs) used auctions for more purchases in FY 2002 than in FY 2001. The value of NAVICP purchases decreased although a large share of the value of its purchases in FY 2001 were for non-NAVICP customers. The value of non-Navy buys in FY 2001 was inflated by two

32. The fees are dependent on the auction provider and the level of support used. NAVSUP publishes the fees on the Web at http://www.auctions.navy.mil/order/index.html#fees.

very large purchases—a $21-million frozen potato auction and an $11-million coverall auction.

Figure 7. Navy auction activity—number of auctions

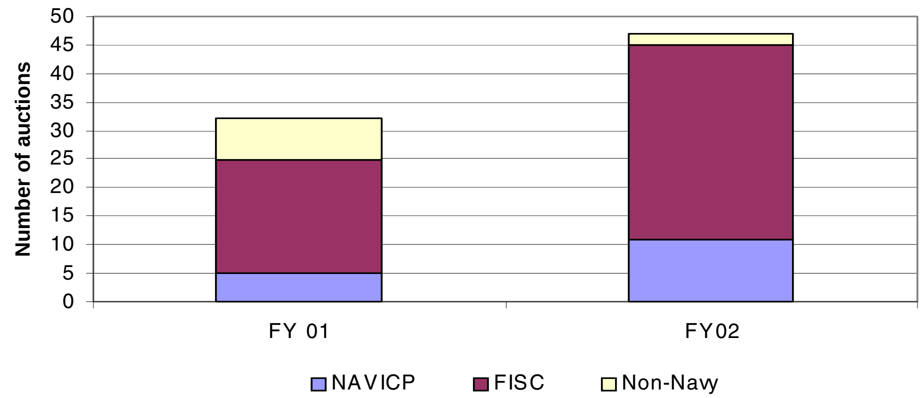
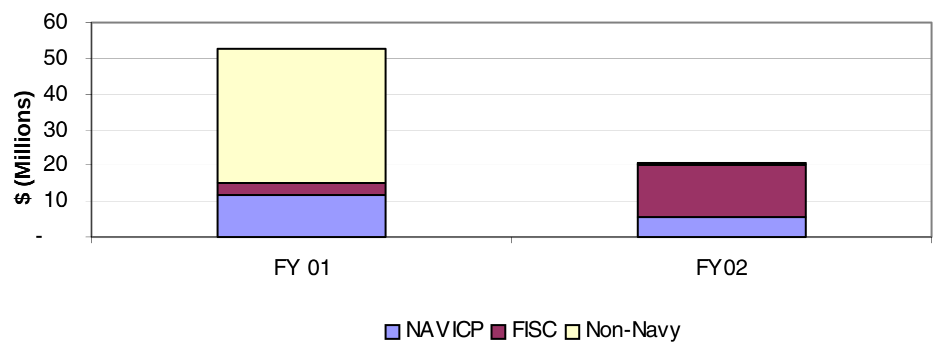


Figure 8. Navy auction activity—value of purchases



Procedures

Navy auctions employ the standard rules for commercial on-line reverse auctions. Typically, bidders are required to pre-qualify by demonstrating that they are technically capable of providing the specified item. Bidders are given password access to the website where the auction will be conducted. The auctions are conducted over the Internet, with a specified start and completion time, often one hour. However, to allow bidders to respond to late bids, the auction is usually automatically extended for a short period of time (for example, 5 minutes) if a bid is received within a window of the closing time. A minimum-bid increment, usually a share of the expected value of the purchase, is imposed on the bidders. Upon completion of bidding, a contracting officer reviews the final bids and determines who will be awarded the contract. The contracting officer can apply a best-value criterion, although usually the lowest-priced, technically-acceptable criterion is used.

Auction data limitations

Difficulty: uncertain reference prices

Determining precise measures of savings from reverse auctions is difficult, because no counterfactual exists to specify the cost of the items if a different pricing mechanism were used. One approach is to use the independent government estimate (IGE) as the reference price. The IGE can be developed through previous purchases or market research. However, in some cases, there are few previous purchases to inform the government estimate, or the available reference prices are from infrequent purchases or significantly modified items. This is particularly true when the item has unique features. Further, market research can result in inaccurate prices, for example, if the estimate is based on list prices that do not reflect discounts that are often incorporated into the final purchase price.[33] When interviewing the buyers to obtain information on the reverse auctions, we were told that some buyers put very little effort into determining the IGE, and that it would be misleading to base savings estimates on the IGE. Another interviewee indicated that the IGE is often provided by the requesting activity, but that the contracting activity determines its own IGE because its experience indicates that the requesting activity's IGE is often inaccurate. Others have asserted that the IGE is a reasonable estimate, based on validated models.[34]

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33. Car pricing provides a common example. Comparing purchase price to list price would suggest that most car purchases are made with significant savings, although the actual price could be close to the average.

34. Although we have inquired, we have not learned of any studies that reflect the accuracy of the IGE in conventional procurements.

Table 11 lists data from two auctions for similar items—submarine camels and CVN camels. These data provide an example of the difficulties involved in using the IGE as a reference price. The IGE for CVN camels is substantially more than the transaction price, whereas the IGE for submarine camels is very close to the actual transaction price. There are a number of possible reasons for the difference. Perhaps the IGE is a valid reference price in both cases, but the different products and competition in those particular cases simply had different results.

Table 11. Government-estimate and reverse-auction price example

Item	Year	IGE	Price	Savings
CVN camels (pilot program)	2000	$36,666,667	$26,766,667	27.0%
Sub camels	2002	$225,000	$211,000	6.2%

Another possibility is that, in this case, the IGE was an unreliable estimate. The CVN camels were a new item, never before procured, and the submarine camels were an item that had been purchased previously. Thus, there may have been insufficient information to form a good IGE for CVN camels.

The question we want to answer, however, is what would the transaction price have been if a reverse auction hadn't been used? If the IGE is inaccurate and a price much closer to the transaction price would have been obtained, then the inaccuracies in the IGE are providing a false picture of the savings. We do not know how many of the items procured by auctions had valid IGEs.

Another possibility is that the IGE for recent purchases incorporates auction effects, so that the IGE for the submarine camel is closer to the auction price. This would make them more accurate relative to the transaction price, but they could be less accurate as a counterfactual price that would have been received had the item been procured using conventional practices.

Although some IGEs may be inaccurate, this does not mean that all IGEs are inaccurate, but it does suggest that they are not always the ideal means for estimating the savings from auctions.

An alternative basis is to compare the final price in the auction with the initial bid in the auction. However, this approach also has significant drawbacks. In particular, the initial bid during the auction is subject to strategic behavior by the bidder. Some bidders may initially bid an artificially high price, hoping to reap windfall profits. Because the cost of bidding down is almost zero in these auctions, there is no reason not to make an initial bid that is well above the minimum price the vendor would offer. Thus, the initial bid can be well above the bid that the vendor might have submitted under a conventional procurement.

Another alternative is to use the price the vendor submitted in the auction qualifying proposal. However, these bids could be subject to strategic bidding. In particular, a bidder might inflate the pre-auction price proposal, hoping to reap large profits if no other firm competes. During the auction, the bidder could drop prices dramatically. If all bidders used this strategy, the pre-auction proposal price would overstate the savings. The auctioneer's option to award the contract based on the pre-auction price proposals may limit this behavior.[35] At the same time, the threat of an auction might cause bidders to initially propose their lowest bid, even below the bid that they would have submitted under a traditional purchase. Thus, it is possible that the initial proposals are lower than the price that would have resulted had a nonauction procurement been used. The pre-auction price proposal is thus an unreliable reference price.

