An Electronic Calendar Auction

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Introduction

Commerce in every era consists of sellers finding buyers at mutually beneficial prices. The task is difficult because buyers and sellers typically understate their willingness to transact in order achieve a better bargain, and so potential transactions are lost. To solve this fundamental problem of commerce, many different market formats have evolved, ranging from random search and haggling, to posted price, to auctions. The most efficient market format (that which maximizes gains from trade, by matching highest value buyers with lowest cost sellers) depends on the nature of the goods or services and conditions of the environment.

New electronic technologies change the environment and therefore create an opening for new and more efficient market formats. In this paper we examine a new electronic format, the Dynamic Price Calendar Auction™, and collect known theoretical and empirical results that bear on its performance. We conclude that it has great potential, and point up key issues for its future evolution.

Auction = A market format in which a seller (and/or a buyer) receives price offers (buyers' bids and/or sellers' asks) and awards the objects to those who offered the highest bids (and/or lowest asks).

Auction Formats and Environments

Auctions have many different formats but all have the same basic rule: transaction priority goes to those who make the best offers, the highest bids and/or lowest asks (McAfee and McMillan, 1987; Friedman and Rust, 1993). Thus auctions use the principle of competition to overcome the fundamental problem of commerce. A buyer (and/or seller) must offer a better price than rivals in order to transact, and so reveals much about his willingness to transact.

Environment = All circumstances relevant to traders' choices and payoffs in a particular market format, including the nature of the good, the buyer values and seller costs, participation costs, and the available information.
Format = Set of rules for making bids and transactions, e.g. ascending, descending, etc.

Auctions go back at least 2000 years; indeed, the word "auction" is derived from the Latin verb "augere," to increase. Goods sold at auction include unique collectibles such as artwork, antiques, manuscript books; homogeneous commodities such as grain and precious

metals; financial assets such as U.S. Treasury bills; contracts for mineral rights and for construction of public works; and in recent electronic flea markets, everything from airline tickets to zoo passes.

When are auctions used instead of other market procedures such as posted price? We see four key conditions that have traditionally favored auctions.

- The good does not have a known, stable price that equates supply and demand (Cassady 1967). For example, fresh fish are often auctioned because the price depends sensitively on the quantity and quality of the day's catch and on demand conditions.
- Buyers' participation costs and waiting costs are low relative to the value of items at auction. Otherwise intermediaries can profitably offer immediacy, and buy from the sellers and sell to the buyers on demand (Demsetz, 1968).
- Inventories are expensive to carry. Otherwise the retailers can profitably create a convenient shop, post a relatively high fixed price and periodically offer clearance sales. (Varian, 1981).
- Buyers do not highly value customization or versioning of the good, so sellers can sell "as is" to a wide range of potential buyers. Otherwise again there is a role for intermediaries in catering to buyers' diverse preferences (Fabozzi, Ferri, and Modigliani, 1998).

Natural buyer = one who purchases for own final use, not for resale.
Intermediary = one who purchases to resell later at a higher price, adding value by offering convenience, immediacy and/or customization, e.g., dealers or retailers.

Here are some key distinctions regarding the environment in which an auction is conducted.

- The goods or services being transacted can consist of *single or multiple units*, divisible or indivisible. Buyers' per unit value and sellers' per unit cost may depend on the number of units bought or sold, or on holdings of substitute or complement goods. Unless otherwise noted, we assume values and costs are independent across units.
- Buyers may know their own value exactly but only know the distribution of other buyers' values. This is the *independent private values* (IPV) environment, which we assume unless otherwise noted. It is a reasonable description for most merchandise. Alternatively, buyers may all share the same value, but each has only his own imprecise estimate of what that value is (the *common values* or CV environment). Offshore oil leases are a classic example: each lease buyer (oil company) makes its own estimate of the amount of oil that can be recovered, but the actual costs and revenues would turn out to be about the same for all buyers. Intermediate cases are also possible, and similar distinctions can be made with regard to sellers' costs.

