RAND Journal of Economics
Vol. 28, No. 3, Autumn 1997
pp. 544–565

Declining values and the afternoon effect: evidence from art auctions

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We study the order of sale in art auctions. The final bid relative to the auctioneer's estimated price declines throughout the course of an auction. A theoretical model shows that in an auction ordered by declining valuation, even in the presence of risk-neutral strategic bidders, the price received relative to the estimate for later items in an auction should be less than the price relative to the estimate for earlier items. Furthermore, ordering heterogeneous items by value maximizes revenue for the auctioneer.

1. Introduction

■ This article reports the results of an empirical study on the order of sale in art auctions. In all auctions of heterogeneous items, auctioneers must purposefully make a decision about the order in which these items will be auctioned. One question addressed by the auctioneer is the approximate order of value in which the items should be placed. Specifically, will the items be auctioned in increasing order of value or declining order of value, or will they be randomly placed throughout the auction? What implications will ordering by value, or not ordering by value, have on price?

We study Contemporary Art auctions that took place at Christie's in London between 1980 and 1994 and Impressionist and Modern Art auctions that took place at Christie's and Sotheby's in New York and London between 1980 and 1990. The datasets consist of 38 auctions entitled Contemporary Art with over 5,000 total items and over 150 auctions of Impressionist and Modern Art containing over 15,000 total items. We test for predictable differences in the auction price, the presale estimate, and the auction price relative to the presale estimate over the sequence of an auction.

Previous studies of art auctions have focused primarily on estimating a price index, or the return to holding art.[1] We are not aware of any studies that have analyzed the structure of an art auction. Previous studies relating prices to order of sale for other

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Special thanks go to Orley Ashenfelter, both for very helpful comments on an early draft and for supplying the data on Impressionist and Modern Art. We would also like to thank Paul Klemperer, Preston McAfee, Rob Porter and two anonymous referees for very useful suggestions.

[1] See, for example, Abowd and Ashenfelter (1989), Baumol (1986), Goetzman (1993), Pesando (1993), and Frey and Eichenberger (1995).

items have focused on declining prices for identical items. Ashenfelter (1989) and McAfee and Vincent (1993) have tested for declining prices for identical bottles of wine in wine auctions, and Ashenfelter and Genesove (1992) have tested for declining prices for identical condominium units in real estate auctions. These empirical studies have selected identical items or controlled for heterogeneities that might occur in order to focus on the homogeneity of the items. Recent theoretical studies of multiple-item auctions have also focused on auctions with identical objects.[2] By using identical items, these studies have not addressed the implicit decision of order by the auctioneer.

This article proceeds as follows. In Section 2 we present some details about art auctions and describe the data. In Section 3 we develop a simple theory of auctions that are ordered by declining value. In Section 4 we test a primary implication of our model, that price should decline relative to the estimate throughout the auction. In Section 5 we summarize alternative theories as to why prices may decline throughout an auction and discuss the relevance of these theories for art auctions. We conclude the analysis in Section 6.

2. Art auctions

■ **The data and summary statistics.** The auction market for fine art is dominated by two auction houses, Christie's and Sotheby's. The most important fine art auctions for these houses are generally held in London and New York. The art auctions are separated into different periods; for example, Old Masters are grouped together, Impressionist and Modern Art are grouped together, and Contemporary Art is grouped together. Our data consist of objects sold in Contemporary Art auctions held at Christie's auction house located on King Street in London and objects sold in Impressionist and Modern Art auctions held at Christie's and Sotheby's auction houses in London and New York.

Prior to an auction, a presale catalogue is published with information on the individual items coming up for sale. Included in the presale catalogue is information on title of painting, artist, order in which items will be auctioned, size of painting, medium, provenance, and whether or not an item is subject to VAT (value added tax). Furthermore, the auction house publishes a low- and a high-price estimate for the work. For the primary analysis in this article, we use a simple average of the high estimate and low estimate. The auction house does not publish, and indeed is very secretive about, the seller's reservation price for the work.