Difficulty: conflicting data

In addition to having several potential baselines of questionable validity, some of the data that we received were conflicting or inconsistent. This may reflect the uncertainty in what should be used as the

35. If one firm makes a pre-auction proposal that is so much better than the others, the auctioneer might determine that the other firms were unlikely to match this proposal price, and not hold the auction. Thus, an unconstrained initial proposal could cost the firm the opportunity to compete.

    Several Navy auctions were cancelled because the bids in the initial proposal were considered so good that an auction was not worthwhile.

estimate basis, and the changes in the procurement or estimates that can occur during the pre-auction process. For example, the quantity of an item can change prior to the auction, and estimates can be updated to reflect these changes. Estimates can also change to reflect additional information. These estimates provide several opportunities for conflicting information to be reported.

We received data from several sources: the NAVICP auctions office, the NAVSUP auction program manager, and the Naval Audit Service.[36] We also received data from several buyers who were connected with individual auctions. Some of these data were in conflict between different sources or were internally inconsistent. The Naval Audit Service report focused extensively on trying to document the estimates and contract prices. It found supporting documentation for the savings for 14 of 45 Navy reverse auctions, and 20 of 20 Marine Corps auctions.

Some of the data, particularly that which is more recent, appears to be reliable, as documentation processes are developed. We are less confident about some of the earlier data, however. Perhaps the most complex example was the first auction after the pilot study. We have the following information on this auction for personal computers:

- The initial data we received indicated that the IGE was $1 million, that the cost avoidance was $287,000, and that the cost avoidance was 21 percent. The data included an annotation that the savings were based on a purchase 3 months prior. Obviously, this information is not consistent—$287,000 of $1 million is a savings of 28.7 percent, so we sought additional information.
- We received an updated spreadsheet reporting the same IGE and a purchase price of $713,000 (or $1 million less $287,000) but correcting the percentage savings to 29 percent.
- We learned that the auction record had a starting price of $1.25 million, which we were told is usually the government estimate. The final purchase price in the record was $983,000, for savings of $267,000, or 21 percent. The estimate may have

36. The Naval Audit Service documents their findings and recommendations in [27].

been updated to reflect new information, or the intent may have been to use the initial price as the basis for savings. It also may be that the initially reported savings of $287,000 was a typographical error.

- The buyer involved indicated that the estimate was based on purchasing 1,000 units, but that the final purchase price was for a purchase of 1,300 units.
- The Navy auction website reports on reverse auctions for computers on two pages. One cites 18-percent savings, the other 29 percent.[37]
- The Naval Audit Service reports that the documented government estimate is $1,292,860, and a supported contract award of $1,277,900, which is a savings of about 1.1 percent.

This example is the most confusing one that we found. However, there are other examples of conflicting data as well. Determining the appropriate values among the conflicting data is a difficult task, as the Naval Audit Service reported. Even if the data were documented, the IGE presents problems as a valid reference point.

Auction data summaries

Naval Audit Service supported results

We are not confident that the estimated price is a valid reference point and that it has been accurately reported. Given this caveat, we provide the following summaries of the data. We focus on the relative savings between different characteristics of the auctions. If the data are of the same quality in all auctions, then the differences might be more meaningful than the estimated savings.

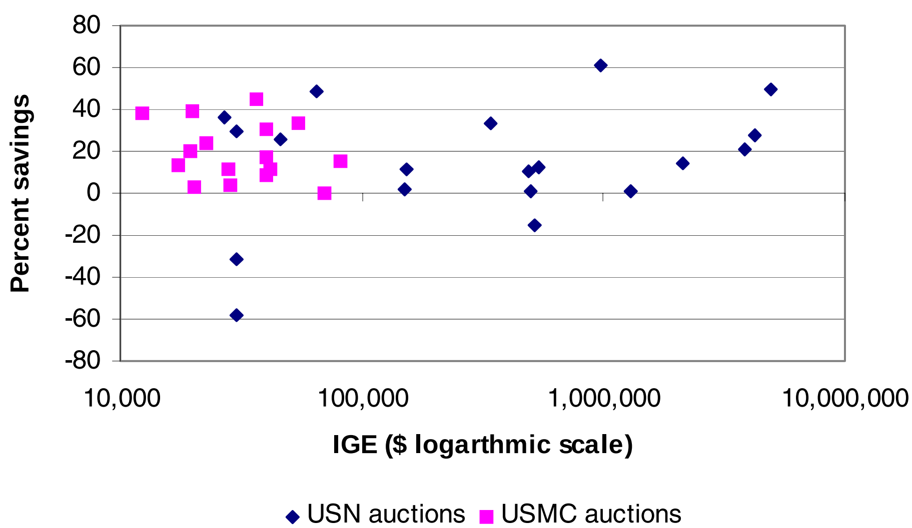
The Naval Audit Service report provides supported cost estimates and contract awards for a total of 39 auctions. Of these, 19 were Navy auctions where the cost estimate is the IGE. The 20 Marine Corps auctions used a "market estimate" that could have been an Internet quote. The Audit Service report is unclear whether the quote was specific to the purchase or was a catalog price obtained through the Internet.

37. http://www.auctions.navy.mil/news/successstories.html and http://www.auctions.navy.mil/news/results.html both accessed 12/20/02.

The savings relative to these reference prices are shown in figure 9. The USN auctions were for a variety of products, including equipment, services, and commodities such as lumber and cables, and ranged in size from IGEs of $27,000 to almost $5 million. The USMC auctions tended to be smaller, and were typically for appliances, furniture, and large office products.

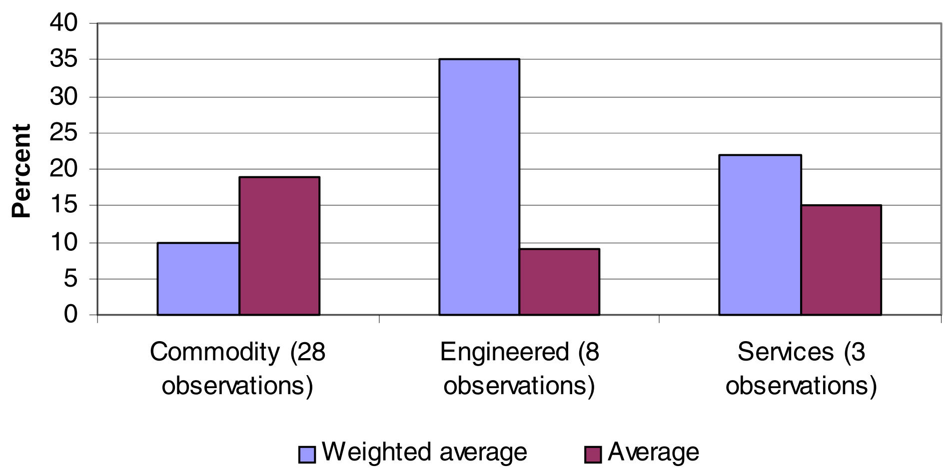
Figure 9 indicates that costs rarely exceeded the estimates. The savings, weighted by the size of the IGE, from the reference price was 26 percent; the simple average of savings was 17 percent. Given these limited data, there is no pronounced trend in savings—the largest savings were realized in auctions with IGEs of $5 million, $1 million, $65,000, and $37,000. Further, the lowest savings are not concentrated at lower or higher IGEs (two of the four negative observations are in the lower range, but two-thirds of the observations are in the lower range, so this is not disproportionate). This suggests that auctions generate interest for both large and small items.