Independent Private Values (IPV) = Each buyer knows the value of the item to himself, but does not know the values of other buyers.
Common values (CV) = The item has the same value to all buyers, but they have different estimates of what that value is.

- The set of potential sellers and the set of potential buyers may not be known in advance. Buyers and sellers may have significant *costs of participating* in an auction, and on top of this they may have *costs of waiting* for the auction to conclude. The sale at auction may not be final, with post-auction bargaining between buyer and seller or other agents. Unless otherwise noted, we ignore these problems.

  Several distinctions are helpful in describing auction formats; see Figure 1.

- An auction is *one-sided* if only bids or only asks are permitted, and *two-sided* if several buyers and several sellers submit bids simultaneously, as in a stock exchange (Friedman and Rust, 1993). This paper focuses on one-sided auctions, and for clarity assumes that the seller chooses the auction format and buyers submit bids. With suitable modifications, all results apply to auctions in which the buyer chooses the format and sellers submit asks, e.g., for government procurement contracts.

One-sided = Only traders on one side (either buyers or sellers) can propose prices, and traders on the other side can only accept one or more units or reject the offers.
Two-sided = Both buyers and sellers can propose prices, and transact by accepting a proposal by the other side.

- An auction can be *open* (sometimes called oral or continuous), allowing all bidders to see earlier bids, or *closed* (sometimes called sealed bid) allowing each bidder a single bid that is not observed until all bids are collected.

Open/oral = Bids are public and adjustable in real time.
Closed/sealed = Bids are private and committed.

- An open auction can be *ascending* (also known as English or bid-up), recognizing only bids that are higher than earlier bids, or *descending* (called Dutch in the academic literature), with the auctioneer (human or automated) decreasing the price over time until some buyer accepts the current price. The Roman auctions presumably were ascending, and it is still the most prevalent format. Descending auctions are traditionally used to sell cut flowers in the Netherlands, fish in Israel, and tobacco in Canada, among other instances.

Ascending = Buyers submit successively higher public bids until no one is willing raise the current highest bids.
Descending = The price at which the item is offered for sale starts from a high level, and declines steadily until one of the buyers stops the clock and buys the good at that price.

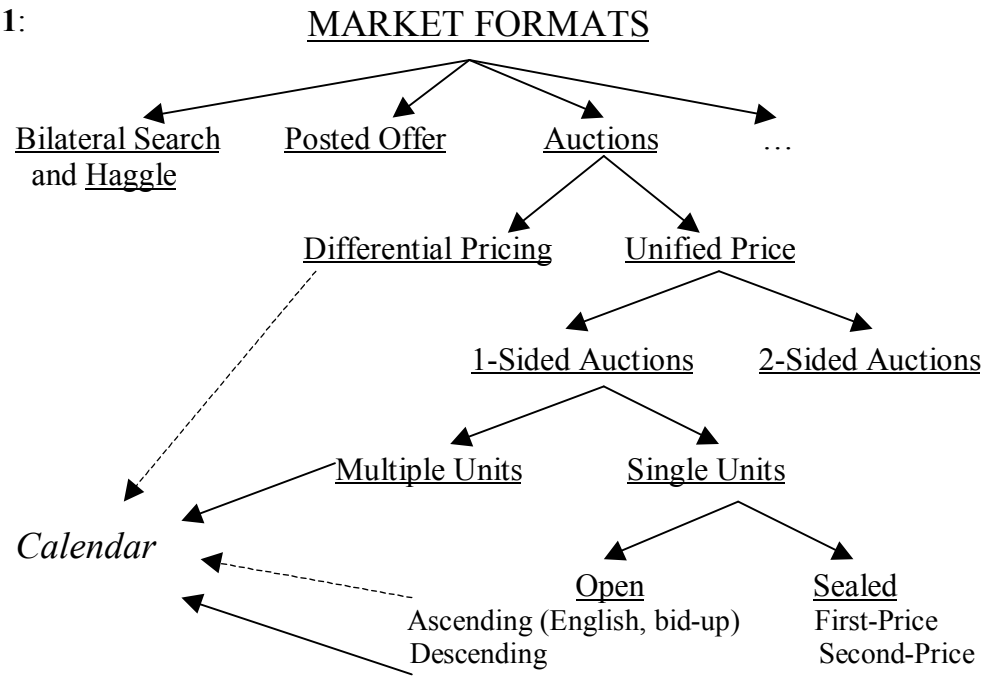
- A closed auction can be *first-price* (the highest bidder buys the object at her bid price) or *second-price* (the highest bidder buys the object, but the price is the second highest bid). Governments usually sell mineral rights and award procurement contracts via first-price closed auctions. Second-price closed auctions are historically rare but have become more popular in recent times (Vickrey 1961, Lucking-Reiley 1999).