The dataset on Contemporary Art consists of all items sold in all Contemporary Art auctions at Christie's King Street location in London between 1980 and 1994; the data were gathered from the archives of Christie's auction house. For each object, the date of execution, the size of the painting, the medium, whether VAT applies, and the presale price estimates were hand-copied from the relevant Contemporary Art presale catalogue. The information on whether or not a lot is sold and the final bid from 1988 onwards was taken primarily from computer printouts from Christie's internal property system.[3] A unique characteristic of this dataset is that final bids exist even for objects

[2] Studies include Bernhardt and Scoones (1994), Black and De Meza (1992), Bulow and Klemperer (1994), Engelbrecht-Wiggans (1994), Gale and Hausch (1994), McAfee and Vincent (1993), Milgrom and Weber (1982b), and von der Fehr (1994). Rather than assuming valuations are identical, Bernhardt and Scoones (1994) and Engelbrecht-Wiggans (1994) assume that valuations are drawn from identical and independent distributions. Gale and Hausch (1994) allow bidders' values to be correlated but allow for only two bidders.

[3] We assume that the highest bid is the sales price for items that are considered sold during an auction. It is possible that the highest bidders defaulted after the auction on some items. However, we have no information on defaults after the auction and have therefore made the assumption that the highest bid is the sales price.

that are not sold. Although some of these bids may be fictitious bids announced by the auctioneer and placed on behalf of the seller in order to get the auction going (Ashenfelter (1989) describes this process in detail), the common sample-selection problem of having data only on lots that were actually sold can be addressed. The regression analysis is performed using both the entire sample of sold items and not-sold items, and a selected sample of only those items that were actually sold at auction.

Before 1988, many of the lots were missing from the internal system, and for December 1980 and June 1981 the auction results were not available from the computerized system. An assistant in the archives department said that after a certain period of time, some of the lots are deleted from the system, for no predictable reason. From December 1982 through December 1987, we had access to the auctioneer's books and were able to track the missing items in that manner. For June 1982 and earlier auctions, we used the results as listed in the price lists in the catalogues available on shelf in the archives.[4]

The dataset on Impressionist and Modern Art auctions was constructed by Orley Ashenfelter and Andrew Richardson (see Richardson, 1992). This dataset is restricted to 58 selected impressionist and modern artists and includes only paintings, not sculptures. These artists were chosen primarily because their work is well represented in auction, and a selected sample of these artists was first used in Abowd and Ashenfelter (1989). The period covered is 1980 to 1990, and it includes over 150 auctions held in London and New York at both Christie's and Sotheby's. The auction prices were collected from public price lists, and the estimated prices and various observable characteristics such as size of work and date painted were collected from catalogues published before the auction. This dataset does not include all items sold in each auction, just a sample of the 58 selected artists.

Table 1 presents summary statistics for the different types of auctions. A simple comparison of the datasets is interesting.[5] The average price for Impressionist and Modern Art is approximately nine times the average price for Contemporary Art, and the standard deviation in the average price for Impressionist Art is more than fifteen times the standard deviation in the Contemporary Art sample. Although the average estimate for items not sold is greater than the average estimate for items sold in the Contemporary Art sample, the average estimate for items not sold in the Impressionist sample is less than the average estimate for items sold. Neither difference is significant.

In Contemporary Art, on two of the 38 dates, there were morning and afternoon sessions of sales; the rest of the auctions took place in single sessions. We group the morning and afternoon sessions as belonging to one auction. Likewise, sessions of Impressionist and Modern Art at a particular house in a single location often take place on sequential days, with the next single auction session, or group of auction sessions, three to six months afterwards. We group these different sessions that take place on sequential days into one auction. The motivation behind this grouping is that buyers often travel in order to attend auctions of Contemporary Art and Impressionist and Modern Art. For auctions grouped either in different sessions on a single day, or for auctions grouped on sequential days, the same buyers will sometimes attend all sessions. Furthermore, the presale catalogues for these groups are available prior to the first auction of the group, and the auction houses assign increasing lot numbers to the

[4] In the auctioneer's book, sometimes the estimate would have been changed before the auction from the estimate printed in the catalogue. This change did not occur frequently, and the changes appeared to be random. In addition, some lots that are included in the presale catalogue are removed by the buyer from sale prior to the auction. Thus, not all lots listed in the presale catalogue actually make it to the auction.

[5] All London prices are converted from sterling into dollars at the exchange rate on the day of the sale. In addition, prices are adjusted for inflation using either the U.S. consumer price index or the U.K. consumer price index, according to location of sale. Prices are in 1990 dollars for Tables 1 through 4.