Figure 9. Navy and Marine Corps auction savings by IGE (Naval Audit Service "supported" only)



The types of items procured through the auctions and savings vary. We classified the items into three categories—services, commodities, and engineered items—and calculated the savings by the different types. Figure 10 presents both the weighted and unweighted savings. These should be interpreted with caution, because the auction description is very brief and thus the classifications are subject to error and the number of observations is relatively small.[38]

Figure 10. Navy and Marine Corps auction weighted and unweighted average savings by type of item (Naval Audit Service "supported" auction results only)



Interestingly, the lowest weighted savings were observed in commodity purchases, where the majority of the purchases were made. This might be due to differences in the way the reference price was formed (20 of the 29 commodity purchases were USMC purchases, and the Marine Corps used a different process to develop a reference price). This might also reflect the difficulties of developing a reference price for "unique" engineered items or services that are provided according to specifications in the procurement itself. If the IGE represents the price that would have been obtained through conventional negotiations, these results may also indicate that creating a market for unique items generates significant savings.

38. For example, we classified the largest single auction, for solenoid valves, as an engineered item, on the assumption that an IGE of $5 million for valves would involve specifically designed items. It may also have been a very large quantity purchase for a commodity solenoid valve. Because this purchase had 50-percent savings, it significantly affects the results.

The differences between the weighted and unweighted savings indicate the role of a few large purchases. In particular, the engineered item procurements had a very wide range of savings: Included in the sample was a $5-million IGE purchase with 50-percent savings, and two $30,000 IGE purchases with negative savings of 30 and 60 percent. The weighted average commodity savings were reduced by a $1.3-million PC purchase that had only 1-percent savings. The variance further suggests that caution should be exercised in interpreting these data. Figure 11 graphs the auction results by the type of purchase, and illustrates the variation in results by the type. [39]

Army auctions

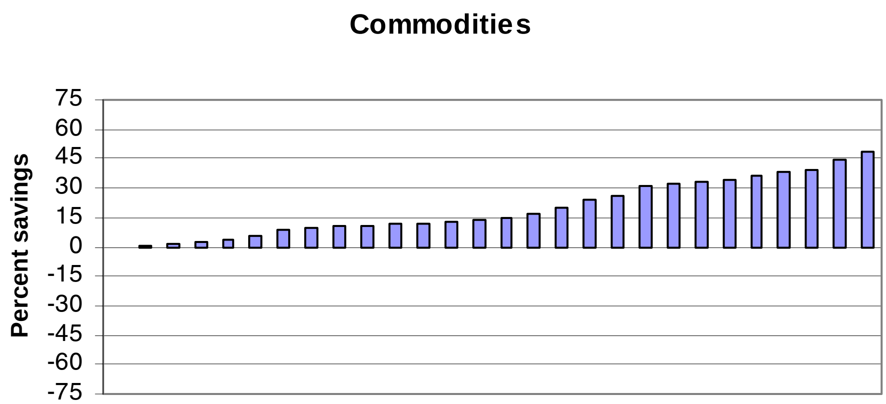
History

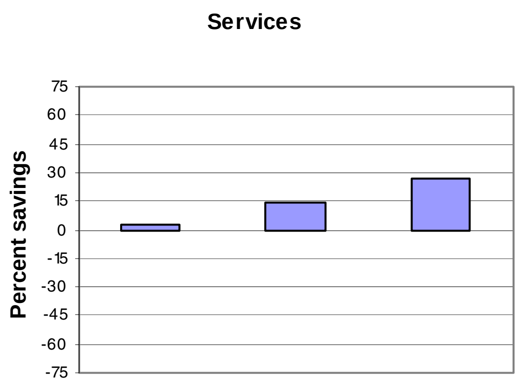
At the same time that the Navy was initiating reverse auctions, the Army's Communications—Electronics Command (CECOM) Electronic Reverse Auctioning Project Team was initiating an Army program. The first Army auction was conducted on May 17, 2000, for a secure fax machine. Table 12 provides summary data on CECOM's auctions. CECOM has contracted with Frictionless, a commercial auction provider, to conduct its reverse auctions.

The Army auctions have been used for a less diverse set of items than is the case for Navy and Marine Corps auctions. Most have been for commodity-type items—the majority of CECOM's auctions have been for electronic products, though they have also been used for household appliances, contract closeout services, and goats. Several Army commands, the Marine Corps, and the Air Force have used the CECOM services.

39. We also examined the data that the Audit Service was not able to verify. The results are similar to verified data. The only qualitative differences are that in the unverified data, a higher portion of the engineered item auctions realized savings, and there are some commodity purchases with negative savings.

Figure 11. Auction results by item type





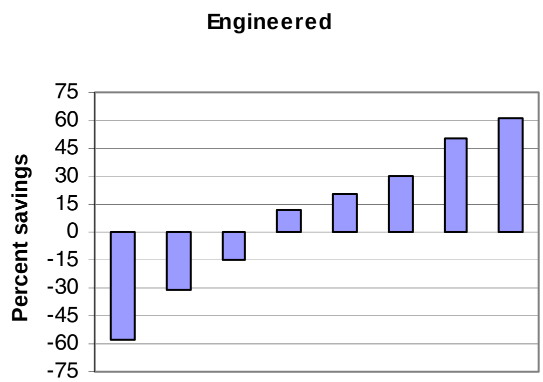


Table 12. Army auction summary

Type of good	Number of auctions	Value of auctions
Computer	22	$19,851,127
Other commodities	24	$7,147,242
Services	2	$12,450
Total	46	$27,010,819

Simple analysis of data

The Army data include information on the estimated or beginning unit price, the actual outcome, the number of units and the number of vendors in the auction. Using the Army data, we derived the two estimates of savings that are provided in table 13. The first column is the simple average of savings in each auction. The second column is the average savings weighted by the total amount of the buy. We do not know how the baseline cost was determined in these auctions, so the cautions concerning counterfactuals from the previous section also apply here as well.

Table 13. Percent savings in Army auctions

Item	Simple average	Weighted average
Computers	25	35
Other commodities	24	25
Services	62	64
Total	26	32

The difference in the weighted and unweighted savings averages for computers suggests that the savings increase as the quantities increase. This could be an effect unique to the auctions, or it could be a quantity discount effect. Because we do not know how the baseline was established, we cannot separate these effects. Both the weighted and simple average savings are substantial.

The data also include the number of vendors bidding. The number of vendors can indicate the level of competition, which affects the savings. Figure 12 shows the savings by number of vendors. To help interpret these data, we provide the number of observations for each category in table 14. There does not appear to be any clear pattern of savings as a function of the number of bidders in the auction. However, note that the sample size for each of the groups is very small. As a whole, the Army savings are fairly significant, even exceeding the savings reported in the private sector. However, the number of observations suggests caution in applying this result widely. The breadth of items purchased is limited, and we have not closely examined whether the comparison price is valid as a counterfactual.