First-price = Sealed auction in which the highest bidder pays his own bid price to acquire the item.

Second-price = Sealed auction in which the highest bidder pays the second highest bid price to acquire the item.

Other variants to the basic auction rules include a *reserve price*, below which the seller rejects bids, and an explicit *entry fee* for the right to participate in the auction. Some bidders may differ in observable ways and be given *privileges* in terms of bid priority (e.g., minority-owned firms in some government run auctions) or access to information (e.g., specialists in the New York Stock exchange).

Figure 1:



Onedayfree's new **Calendar Auction** can now be described succinctly as a multiple unit descending auction with advanced bid posting. The price descent begins after the pre-live period, and every day thereafter the price steps down by a preset amount. Buyers can immediately purchase some or all of the remaining units at today's price, or use "order agents" to place bids for a later day at that day's price. The auction is completely transparent in that all earlier transactions and advanced bids are publicly listed.

The advanced bids give the Calendar an ascending character because priority goes to bids for nearer dates (at higher prices). See McCabe et al. (1992) for a two-sided auction format that also has simultaneous ascending and descending characters. They find that their two-sided format (called Double Dutch) is the most efficient format in a simple laboratory environment.

For which goods and environments will the Calendar Auction be more efficient than alternative formats? When will it yield higher revenue to sellers or attract market share? The next two sections summarize known theoretical and empirical results bearing on these questions.

Theoretical Results

Modern auction theory goes back to Vickrey (1961) and has been very active since Milgrom and Weber (1982).[1] The theory compares auction formats in various environments, assuming that every buyer fully understands the environment, does not try to collude, and otherwise acts in his own best interest. The classic results listed below further assume that the seller is auctioning a single item, that all buyers are present at no participation or waiting cost, and that none have special privileges. The results consider the impact of buyers' risk attitudes and value correlations (e.g., IPV vs. CV environments).

Result 1 (Vickrey, 1961): *The descending auction yields the same outcome as the first-price auction regardless of buyers' risk attitudes and value correlations.* The intuition is worth explaining. A buyer in a first-price closed auction chooses his bid by trading off the probability of winning (by placing the highest bid) against the profitability if he does win (higher bid means higher price and lower profit). The tradeoff calculation is exactly the same in a Descending auction; the only difference is that he is choosing when to accept the current price rather than writing down a bid. Either way, Vickrey showed that the equilibrium is for all buyers to bid at some discount from their own estimated value, e.g., bid 75% of value when there are 3 other bidders in an IPV environment with uniformly distributed values (McAfee and McMillan, 1987).

Result 2 (Vickrey, 1961): *the ascending auction yields the same outcome as the second-price auction in the IPV environment, regardless of risk attitudes: the item is purchased by the highest value buyer at a price equal to the second highest buyer value*. The intuition here is simple. In both auction formats it is optimal for every buyer to fully reveal his value, no matter what other buyers do. This means staying in the ascending auction until the bid rises above his value, and bidding his actual value in the second-price auction. Bidding higher than one's value (or staying in longer) can never give a positive profit, and bidding lower (or dropping out early) means passing up profitable opportunities. As a result, the highest value buyer wins the auction and pays the price set by the next highest value buyer.