TABLE 1 Summary Statistics

	Impressionist and Modern Art Christie's and Sotheby's, London and New York		Contemporary Art Christie's, London	
	Sold	Not Sold	Sold	Not Sold
Average bid	$310,609		$36,274	$32,971
Standard deviation	($1,382,150)		($75,348)	($129,794)
Average estimate	$251,587	$243,341	$32,910	$52,833
Standard deviation	($971,797)	($802,370)	($70,095)	($184,377)
Proportion not sold	.29	.29	.22	.22
Number of auctions	153	153	38	38
Number of observations	11,544	4,682	3,531	1,027

Note: Bids and estimates for Tables 1 through 4 are in 1990 dollars.

sessions grouped on successive days. Often the different sessions are contained in the same catalogue. In total, we have 38 different auctions of Contemporary Art and 153 different auctions of Impressionist and Modern Art. Because the Impressionist Art dataset consists of auctions from both Christie's and Sotheby's in London and New York, the dataset is approximately four times as large as that for Contemporary Art.

□ **Order.** A reasonable place to begin a study of order in Impressionist and Modern Art auctions and Contemporary Art auctions is to simply ask the auction houses how they order their items that are for sale. According to a representative from the Impressionist and Modern Art department at Christie's in London, Impressionist and Modern Art is "loosely ordered by date . . . with certain possibilities." According to the representative, there is always a "good place to be" in an auction. For example, the auction house might place a watercolor immediately after the sale of a major oil by the same artist in order to benefit from "excitement" created by the sale of the oil. When asked whether sellers had a preference on ordering, the representative answered that some clients don't like objects at the end of the sale or at the very beginning. A representative from the Contemporary Art department made similar statements. Ordering of the sale is approximately chronological, for example postwar European to Contemporary. When asked whether value had anything to do with ordering, the representative responded that the most important lots are often in the middle, as the auction house needs "time to create an increasingly exciting atmosphere," and "people get tired [toward the end of the auction]."

In Tables 2 and 3 we look at the way in which paintings are ordered. It does appear that ordering is indeed chronological by painting date. In columns 1 and 6 of Table 2 and columns 1 and 5 of Table 3, we present the means and medians of the painting dates, by order decile, within the auctions. The dates are clearly increasing with order.

Because earlier paintings of Impressionist and Modern Art and earlier paintings of Contemporary Art are often valued higher than later works, ordering by date results in an approximate, nonmonotonic decline in value throughout the auction. Columns 2 and 7 of Table 2 and columns 2 and 6 of Table 3 present the means and medians of the estimates by order decile. Once again, it appears that values decline approximately throughout the auction. It is quite interesting that between the first and second deciles for Contemporary Art, there is an increase in estimate values. This may be due to the auctioneer's need to "create excitement" before selling expensive lots. There is not an increase for Impressionist and Modern Art, but note that we only have the 58 most

TABLE 2 Summary Statistics by Order Decile for Contemporary Art

	Medians				
	1	2	3	4	5
Order Decile	Painting Date	Estimate	Bid	Bid/Estimate (All Items)	Bid/Estimate (Sold Items)
1	1958	$10,347	$10,324	.89	1.00
2	1960	$17,337	$17,985	.89	1.01
3	1962	$16,689	$16,543	.93	1.07
4	1963	$15,980	$16,192	.90	1.00
5	1965	$15,304	$15,561	.88	.97
6	1968	$14,149	$14,187	.86	1.00
7	1970	$9,721	$8,566	.88	.94
8	1973	$7,481	$7,506	.88	.99
9	1976	$8,388	$8,066	.85	.92
10	1980	$9,407	$9,264	.86	.91

Note: Standard errors are in parentheses.

important Impressionist and Modern Artists in this sample, and the order decile is constructed only for these artists. It may be that less-expensive works are sold on average in the first decile for Impressionist and Modern Art, but this effect is not captured in our sample. As reflected by the differences in the means and the medians for Contemporary Art, some of the peaks in the center of the graph of Contemporary Art are largely driven by outliers of estimates in paintings that did not sell.[6]

In column 11 of Table 2 and column 9 of Table 3, we also present evidence on the way buy-in rates vary throughout the auction. A painting is bought-in (or unsold) if it does not meet its reserve price. The reserve price is generally less than or equal to the low estimate, and is secret. During the auction it is possible, but sometimes difficult, to discern immediately after a painting has been bid upon whether or not it has been sold. There do not appear to be systematic differences in the buy-in rates throughout the auctions.