Figure 12. Weighted average savings by number of bidders, Army auctions

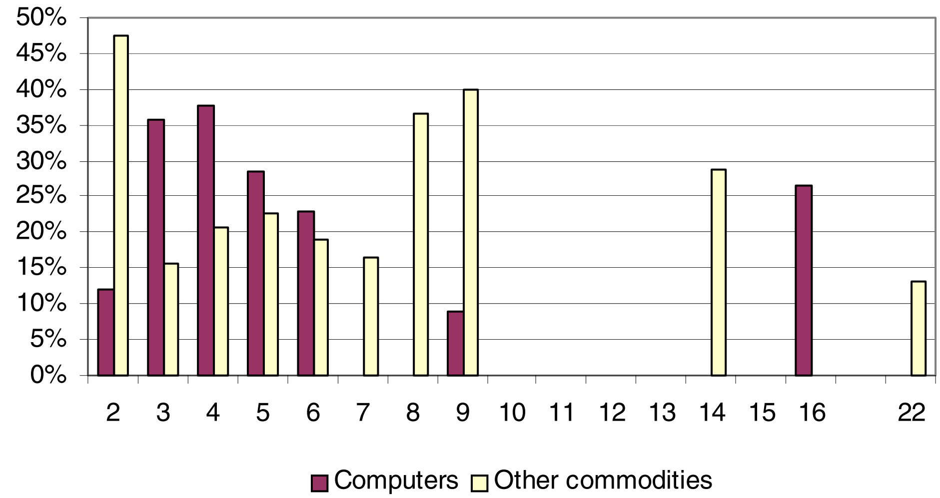


Table 14. Number of bidders in auctions

Number of bidders	Number of auctions	
	Computers	Other commodities
2	1	4
3	4	3
4	6	3
5	4	5
6	3	3
7		1
8		2
9	3	1
14		1
16	1	
22		1

Why do DIBBS results and Service auction results differ?

The Army and Navy auction data indicate that auctions result in much higher savings than do the DIBBS data. This raises issues about why the differences exist and which type of data provides a more accurate projection of the potential for reverse auctions.

The data may differ for a number of reasons including selection bias, different product types, and different auction rules.

Selection bias

As previously noted, selection bias occurs when the observed data do not represent the entire population. In DIBBS data, this might be the case if the FSCs that were selected for open auctions are special. In fact, DSCC selected those FSCs because it believed they thought that auctions for those items might generate savings, though they had not formally studied the decision of which FSCs. However, once the FSC was selected, all NSNs were subject to auctions, regardless of the specifics of the items' markets. The combination of a variety of FSCs and a uniform application of auctions once selected probably limits selection bias in DIBBS data. Further, our regression is conducted based solely on items that met exactly the same criteria that were used for automated procurement.

However, Navy and Army auction data might be more subject to selection bias. In particular, Navy and Army auctions were the result of deliberate decisions to choose an auction. The buyers could choose items that were likely to be successfully auctioned. This might be due in part to the costs of conducting the reverse auctions. In some cases fees were charged, and in almost all cases there were additional administrative burdens imposed by using a procurement that was not the familiar method. To adopt a new method required some compelling reason, one of which could be the possibility of high savings. Also, some of the auctions were for unusually large purchases, such as large lots of computers. Thus, the Navy and Army auction record to date might represent the "low-hanging" fruit, and savings from more widespread use of auctions might not be as high.

Product differences

A significant number of Navy and Army auctions were for items that did not fit the definition of commodities. Even computers, which can be bought off the shelf, are often customized to meet the specifications of the customers. In other cases, the items were engineered (the CVN camels, for example). These products may have had limited price competition before the reverse auction. If the previous purchasing mechanism involved negotiating on both price and quality, then the vendors' offers may have been more conservative, because they sought to convince the purchaser that they were providing a unique service or value. Thus, they may not have competed on the basis of price. Because the reverse auction may have led to more detailed specifications, and focused the competition on pricing, additional competition and savings might have been realized. To the extent that more widespread use of auctions in the DoN would have the same effect, this would not bias the results. Rather, it would be an indicator that auctions actually have a relatively high return in the DoN.

In contrast, DIBBS auctions were for commodities, for which price competition may have already occurred. In particular, because the comparison group is the open-auction items, the "conventional" purchase was essentially a sealed-bid, first-price auction. Thus introducing the auction may have had a smaller impact.

Further, there may be differences in the environments associated with the different products. In particular, DIBBS items may be closer to the private- values environment than are items in the Navy auctions. Frequently produced items might be private values because less uncertainty is involved than there is when the item is unique or rarely produced. Thus, because several of the Navy auctions were for engineered items, the price change associated with a change from conventional procurement—which may be more like a sealed-bid, first-price auction to the open-bid auction—might be more pronounced.

Auction rules

DIBBS auction rules may have reduced the price competition induced by the open auction. In particular, a fixed-auction period and the ability to increase and withdraw bids could have significant impacts. By submitting a bid at the last possible moment, a vendor could effectively limit the opportunity of other vendors to respond with a lower price. By allowing price changes, some vendors could have made initial bids that were artificially low to discourage other vendors from bidding. Then, with the reduced competition, the vendor could change his artificially low price at the last minute, resulting in a higher purchase price. This may have restricted the savings that could have been realized from DIBBS auctions. However, we only have the final bids for each vendor, not any intermediate bids, so we cannot determine whether this behavior occurred.

Different comparisons

A fourth possible difference is that the two results are making somewhat different comparisons. The DIBBS auction results compare the open-bid results with the sealed-bid results. Thus, if strict sealed-bid auctions have additional savings relative to conventional procurements, the DIBBS estimate of 4.4-percent savings is only a lower bound. However, to the extent that conventional procurements are selected as the lowest price offer, the DIBBS results are reasonable. Further, the DIBBS estimates are based on historical transaction price data, whereas the Navy and Army estimates are based on the IGE. The accuracy of the IGE is uncertain, and may be a source of the higher estimates that are observed in Navy and Army auctions.

Issues in using auctions

Alternatives: auctions, negotiations, and price taking

Reverse auctions might achieve lower prices relative to traditional negotiation or price taking for a number of reasons. When competition is focused on price, as auctions tend to do, strategic behavior by competing firms (even if there are only two competing firms) can lead to a Bertrand equilibrium in which price equals the lowest possible price (that which would prevail in a perfectly competitive market). This contrasts with an environment in which firms can compete strategically along non-price dimensions, as can occur in negotiation, where each vendor presents a slightly unique product and seeks to extract profits from that unique position. In the latter environment, theory predicts that the equilibrium price will remain above the perfectly competitive level when there are few suppliers. That environment also contrasts with a price-taking environment, where the buyer relies on the existing market to set the price, though the possible imperfections in the market might enable the vendor to maintain an artificially high price.

Also, when an apples-to-apples comparison is enforced, there is less room for product differentiation. This constrains the other features the bidders can "put on the table" and the consequent price markups.

Additionally, the transparency of open auctions may allow bidders to share information and reduce uncertainty about the "common value" of the contract up for bid. The reduced uncertainty will lead them to shade their bids less. We used the same reasoning earlier to explain why the English auction is better for the auctioneer than the sealed-bid first-price auction.

Note that even the possibility of an auction may be sufficient to achieve price reductions. For example, the U.S. Postal Service (USPS) reserves the right to run an auction (after receiving initial bids) in all its procurements. This means that USPS also has the option of awarding the contract based on the initial bids. USPS will not hold an auction if it is unlikely to yield additional savings to cover its cost. As a result, firms may submit more aggressive initial bids.

What should be bought by auction?

The question of which items are suitable for auction has generated much speculation. In this section, we provide some suggestions for deciding what to purchase by reverse auction. Some criteria extend auctions to items sometimes considered poor candidates, and some exclude items that might initially be thought of as good candidates.