The first two results together show that, compared to the descending (or first price) format, buyers in the ascending (or second price) format bid higher, but the auction price is lower for given bids. So which effect is more important? Vickrey showed, to the surprise of many, that on average the effects exactly cancel, so all four formats produce the same revenue.

Result 3: Revenue-Equivalence Theorem (Vickrey, 1961): *Assume IPV with risk neutral buyers. Then the descending, ascending, first-price and second-price auctions all are efficient with respect to the participating buyers and all produce the same average revenue for sellers. Increasing the number of bidders increases the seller's average revenue.* The last part is clear enough: the revenue is equal to the second highest buyer value, which tends to be higher when there are more buyers. Efficiency is also clear: in each format, the highest value buyer wins the auction.

[1] William Vickrey shared the 1996 Economics Nobel Prize for this and other work. He died of a heart attack a few weeks after the prize was announced, and Paul Milgrom gave the Nobel Lecture that year on Vickrey's behalf.

Risk Aversion. Note that revenue equivalence holds only on average. Depending on the particular alignment of buyer values, the descending/first-price auction could produce higher or lower revenues than the ascending/second-price. It can be shown that revenue has higher variance (depends more sensitively on the alignment of buyer values) in the descending/first-price formats. Thus, if the seller were risk averse and the buyers were risk neutral, then the seller would prefer the ascending or second-price auction. However, risk averse buyers will bid higher than risk neutral buyers in the descending or first price auction; bidding closer to true value is a form of insurance against losing the auction. This insight leads to

Result 4: *When bidders are risk averse, the descending or the first-price auction on average produce higher revenues than the ascending or the second-price auction.*

What if buyers don't know how many other buyers are present? It doesn't matter if they are risk neutral, but it does matter if they are risk averse.

Result 5: *When bidders are risk averse*[2] *in a descending or first-price auction, the average revenue is higher when the bidders do not know how many other bidders there are.*

Correlated Values: Winner's Curse. Now consider the CV environment, in which the uncertainty is not due to different actual buyer values, but instead is due to buyers' different estimates of the item's true value. For example, buyers all might have the same plan to resell the good but might have access to different information about the resale price. Here an important phenomenon called *winner's curse* can arise. The basic idea is that, since the bidder who has the highest estimate wins the auction, the very act of winning conveys the bad news that everyone else had a lower estimate of the item's value. Unless the bidder had already taken this into account, he will find that he overestimated the true value and paid too much.

A rational bidder will escape the winner's curse by presuming that her own estimate of the item's value is the highest and discount it accordingly. This strategy is rational because when some other buyer has a higher estimate she should not try to outbid him. With rational bidders, the auction price is equal on average to the true value even though no individual in the economy knows what this true value is and no communication among the bidders takes place. The 'on average' qualification can be dropped as the number of buyers increases.

Result 6: *If information is sufficiently dispersed among the bidders in a CV environment, then the selling price converges to the item's true value as the number of bidders becomes arbitrarily large.*

Let us now consider cases between IPV and CV. Here the bidders' estimates of the item's value are *affiliated* in the sense that one buyer's perception that the item's value is high makes it more likely that other bidders also perceive it to be high. In this case, bidders in an ascending auction have more information than in the other formats because they can observe at which prices the other bidders drop out. This information dispels the winner's curse, allows bidders to be more aggressive, and increases the seller's average revenue.

[2] This result holds under constant or decreasing absolute risk-aversion, but not necessarily for arbitrary specifications of risk aversion.

Result 7 (Milgrom and Weber, 1982): *When bidders' estimates are affiliated, the average revenues can be ranked as follows: Ascending > second-price > first-price = Descending auction*.