Representatives from both the Contemporary Art department and the Old Masters department also stated that the most important lots go in separate sales. Different types of works are clearly grouped into different sessions. Table 4 reports summary statistics for ten different auctions of Impressionist and Modern Art in which there were sessions on three different days, and summary statistics for the two auctions of Contemporary

[6] For example, a work by Francis Bacon, *Study from Portrait of Pope Innocent X by Velazquez,* has an average estimate of $3,318,310, but the bidding reached only $2,237,930 and the painting did not sell. The work is located in approximately the 55th percentile.

TABLE 2 *Extended*

		Means			
6 Painting Date	7 Estimate	8 Bid	9 Bid/Estimate (All Items)	10 Bid/Estimate (Sold Items)	11 Buy-in Rate
1959 (10)	$27,225 ($44,508)	$25,589 ($45,063)	1.17 (.99)	1.32 (1.07)	.21 (.41)
1962 (9)	$39,438 ($62,866)	$40,202 ($68,281)	1.19 (1.57)	1.36 (1.76)	.24 (.43)
1963 (9)	$44,694 ($86,343)	$45,835 ($88,066)	1.14 (.89)	1.28 (.95)	.22 (.42)
1964 (9)	$38,711 ($69,038)	$37,727 ($64,827)	1.08 (.64)	1.20 (.66)	.20 (.40)
1966 (10)	$46,651 ($101,225)	$41,940 ($77,318)	1.05 (.62)	1.16 (.64)	.20 (.40)
1968 (10)	$37,300 ($85,108)	$34,255 ($71,154)	1.04 (.72)	1.23 (.86)	.23 (.42)
1970 (9)	$64,030 ($270,827)	$57,267 ($213,359)	1.10 (.80)	1.16 (.76)	.22 (.41)
1973 (10)	$27,845 ($56,169)	$24,917 ($46,606)	1.03 (.60)	1.16 (.63)	.24 (.43)
1975 (10)	$23,337 ($38,427)	$20,270 ($31,996)	.99 (.62)	1.13 (.66)	.25 (.43)
1977 (8)	$25,179 ($44,212)	$27,519 ($58,126)	1.10 (1.09)	1.25 (1.20)	.24 (.43)

Art in which there were morning and afternoon sessions. The value ordering is striking. In eight of the ten auctions, the auction sessions are ordered strictly monotonically by value. For two of the ten auctions, the second session contains the painting with the highest value. In both sessions of Contemporary Art, the morning session is valued higher than the afternoon session. While the differences of the average estimates and bids in the different auction sessions can be exceedingly large, the standard deviations in averages are also very large. Less-valuable items are mixed in with very valuable items in the same auction session.

In the following section, we develop a simple model to study the empirical implications of ordering by value. Although in some instances the most valuable works are placed in the middle of an auction, approximate ordering by chronological painting date and grouping different types of paintings into different auctions results in an overall decline in average value. This decline in value is tested and confirmed using regression analysis in Section 4 by regressing the log of the presale estimate on order, controlling for different auctions. In our model below, we therefore begin by assuming that objects are auctioned in decreasing order of value in order to capture this feature of the art market.

Two other important assumptions drive the following model, both of which we believe reflect the spirit of art auctions. First, we assume that each buyer wishes to buy only one object. We think this reflects the fact that some buyers are rapidly satiated by paintings because they are either dealers buying to order for a specific client, or private buyers with either finite wall space or resource constraints. Second, we assume that a buyer's value for one item is correlated with his value for the next item. For some

TABLE 3 Summary Statistics by Order Decile for Impressionist and Modern Art

	Medians			
Order Decile	1 Painting Date	2 Estimate	3 Bid	4 Bid/ Estimate
1	1889	$257,384	$307,509	1.17
2	1912	$254,839	$290,694	1.10
3	1920	$119,706	$116,448	1.12
4	1915	$54,857	$60,560	1.10
5	1925	$44,278	$52,452	1.10
6	1928	$36,307	$41,596	1.12
7	1925	$36,796	$46,163	1.14
8	1925	$41,916	$45,608	1.10
9	1933	$41,916	$46,306	1.11
10	1947	$38,889	$44,809	1.10

Note: Standard errors are in parentheses.

items, for example an oil followed by a watercolor by the same artist, this correlation appears valid. For other items that are not closely related, this assumption may be less realistic. Nonetheless, it is a relevant feature for at least some items in the auction.