Items that can be specified and have acceptable switching costs

A recent survey of commercial use of electronic reverse auctions listed five criteria for using auctions [28]. The paper asserts that good candidates have the following attributes:

1. Items can be clearly specified.
2. There is a high likelihood that prices can be reduced.
3. Switching costs are acceptable.
4. Sufficient numbers of suppliers exist.
5. Suppliers are willing to participate.

Of these, the most useful criteria are that the items can be clearly specified and that switching costs are acceptable. The likelihood that prices can be reduced is hard to determine in the absence of an auction—it requires more knowledge than buyers normally have. The Navy auction mechanism requires sufficient bidder competition (a minimum of two bidders and three potential suppliers) so the last two criteria do little to help buyers decide whether an auction is appropriate, rather than just possible.

Items that can be specified are good candidates

Items that can be accurately and completely specified are attractive auction candidates. When an item is purchased through an auction, the selection of a vendor is focused on price. To make the best choice by price, care should be taken that the same item is being offered by all vendors. This can be achieved when the item can be fully specified by design, delivery, and function descriptions.

Switching costs should be considered

The relative cost of switching providers is also an important decision criterion. A procurement auction implies a willingness to change to a new provider. Thus, before the auction, the buyer must determine whether the costs of switching providers are relatively low. If there is a large investment of relationship-specific capital relative to the cost of the item (and thus relative to the potential savings from lower prices), then an auction might not be appropriate. For example, if a frequently purchased item itself costs relatively little, but the buyer has implemented systems specifically designed to streamline purchases from a given contractor, then the item might not be an attractive auction candidate. The potential savings may not be worth the costs of switching providers.

Auctions can be used for items with relationship-specific investment. If the item is very expensive, even the sunk cost in the relationship can be small relative to the potential savings that might be obtained from competition. Similarly, an auction for a long-term contract can reduce the relative value of the relationship-specific costs to the point where they are not overwhelming.

Further, the costs to the providers of switching should be considered. If the purchase imposes significant retooling costs to a new provider for relatively small purchases, the incumbent will hold a significant advantage. In fact, because the other entrants might bid high, the incumbent will have little incentive to bid low. In contrast, a negotiated procurement might give the buyer the leverage by having the ability to exercise an option to use an alternate provider in a long-term contract. (An auction for a long-term contract could be used to mitigate the re-tooling cost.)

Together, specificity of items and the cost of switching providers suggest that auctions are not appropriate for items where a strategic partnership with a supplier is important. In a strategic purchasing arrangement, the items being purchased are often jointly developed, and high relationship-specific investments are made.

Commodities and non-commodities

A common perception among Navy and Army personnel is that online auctions work best when the item being procured is a commodity[40] or can be bought off-the-shelf (COTS). Almost by definition, commodity purchases usually satisfy the criteria for auction candidates, especially the two main criteria of clearly specified items and low switching costs. Thus, they are good auction candidates. However, the active commodity market with multiple suppliers and buyers that generates the availability of the COTS item might also generate sufficient competition to force prices nearly as low as they can go.

Reverse auctions for customized items may yield even greater savings. Customized items can also meet the above criteria, with the potential for significant savings. If the buyer can accurately and completely specify the performance requirements and the items have multiple potential suppliers but are not commonly traded in the market, the potential savings may be high. Unique items with these criteria may lack an active market, and thus also lack the competition that can lower prices. Thus, a procurement auction can be used to generate this competition where demand does not normally exist for the item.

One auction service provider reports above-average savings from auctions in professional services (legal, information technology, consulting, landscaping, etc.). These contracts can be complex and typically must be customized to the needs of the individual buyer, thus demonstrating that auction savings are not limited to commodities or COTS items. This may explain the very high savings that the Navy may have realized in the CVN camel procurement. The camels were a newly designed item, and several providers may have had the capability to

40. A commodity is defined as an item that is completely interchangeable in the market—one firm's product is precisely the same as another firm's object.

build it. The alternative may have been negotiations, where the degree of competition could have been lower.

Auctions for items with cost-quality tradeoffs

Auctions for fully specified items can overlook valued alternatives

One possible drawback to specifying requirements very precisely is that there is less room for suppliers to reveal any superior information they may have about production possibilities, including reliability, durability, or the likelihood of failing to meet contract requirements. For instance, a DoD buyer may require that the batteries for a given radio unit last at least a week between charges but weigh no more than 2 pounds. Several suppliers may be able to build a battery that weighs only half a pound but lasts only 6 days. Whereas this information would likely be revealed in a traditional negotiation process, these suppliers would not even qualify for bidding if a procurement auction were to be held.

Developing better specifications through market research or specifying tradeoffs

Good market research is one way to make sure that the best available technology is not inadvertently excluded from consideration. A buyer who becomes informed about the state-of-the-art prior to determining requirements and running an auction runs less risk of overlooking promising leads. Given this knowledge, a procurement auction for a well-specified product can be fruitful.

Another way around this problem is for the buyer to specify how he values the cost-quality tradeoffs—for example, how valuable an additional ounce of weight reduction is relative to an additional hour of battery life. Suppliers can then consider a larger set of production options to maximize the buyer's value. In practice, it may be difficult or time-consuming to assign precise numbers to value every combination of weight and battery life. As a result, procuring by auction may not be feasible, or may not yield the hoped-for savings in transactions costs.

Best value auctions

Still another way to approach the price-quality problem is to use the auction as a negotiation mechanism in a best value procurement. Here, the buyer solicits bids for an item that involves variation in quality, but does not necessarily enumerate the tradeoff values. These tradeoff values might not be listed because the buyer does not want to restrict the dimensions that bidders can compete in, or because the cost of specifying them is too great. The buyer selects the vendor based on a combination of the price and non-price aspects of the vendors' offers. Bidders will then compete on both price and quality features.

Thus, auctions for items involving tradeoffs can be used, but they may not result in the same degree of price competition, because bidders might rely on the non-price characteristics of their product to differentiate themselves from their competitors. The Bertrand equilibrium of a competitive market price even in the presence of imperfect competition relies on pure price competition. By allowing variation in products to enter the vendor selection decision, vendors can rely on unique attributes to set themselves apart. The resulting environment is termed "monopolistic competition." In general, the prices will not be as low as those realized in perfect competition, because the sellers each have some degree of monopoly power that enables them to maintain higher prices. Nevertheless, the gains from additional price-quality choices may offset the foregone benefits of additional price competition.

Multiple lines/multiple lots: combinatorial auctions and economies of scale and scope

Finally, auctioneers should give careful consideration both to the quantities of items and the combinations of items they put up for bid simultaneously. There may be economies of scale or scope (synergies) that can be realized by grouping items together. However, this requires the auctioneer to know the ideal groups before the auction, which may not be possible. One alternative is to have a simultaneous auction for several related items that allows vendors to bid on their choice of sets of the items for a single price. This can allow the vendors to select the appropriate grouping of items to realize the best economies of scope and scale. Such auctions are termed **combinatorial auctions.** They present different challenges, one of which is how to select the winning bids. A full discussion of combinatorial auctions is beyond the scope of this paper. For a summary, see [29].

Why should individual commands/programs use auctions?

The adoption of online reverse auctions has occurred much more rapidly in the private sector than in the federal government. A major obstacle to expansion of government auctions is that government procurement managers have less incentive to use auctions than do managers in the private sector. A DoD procurement program office that uses reverse auctions to achieve savings of 10 percent may fear that its future budgets will be reduced by that amount.