Result 8 (Milgrom and Weber, 1982): *When bidders' estimates are affiliated, the seller can increase average revenue by having a policy of publicizing any information he has about the item's true value.* The reason is that the new information tends to increase the value estimates of those bidders who perceives the item's true value to be relatively low, causing them to bid more aggressively.

Participation Cost and Uncertainty. Dooley et al. (1993) study the failure of privatization auctions for state-owned enterprises in Eastern Europe. They show that a combination of participation cost (e.g., for inspecting the item to estimate its value) and post-auction bargaining over use of the item (e.g., with labor unions) can discourage buyers from bidding realistically or even participating. The idea is that once the buyer has revealed his value by winning the auction he is subject to aggressive post-auction bargaining and may not be able to recover the sunk cost of participation. The revenue losses are likely to increase more than proportionally with the value of the item at stake.

The main lessons for our purposes are that not all valuable items can be auctioned successfully, and that sunk participation costs can have a disproportionate effect on participation.

Multiple Units and Interrelated Goods. Ausubel (1997) and Ausubel and Cramton (1998) studied the problem of multiple-unit auctions. When the seller has more than one unit of the same good or many related goods to sell, and bidders may demand more than one unit, the classic results listed above are no longer valid. In particular, even the second-price auction is generally inefficient with multiple units. Buyers who value several units have an incentive to reduce demand for the last few units in order to reduce the price paid on the first units. As a result, sometimes they lose the last few units to buyers with lower values for those units.

Ausubel (1997) proposes a different ascending format that might avoid inefficiency in auctioning multiple identical units when values are affiliated. The auction organizer announces a current price, the bidders report back the quantity demanded at that price, and the auctioneer raises the price. Objects are awarded to bidders at the current price whenever they are "clinched", and the process continues until the market clears. With private values, this design yields the same efficient outcome as a second-price sealed-bid private auction, but might be easier for the bidder to understand. See Milgrom (2000) for efficiency limitations on any auction format in environments with interrelated goods.

Economies of Scale. The fact that a new auction format would yield higher revenues or greater efficiency does not automatically imply that it will displace a pre-existing alternative format. There are at least three obstacles (Friedman, 1993). First, those who profit from the old format may be able to enlist political support to suppress the new rival (Olson, 1982). Second, a buyer might actually prefer trading in an inefficient format if it reveals less of his information.

Third, transaction volume itself is a source of efficiency. Sellers prefer a format where they expect to find more buyers (recall result 3), and likewise buyers prefer a format where they expect to see more sellers. Thus a popular old format has a built-in advantage, called a network effect or an economy of scale. Indeed, a new format with small market share may have lower efficiency than the old format at large share, even though it would surpass it at equal share (David, 1985).

Presumably traditional auction formats were relatively efficient in the original environment, but may no longer be in new electronic environments. It will take entrepreneurial skill as well as greater efficiency to displace an entrenched auction format.

Table1: Summary of Theoretical and Empirical Results

	Theory	Empirical Results	
		Laboratory	Field
IPV and Risk Neutrality	• Avg. Revenue is equal in Descending, First-price, Ascending, second-price. • Increasing number of bidders increases Avg. Revenue.	• Avg. Revenue in First-price is higher than in Descending. • Avg. Revenue in Second-price is higher than Ascending. • Increasing number of bidders increases Avg. Revenue.	• Avg. Revenue in Descending is higher than in First-price. • Avg. Revenue in Ascending is similar to Second-price. • Increasing number of bidders increases Avg. Revenue.
IPV and Risk Aversion	• Avg. Revenue is equal in Descending and First-price, but greater than Ascending and Second-price. • Uncertainty about number of bidders increases Avg. Revenue.	• Uncertainty about number of bidders increases Avg. Revenue.	• Bidders with higher value submit higher bids.
Affiliated Values	• Avg. Revenue in Ascending is higher than Second-price which is higher than First-price which is equal to Descending. • Increasing number of bidders drives price to item's true value. • Public info about other bidders' estimates increases Avg. Revenue for seller.	• Winner's Curse is found in First-price, second-price and Ascending. • Public info about other bidders' estimates has an uncertain effect on Avg. Revenue for seller.	• Public info about other bidders' estimates increases Avg. Profit for bidder.