3. Ordering by declining value

■ The following model deals only with the case of two objects for simplicity, but all the results can be extended without difficulty to the case of many objects. Suppose that there are two objects for sale and n bidders. Each bidder wishes to buy only one object, and his utility from buying an object with value to him v at price p is $v - p$. The value of the object to the seller is, without loss of generality, assumed to be zero. Bidders are assumed risk neutral. (In the case of the English auction analyzed, this is irrelevant, but it would matter if the auction were a sealed-bid auction.) It is assumed that all buyers agree that the first object to be sold is of higher quality than the second. More precisely, if a buyer has value v for the object, then he has value αv for the second object, where $0 < \alpha \leq 1$. α is common to all buyers.

This multiplicative specification has the feature, which seems plausible, that the premium a bidder is willing to pay for the better painting is an increasing function of the common component of his valuation. So, for example, a bidder who is generally keen on Picasso is prepared to pay a higher premium for a good Picasso than is a person who does not much like Picasso. This seems more appealing than the other obvious simple formulation that quality is additive $(v - \alpha)$, in which the premium

TABLE 3 ***Extended***

Means				
5 Painting Date	6 Estimate	7 Bid	8 Bid/ Estimate	9 Buy-in Rate
1890 (18)	\$748,055 (\$2,121,150)	\$957,077 (\$3,137,392)	1.31 (.58)	.24 (.43)
1912 (21)	\$671,564 (\$1,493,840)	\$868,094 (\$2,101,031)	1.26 (.51)	.30 (.46)
1920 (28)	\$366,088 (\$835,123)	\$438,415 (\$1,674,641)	1.28 (.52)	.30 (.46)
1915 (23)	\$188,561 (\$625,638)	\$225,989 (\$802,477)	1.27 (.54)	.30 (.46)
1924 (21)	\$119,793 (\$509,735)	\$129,892 (\$510,443)	1.29 (.60)	.30 (.46)
1926 (24)	\$80,971 (\$151,438)	\$94,794 (\$224,919)	1.28 (.57)	.30 (.46)
1924 (25)	\$91,431 (\$208,850)	\$103,741 (\$188,445)	1.30 (.59)	.29 (.46)
1924 (24)	\$83,081 (\$121,548)	\$100,896 (\$163,700)	1.25 (.49)	.29 (.45)
1933 (18)	\$85,348 (\$183,275)	\$94,427 (\$142,891)	1.29 (.56)	.28 (.45)
1945 (19)	\$93,094 (\$213,173)	\$107,017 (\$257,374)	1.28 (.57)	.29 (.45)

would be the same for all bidders. Later in the section we consider more general specifications of preferences and show that our results can be extended.

The objects are assumed to be sold in a sequence of English auctions, as are auctions of art and wine. That is, the auctioneer raises the price in each auction until there is only one buyer left. It is well known that if the buyers have independent private values, a single English auction is strategically equivalent to a sealed-bid second-price auction (see Vickrey, 1961). In the latter, bidders submit bids privately to the seller. The highest bidder wins but pays the bid of the second-highest bidder. It is easy to check that it is a dominant strategy in such an auction to bid one's own valuation and that in an English auction it is a dominant strategy to stay in the bidding up to one's own valuation. The auctions in this context are therefore equivalent. This equivalence, however, breaks down with a sequence of auctions, since with an English auction one can observe other bids in the first auction and so learn something about other bidders' valuations. It is unclear precisely what buyers observe in practice. The analysis below assumes that all bids in the first auction are observed. This would be the case if one adopts the model of an English auction found in Milgrom and Weber (1982a). Bidders are thought of as pressing a button to signal that they are in the auction. Once they release the button, they are out of the auction and cannot return. The auctioneer raises the price, and the identities of those in the auction are displayed on a screen so that it can be observed at what point bidders drop out. In practice, rather less may be known about who is currently active, but it will be shown below that the polar opposite assumption that nothing is observed except that the object has sold, so that the auction is effectively a second-price sealed-bid auction, would not affect the results.