Possible improved incentives

As we discussed earlier, the savings that result from an auction are hard to measure objectively, and this makes it difficult to design an incentive-pay schedule for program managers. One concern with such a scale is that the baselines might be "gamed" to change the manager's rewards.

Small changes in the federal acquisition regulations may allow more widespread use of reverse auctions in programs in which they are likely to yield savings. For instance, legislation now under consideration[41] would improve incentives by allowing program managers to use their budget surpluses to buy additional units of the item being procured.

How should auctions be conducted?

Auction rules

Auction theory and the DIBBS auctions indicate that auction rules can significantly affect the outcomes of the auctions, including the desired revenue. Thus, it is important to try to match the environ-

41. Service Acquisition Reform Act (SARA).

ment with the appropriate auction design. This is not an easy task. One must know who the bidders are, and have a fairly solid understanding of the nature of the firms. This information may be impossible or cost prohibitive to obtain. One approach to finding the best auction format is to experiment with different formats for different types of items, and then analyze the data to determine which format yields the best results for each class of items.

In principle, auction rules can be tailored to yield the auctioneer's desired outcome (efficiency or minimum cost, for example). Often, however, this requires additional complexity, such as the suggestion in Maskin (2000) to require bidders to submit bidding schedules that specify a bid for each possible profile of their competitors' bids. In practice, the costs associated with learning the auction rules may be considerable and may deter potential bidders from participation. Consequently, it may be efficient to opt for a simple, familiar set of bidding rules, even if it means sacrificing some part of the desired outcome (by paying a slightly higher price on average, for example). The resulting increase in the number of bidders should more than outweigh the gains from optimal auction rules.

Auction design also affects research and development investment. Theoretical research has found that second-price auctions result in stronger incentives for investment in cost-reducing R&D than first-price auctions when the competing firms are asymmetric. This is because investment has a negative strategic effect—competing firms respond to the investment by collectively bidding more aggressively, thus lowering the value of the investment.[42] In contrast, in a second-price auction, bidding strategies are independent of the distributions of opponents' costs, so there are no disincentives to investments [30].

42. Specifically, the result holds when there are only two bidders, when the investing firm's opponents are symmetric, and under asymmetry when the investment changes market leadership.

Collusion concerns

Many authors have commented that open auctions give bidders a fast, legal, and low-cost way to signal intentions to collude. As an example, see [31]. Also, Klemperer finds that spectrum auctions in the United States and elsewhere have fallen prey to collusion and predation [7]. He concludes that auction design is not "one-size-fits-all" and that specific steps can be taken to reduce the likelihood of collusion.

For instance, Klemperer (1998) suggests a hybrid auction format to reduce the potential for collusion or entry deterrence associated with open auctions. In this hybrid format, bidding is open until only two bidders remain. The open bidding stage allows bidders to make the usual inferences from other bids about any unknown common value. However, the final two bidders must then submit sealed, "best-and-final" offers. The sealed bids make it difficult for the last two bidders to signal each other. Furthermore, when one bidder is widely perceived as stronger than any other, many of the weaker competitors may choose not to participate in an open auction. With the hybrid format, the sealed-bid stage gives weaker bidders some chance of winning, thereby increasing auction participation.

Despite the examples of collusion, it is possible that collusion concerns may not be too serious. First, collusion requires a small number of bidders to begin with. In such markets, the suppliers would probably impose some cost of market power under any procurement process. Thus, only part of any collusion costs in these markets should be attributed to auctions. Second, sustaining collusion requires bidders to have a credible way to punish those who deviate. This generally requires the same bidders to be active in multiple auctions, either simultaneously (as in the FCC auctions) or over time (as in the milk auctions).

Industrial base concerns

There is also concern that if auctions become the norm, one dominant supplier may eventually win a disproportionate number of auctions, driving all other firms out of the market. It is argued that the traditional negotiation process allows program managers and procurement executives to sustain a competitive landscape by "spreading out" contracts to a sufficient number of different suppliers. However, if all suppliers realize they will earn their share of government contracts regardless of performance, they are unlikely to become more efficient. To the extent that auctions reduce the transaction cost of government procurement, they may actually expand the industrial base by encouraging more suppliers to enter the bidding process.

A related concern is that winning firms will bid too low on a regular basis, thereby leading to perpetual losses. This concern does not seem reasonable because suppliers should have enough self-interest and management skill to avoid this situation. No supplier is compelled to make a bid that will not cover his costs. The CAPS study also reports that "there is little or no evidence that electronic reverse auctions are driving suppliers into non-sustainable relationships with buyers [28]."

Appendix

Price comparisons

In this section, we present additional data on the change in price in an item from one purchase to the next. While this is an imperfect comparison because there is no control for quantity discounts, they provide information on how prices can change.

Excluded vs included: open-bid auction purchases compared to auction-period conventional purchases

Although an item is in the FSCs selected for open-bid auctions, it is often still purchased through the traditional purchase procedures. During the open-bid auctioning period, any non-auction purchase is because the item either failed the pre-solicitation or post-bidding check. Figure 14 compares successive purchases made within the open-bid auction period. Specifically, we compare an auction purchase price to the previous price for that NSN, when the previous purchase did not meet the pre-solicitation criteria, for example because it was a high-priority purchase. There are 522 observations in this histogram, with a mean of -.159, a median of -.048 and standard deviation of .358. This indicates that the open-bid auction purchase price was noticably lower than the purchase price for the same item that was not eligible for an auction. If priority is the primary reason for items switching categories, this indicates that the priority effect (likely a combination of both urgency and allowing buyers more discretion in their purchases) increases prices noticably.

Within auction price comparisons

Finally, we compare the variability in the prices of items within the auction formats. Figure 15 presents the log of the ratio of one sealed-bid purchase to the next sealed-bid purchase of an NSN, and Figure 16 presents the same information for open-bid purchases. An interesting feature of these figures is that the volatility of prices is relatively low compared to the variation in the conventional-to-conventional purchases (see figure 1 and table 6), suggesting that auctions can actually increase price stability. Summary statistics for these two price ratios are provided in table 15. The mean of the change in prices was smaller in subsequent open-auction purchases than the change when the open-auctions were first used. Repeated use of open-auctions will likely not continuously drive prices down.