Empirical Results

Field studies and laboratory experiments are complementary tools to study actual behavior in auctions. The advantage of field data is that it reports the outcomes when

experienced and skilled professionals bid in full-scale auctions for high stakes. The disadvantage is that key variables are uncontrolled or unobservable, so conclusions are hard to draw. For example, if revenue is higher for flower auctions in the Netherlands than in Brazil, is because of environmental differences such as buyers' values, or is it because of the different auction formats? Laboratory experiments allow control of theoretically relevant variables, including buyer values and the auction format, and provide matched comparisons that allow sharp inferences. Bidders' experience is less in most laboratory experiments and stakes are usually smaller, but the results listed below come from subjects who have mastered the laboratory environment and who have enough at stake (usually $5-$30) to do their best.

Laboratory Evidence, Result 1. Contrary to theory, Coppinger et al. (1980) and Cox et al. (1982) show that average revenue in descending auctions is 5% lower than in first-price auctions. In follow-up work, Cox et al. (1982) and (1983) test two possible explanations. They find little support for the explanation that bidders enjoy playing the "waiting game" in the descending auction. Their results support the alternative explanation that in a descending auction lasting only a few minutes or seconds, the bidders mistakenly revise downward their estimates of rivals' values as time passes with nobody stopping the clock to win the item.

Tests of Result 2. Kagel et al. (1987) find that theory predicts well the outcomes in ascending auctions, but that prices are 11% higher than predicted in second price auctions. Later work, e.g., Harstad and Rothkopf, (2000), shows that with enough experience bidding in second-price auctions eventually converges to the theoretical prediction. It seems that many subjects are slow to realize that bidding above one's true value is never profitable in second price auctions; you do win the auction more often but only when winning is unprofitable. But losses from overbidding are infrequent and usually small, so learning is weak compared to the ascending auction where the futility of bidding above value is immediately apparent.

Tests of Result 3. Why are prices higher in the first-price and second-price auctions, where buyers explicitly state prices, than in open auctions where the decision is whether or not to accept the price announced by the auctioneer? Kagel (1995) suggests that the reason is psychological. In sealed auctions the attention is focused on price, while open auctions focus on profitability, generating somewhat lower prices.

Effects of Increasing the Number of Bidders and of Concealing their Number. Cox et al. (1988), Kagel and Levin (1993) found that, consistent with theory predictions, increasing the number of rivals almost always resulted in higher (more aggressive) bidding in first-price auctions. Dyer et al. (1989) showed that concealing the exact number of bidders raises average revenue, as predicted for risk-averse bidders.

Auctions with Affiliated Private Values. Kagel et al. (1987) found that in first-price auctions with affiliated private values, public information about others' estimates increases average market prices but only about 30 percent of the increase predicted by theory and often not significantly different from zero.

Effects of Information in Private Value Auctions. Most of the theory analyzes single period auctions, so it has been left to experiments understand the effect of how price information feeds back on bidding. Cox, Smith, and Walker (1984) and Battalio et al. (1990) studied the effects of price information following bid submission, and found no effect on bidding. Isaac and Walker (1985) reported that under limited information prices were consistently higher.

Common Value Auctions and the Winner's Curse. Kagel and Levin (1986), Kagel et al. (1989) showed in their laboratory experiments that inexperienced bidders are quite susceptible to the winner's curse in first and second-price auctions: they bid too high and earn much lower profits than fully rational buyers in equilibium. The winner's curse declines slowly with experience, and is smaller (but still present) in ascending auctions. Cox and Smith (1992) find that the winner's curse disappears much more quickly when buyers choose whether to participate.