TABLE 4 Auction Sessions

Date (yymmdd)	House	Location	Estimate Mean	Estimate Standard Deviation	Bid Mean	Bid Standard Deviation
Impressionist and Modern Art						
860623	CH	LO	$205,476	$106,625	$260,157	$142,215
860624	CH	LO	$39,648	$32,130	$53,672	$44,950
860627	CH	LO	$2,837	$2,127	$3,059	$2,703
861201	CH	LO	$486,272	$588,591	$670,909	$702,177
861202	CH	LO	$43,535	$38,641	$54,614	$52,824
862105	CH	LO	$5,406	$5,801	$7,802	$7,311
870330	CH	LO	$517,230	$678,402	$803,997	$1,271,291
870331	CH	LO	$46,346	$45,099	$63,931	$57,444
870402	CH	LO	$4,508	$3,741	$5,608	$7,855
881114	CH	NY	$1,109,096	$1,681,465	$1,975,841	$3,042,793
881115	CH	NY	$352,039	$537,614	$457,708	$672,449
881116	CH	NY	$148,406	$78,006	$186,409	$114,938
891113	CH	NY	$573,318	$1,189,083	$780,300	$1,257,736
891114	CH	NY	$2,451,479	$3,030,129	$3,104,383	$3,714,699
891115	CH	NY	$137,179	$136,774	$198,744	$254,637
821201	SO	LO	$149,022	$138,325	$154,141	$137,100
821202	SO	LO	$183,405	$161,168	$180,190	$170,470
821203	SO	LO	$29,849	$15,444	$31,934	$17,317
851203	SO	LO	$299,919	$189,335	$378,059	$304,929
851204	SO	LO	$52,826	$25,412	$59,659	$44,294
851205	SO	LO	$35,105	$31,812	$36,193	$30,405
800512	SO	NY	$339,946	$324,479	$380,192	$376,879
800514	SO	NY	$215,570	$203,617	$179,591	$181,451
800515	SO	NY	$21,730	$23,650	$26,247	$23,023
841114	SO	NY	$377,743	$355,163	$461,332	$570,246
841115	SO	NY	$46,047	$35,586	$53,062	$48,092
841115	SO	NY	$21,919	$60,549	$30,126	$79,566
901112	SO	NY	$2,514,474	$3,456,641	$2,605,612	$4,274,144
901113	SO	NY	$2,087,402	$1,888,018	$2,413,905	$2,196,037
901114	SO	NY	$206,660	$223,576	$170,059	$177,292
Contemporary Art (Christie's London)						
871203	(morning session)		$93,510	$83,901	$78,738	$95,791
871203	(afternoon session)		$17,333	$11,283	$14,041	$9,721
931202	(morning session)		$75,666	$74,444	$73,741	$90,362
931202	(afternoon session)		$11,540	$10,053	$10,543	$10,079

Note that we assume valuations to be independent across bidders, that is, learning another bidder's valuation for an object does not affect a bidder's own valuation for the object. Milgrom and Weber (1982b) show that if bidders' valuations are positively correlated (more precisely, affiliated), then prices will tend to rise over time in a sequence of auctions of identical objects. The same logic would apply here, so allowing for common values would not explain price decline. There is some evidence of an upward drift in the first few observations, and common-value effects might explain this drift. An alternative explanation for the upward drift could be the arrival of new bidders, rather than the common-value element. After the common information about the state of the market has been revealed, or an influx of new bidders has occurred, the forces studied in our model might be dominant.

In the case of the English auction, suppose that the bidders have valuations $v_1 > v_2 > \ldots > v_n$ for the first object and α times these valuations for the second object. In the second auction it is clearly a dominant strategy to bid up to one's valuation. Hence the object will sell for the valuation of the second-highest remaining bidder. If, as will be seen to be the case, the first object goes to the bidder with highest valuation, the second object will therefore go to the bidder with second-highest valuation and sell for αv_3. (If $n = 2$, set $v_3 = 0$.) Consider the strategy of a bidder in the first auction. So long as more than one other bidder is active, he should continue bidding unless the price exceeds his valuation. If all other bidders follow this strategy, then they will drop out until the bidder with third-highest valuation drops out at price v_3. At this point, both remaining bidders know that whichever of them wins this time, the other will win the second object at price αv_3. Now a bidder with valuation v is indifferent between winning today at price p and tomorrow at price αv_3 if