Figure 13. Log ratio of open-bid auction purchases to conventional purchases during open-bid period

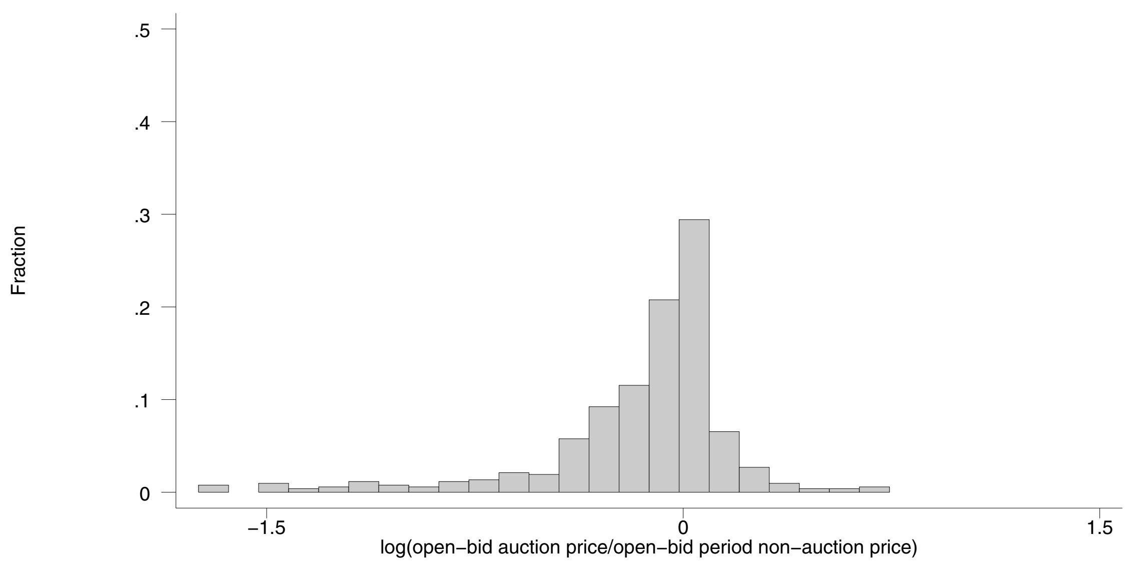


Figure 14. Log ratio of consecutive sealed-bid auction purchases

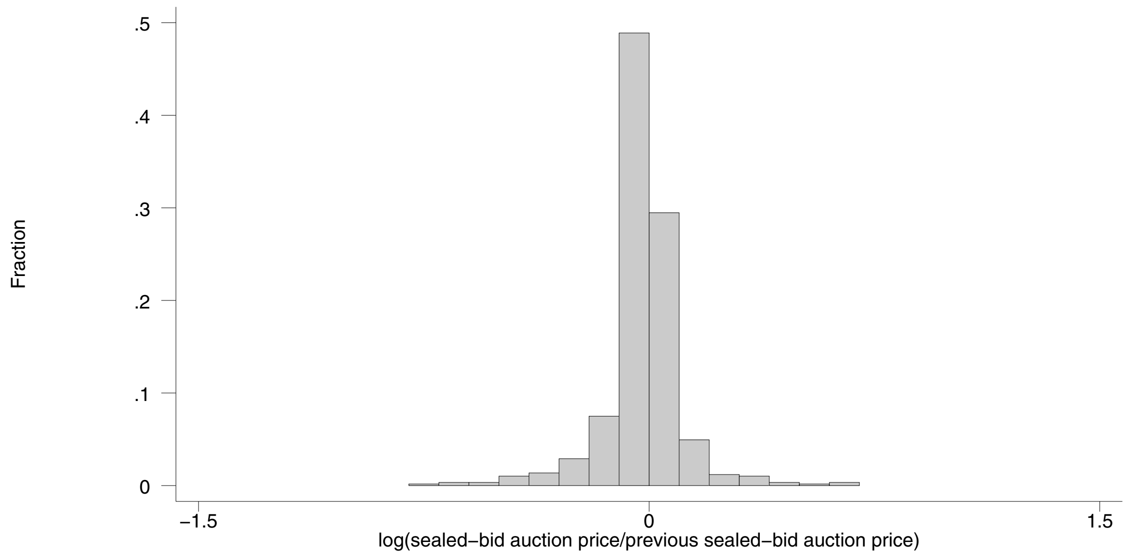


Figure 15. Log ratio of consecutive open-bid auction purchases

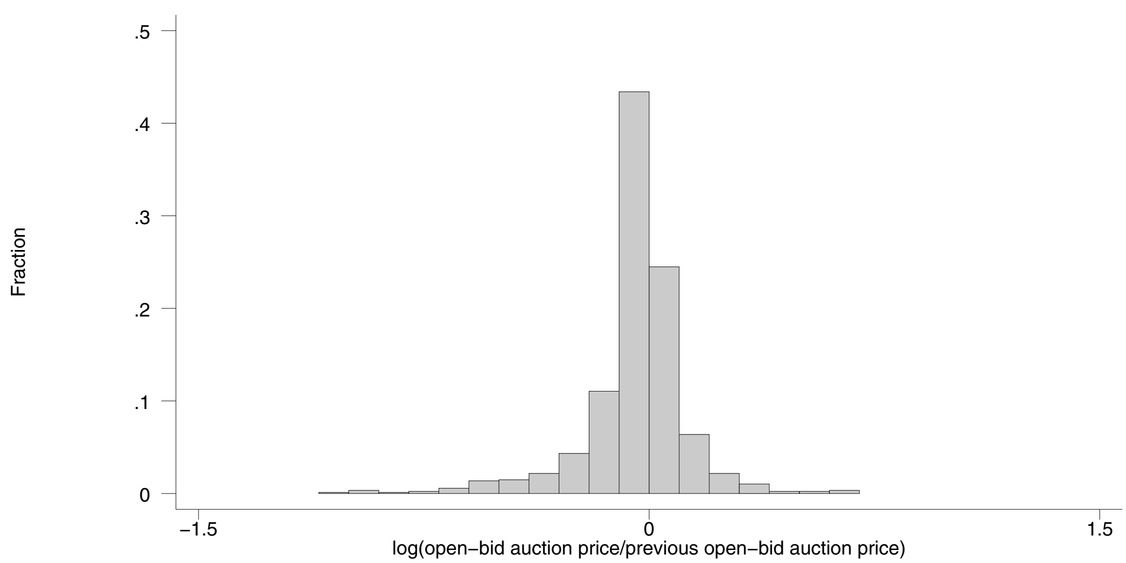


Table 15. Summary statistics of purchase-to-purchase price ratios

Log of	Observations	Mean	SD	Median
Sealed-bid PACE/sealed-bid PACE	587	.021	.129	-.012
Open-bid PACE/open-bid PACE	876	-.040	.171	-.017

Additional regression results

Full regression results

Table 7 in the text does not include the FSC specific time trend terms. For completeness, the time trends are included in table 16. In most cases, these coefficients are statistically significant, indicating that regressions including those time trends are preferred.

Table 16. Time trend coefficients for results reported in table 7[a]

	(2)	(3)	(4)
FSC2530*t	-0.016	-0.016	-0.016
	(4.05)**	(3.84)**	(4.01)**
FSC4730*t	-0.018	-0.017	-0.018
	(4.25)**	(3.99)**	(4.27)**
FSC5930*t	-0.016	-0.016	-0.017
	(3.24)**	(3.17)**	(3.26)**
FSC2530*t^2	0.000	0.000	0.000
	(4.08)**	(3.86)**	(4.04)**
FSC4730*t^2	0.000	0.000	0.000
	(4.24)**	(3.99)**	(4.27)**
FSC5930*t^2	0.000	0.000	0.000
	(3.26)**	(3.19)**	(3.28)**

a. Absolute value of t-statistics in parentheses. * significant at 5 percent; ** significant at 1 percent

Subsample regression results

The analysis in the paper uses the sample of NSNs that had a PACE sealed- or open-bid auction. Alternatively, we could have restricted the sample to NSNs that had *both* a PACE sealed- or open-bid auction. This restricts the sample size. We provide the results of estimation using this sample in table 17. The results are nearly identical. The only difference is the effect of the number of bidders. While similar qualitatively—a single bidder will imply a price increase but multiple bidders a price decrease—the magnitudes are slightly different. The subsample indicates that with one bidder, the price rises .4 percent, and savings begin to accrue from the second bidder on. Again, each additional bidder has a smaller impact.