Field Evidence. Three predictions of auction theory, supported by experimental data, have been confirmed using a variety of field data. See Kagel (1995) for a summary and Porter (1995) for more perspectives.

1. A bidder with a higher value will submit a higher bid.
2. As the number of bidders increases, so does average seller revenue.
3. In common value auctions, better-informed bidders make a higher rate of return than less informed bidders.

An interesting result is that professional bidders incur into the winner's curse in laboratory offer auctions (experiments have been done with skilled individuals from the construction industry).

An Internet Field Experiment. David Lucking-Reiley (1999) reports a small stakes experiment run on the Internet with natural buyers. Beginning in 1994 he purchased over $2,000 of Magic game cards and resold them via auctions over the Internet. The basic procedure was to auction two copies of the same card in two different auction formats to obtain a matched comparison across formats. The ascending and descending auctions lasted days or weeks, rather than the seconds or minutes in most laboratory experiments. The results show that, contrary to theory and laboratory results, *the descending auction produces 30 percent higher revenues than the first-price sealed-bid auction*, while the ascending and second-price sealed-bid auctions produce roughly equivalent revenues.

Discussion

The Calendar Auction is a new format and as such has not yet been studied rigorously. But existing theory and evidence point to a number of important advantages.

- The Calendar Auction's descending format, extended over several days or weeks, allows buyers to participate at their own convenience and minimizes participation costs. This should maximize the number of natural buyers and thereby increase efficiency and average seller revenue.
- Theory predicts (and available evidence confirms) that the descending format further enhances seller revenue when buyers are risk averse and when they don't know how many other buyers will participate. These conditions seem to apply to most Internet auctions.
- Differential pricing in the Calendar Auction allows buyers to purchase as many of the remaining units as they choose, and to purchase them immediately at a known price. Such immediacy offers buyers the most attractive feature of non-auction, posted price markets. An Internet field experiment suggests that immediacy is also advantageous to sellers: average revenue was 30% higher in single unit descending auctions in matched comparisons with first price auctions. (Laboratory descending auctions had lower revenue but did not offer an immediacy advantage.)
- Classic descending auctions suffer disadvantages in environments where buyers don't know the precise value of the items at auction (affiliated values and CV environments). These disadvantages are mitigated (and perhaps completely reversed) by the advance bid and transparency features of the Calendar Auction, which give it an ascending character. Bidders can observe lower bounds on other buyers' estimated values, and therefore have less reason to fear the "winner's curse."
- Classic auction formats are generally inefficient in multiple unit environments. The differential pricing and dual ascending/descending character of the Calendar auction should increase efficiency, perhaps to the level of Ausubel's clinching auction.

Greater efficiency and higher seller revenues are important competitive advantages, but are not always decisive. Initial market share can sometimes make the difference. The Calendar Auction will have the best chance of success where its efficiency and seller revenue advantages are strong *and* electronic versions of traditional formats are not yet entrenched.

Unproductive assets, such as surplus equipment and excess inventories, do not yet have well established electronic auctions. The set of natural buyers is unknown and their participation costs would be excessive in traditional auctions. Many of them value immediacy, can use several units of the asset, and are not quite sure of its value. For all these reasons, unproductive assets are an excellent choice for establishing the Calendar Auction format. Time sensitive goods, and services that can be scheduled reliably (ranging from airline or concert tickets to cargo space), would be tempting targets once the Calendar Auction is established.

The Calendar Auction can be fine tuned in several ways. One can adjust the premium required for placing advanced bids and the number and size of the daily price steps, and can reverse the roles of buyer and seller for procurement auctions. For example, a lower premium (perhaps even a discount) might be appropriate to encourage advance bidding when values are very uncertain, and smaller daily price steps might be appropriate when a large fraction of natural buyers are thought to have high participation costs and high values for immediacy.

Given a suitable initial niche (such as auctioning unproductive assets) and with proper tuning of its features for different items and environments, the Calendar Auction could become the leading auction format on the Internet.

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