Table 17. Regression results on subsample of NSNs with both sealed- and open-bid auctions[a]

(1)	(2)	(3)	(4)	
Ln(quantity)	-0.158	-0.157	-0.156	-0.157
	(24.06)**	(23.79)**	(23.67)**	(23.78)**
Open-bid auction indicator	-0.034	-0.048	0.020	-0.048
	(3.94)**	(5.11)**	(1.07)	(5.11)**
Award date	-0.001	0.001	0.001	0.001
	(0.97)	(0.36)	(0.19)	(0.36)
Award date squared	0.000	-0.000	-0.000	-0.000
	(0.99)	(1.89)	(1.78)	(1.89)
Fast purchase	-0.150	-0.141	-0.142	-0.141
	(9.50)**	(8.88)**	(8.96)**	(8.87)**
FSC2530*t		-0.004	-0.004	-0.004
		(1.07)	(0.97)	(1.07)
FSC4730*t		-0.005	-0.004	-0.005
		(1.10)	(0.89)	(1.10)
FSC5961*t		0.007	0.007	0.007
		(1.22)	(1.24)	(1.21)
FSC2530*t^2		0.000	0.000	0.000
		(2.38)*	(2.33)*	(2.38)*
FSC4730*t^2		0.000	0.000	0.000
		(2.32)*	(2.17)*	(2.32)*
FSC5961*t^2		0.000	0.000	0.000
		(1.22)	(1.24)	(1.21)
Number of bids			-0.016	
			(3.89)**	
Number of bids squared			0.001	
			(2.93)**	
Fifth or greater auction for NSN				-0.002
				(0.05)

Table 17. Regression results on subsample of NSNs with both sealed- and open-bid auctions[a] (continued)

(1)	(2)	(3)	(4)	
Constant	16.041	12.949	14.185	13.028
	(1.41)	(1.13)	(1.25)	(1.13)
Observations	3,489	3,489	3,489	3,489
Number of nsn	933	933	933	933
R-squared	0.22	0.23	0.24	0.23

a. Absolute value of t-statistics in parentheses. * significant at 5 percent; ** significant at 1 percent

List of Acronyms

CECOM	Army Communications-Electronics Command
COTS	Commercial off-the-shelf
DIBBS	DSCC Internet Bid Board System
DSCC	Defense Supply Center Columbus
FISC	Fleet and Industrial Supply Center
FSC	Federal Stock Class
PACE	Procurement Automated Contract Evaluation
NAVICP	Naval Inventory Control Point
NSN	National Stock Number
PPI	Producer Price Index (Bureau of Labor Statistics Series PCUOMFG#)
FCC	Federal Communcations Commission
IGE	Independent government estimate

References

[1] http://wireless.fcc.gov/auctions/summary.html#completed, accessed Dec 18, 2002

[2] http://pages.ebay.com/community/aboutebay/overview/index.html, accessed Dec 18, 2002

[3] http://www.gxs.com/gxs/press/release/press20020508,accessed December 18, 2002

[4] http://www.freemarkets.com/en/benefits/default.asp,accessed December 18, 2002

[5] Major Susan L. Turley, USAF. "Wielding the Virtual Gavel—DOD Moves Forward with Reverse Auctions. "undated manuscript

[6] Paul Klemperer. "Auction Theory: A Guide to the Literature." *Journal of Economic Surveys,* 13(3), Jul 1999, pp 227-286

[7] Paul Klemperer. "What Really Matters in Auction Design." *Journal of Economic Perspectives*, 16(1), Winter 2002, pp 169-189

[8] David Lucking-Reiley. "Auctions on the Internet: What's Being Auctioned, and How?" *Journal of Industrial Economics*, 48(3), Sep 2000, pp 227-252

[9] Partha Dasgupta and Eric Maskin. "Efficient Auctions." *Quarterly Journal of Economics,* 65(2), May 2000, pp 341-388

[10] Paul Klemperer. "Auctions with Almost Common Values: the Wallet Game and its Applications." *European Economic Review*, 42, May 1998, pp 757-769

[11] Paul R. Milgrom and Robert Weber. "A Theory of Auctions and Competitive Bidding." *Econometrica,* 50(5), Sep 1982, pp 1089-1122

[12] Paul Milgrom. "Auctions and Bidding: A Primer." *Journal of Economic Perspectives.* 3(3), Summer 1989, pp 3-22

[13] William Vickrey. "Counterspeculation, Auctions and Competitive Sealed Tenders." *Journal of Finance,* 16, pp 8-37

[14] John McMillan, ed. "Subject Index of Articles in Current Periodicals." *Journal of Economic Literature,* 40, Dec 2002

[15] Bruce G. Linster and David R. Mullin. "Auctions in Defense Acquisition: Theory and Experimental Evidence." *Acquisition Review Quarterly,* Summer 2002, pp 213-223

[16] Eric Maskin and John Riley. "Asymmetric Auctions." *Review of Economic Studies,* 67, 2000, pp 413-438,

[17] Jeremy Bulow and Paul Klemperer. "Auctions Versus Negotiations." *American Economic Review,* 86, 1996, pp 180-194

[18] David Lucking-Reiley. "Using Field Experiments to Test Equivalence Between Auction Formats: Magic on the Internet." *American Economic Review,* 89(5), Dec 1999, pp 1063-1080

[19] Robert G. Hansen, "Sealed-Bid Versus Open Auctions: The Evidence." *Economic Inquiry,* 24, Jan 1986, pp 125-142

[20] Jacob K. Goeree and Theo Offerman, "Efficiency in Auctions with Private and Common Values." *American Economic Review,* 92(3), Jun 2002, pp 625-643.

[21] Anders Lunander, "Procurement Bidding in First-Price and Second-Price Sealed Bid Common Value Auctions." Manuscript, Oct 1999

[22] Lance Branman, J. Douglass Klein and Leonard W. Weiss. "The Price Effects of Increased Competition in Auction Markets." *The Review of Economics and Statistics,* 69(1), Feb 1987, pp 24-32

[23] DSCC Master Solicitation for Automated Solicitations and Resulting Awards (PACE), available at http://dibbs.dscc.dla.mil/refs/provclauses/

[24] Alvin E. Roth and Axel Ockenfels. "Last-Minute Bidding and the Rules for Ending Second-Price Auctions: Evidence from eBay and Amazon Auctions on the Internet." *American Economic Review,* 92(4), Sep 2002, pp 1093-1103

[25] StataCorp. *Stata Statistical Software: Release 8.0, Reference Manual.* College Station, TX: Stata Corporation, 2003

[26] Qi Li. "Nonparametric Testing of Closeness between Two Unknown Distribution Functions." *Econometric Reviews,* 15(3), 1996, pp 261-274

[27] "Department of the Navy's Reverse Auctioning Process," NAVAUDSV P-7520.1, N2003-0030, 5 Mar 2003

[28] Stewart Beall, et al. "The Role of Reverse Auction in Strategic Sourcing." CAPS Research, 2003

[29] Sven de Vries and Rakesh Vohra. "Combinatorial Auctions: A Survey." *INFORMS Journal on Computing,* forthcoming

[30] Leandro Arozamena and Estelle Cantillon. "Investment Incentives in Procurement Auctions." *Review of Economic Studies,* forthcoming

[31] Martin Pesendorfer. "A Study of Collusion in First-Price Auctions." *Review of Economic Studies,* 67, 2000, pp 381-411

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