$$v - p = \alpha(v - v_3),$$

so he will continue bidding up to price

$$p = (1 - \alpha)v + \alpha v_3.$$

It follows that the first object will be bought by the bidder with highest valuation at the reservation price of the second bidder, that is,

$$(1 - \alpha)v_2 + \alpha v_3. \tag{1}$$

This clearly exceeds the price of the second object, αv_3, so there is price decline. Now this decline is due in part to quality decline, so it is natural to correct for this by dividing by estimated valuation. Suppose that the presale estimate of the first object is k. Since quality of the second object is α times that of the first, it is reasonable to assume that the presale estimate of the second will be αk. The ratio of price to estimate will therefore be

$$(1 - \alpha)\frac{v_2}{k} + \alpha\frac{v_3}{k} \tag{2}$$

for the first object and

$$\frac{v_3}{k} \tag{3}$$

for the second. Since v_2 exceeds v_3, it follows that (2) exceeds (3) and so there is price decline relative to the estimate. Hence a primary implication of ordering by declining values is a price decline relative to the estimate throughout the auction.[7]

This argument implicitly assumes that the auctioneer's estimates are made without taking into account the order of the auction. This seems realistic, as sellers approach

[7] This argument ignores the possibility that the auctioneer may set a reservation price. It is shown in the Appendix that the optimal reservation prices have the form K for the first object and αK for the second object. If all values are replaced by $\max\{v, K\}$, equations (1) to (3) continue to hold.

auction houses and are given estimates independently. Furthermore, a representative responsible for publishing the estimates in wine auctions stated that her purpose at Christie's was not to predict the price of the sale, but rather to establish a range in which the item will likely sell, based on previous sales. There is no evidence that the auctioneer takes account of the order when preparing the estimate. Even if the auctioneer wished to do so, the position a painting will appear in depends on the other paintings in the auction; since the age and nature of these varies widely between auctions, it would be hard to predict order accurately. It therefore seems reasonable to assume that estimates do not reflect the consideration of ordering but rather the differences in market value attributable to the intrinsic features of the painting.

If the auction were a sequence of sealed-bid auctions, then expression (3) would be unchanged but v_3 in (2) would be replaced by the expected value of the valuation of the third-highest bidder given that v_2 is the second-highest valuation. The latter (times α) is the second-highest bidder's estimate of the price for the second object. The rest of the results are unchanged, and there is price decline in expectation.

One might ask whether the seller is well advised to sell the objects in this fashion. In the Appendix we show that such a mechanism maximizes expected revenue when bidders are symmetric and their valuations are independent. The explanation given is therefore consistent with the use of sequential auctions. The obvious alternative mechanism of selling in reverse order of quality is in fact somewhat problematic. The intuition can be demonstrated using a simple example of two objects and two buyers. If bidder 2 drops out at price zero for the first object, then bidder 1 will have surplus αv. But if bidder 1 were to drop out first, he would win the second object at price zero and have surplus v. It follows that both bidders will drop out immediately (assuming negative bids are not allowed!). The first object will then presumably be allocated randomly to one of the bidders. The argument in the Appendix shows that an efficient mechanism must allocate the higher-value object to the bidder with higher value with probability one, so this mechanism cannot be efficient.[8] It is in fact easy to see this directly. Note that the seller receives revenue zero. By contrast, if the objects are sold in decreasing order of quality, the seller will receive $(1 - \alpha)v_2$ (see (1)) for the first object and zero for the second.[9] Revenue is therefore greater by selling in order of decreasing quality.[10] This may explain why objects tend to be sold in declining rather than ascending order of quality.

Our analysis so far has assumed that quality affects preferences in a simple multiplicative way. Though this is a common and arguably natural specification, it is somewhat restrictive. Suppose instead that if a buyer's valuation for the first object is v, then his valuation of the second object is $\phi(v)$, where $v > \phi(v)$ and ϕ is increasing. Suppose further that $v - \phi(v)$ is increasing. This implies, as noted at the beginning of the section, that someone who likes Picasso in general is likely to be willing to pay a higher premium for a good Picasso, as seems plausible. We show below that even though the price-to-estimate ratio need not decline for every possible realization of seller valuations, as is the case with multiplicative preferences, this ratio will decline on average under reasonable assumptions.[11]

[8] It may be optimal to set a high reserve price and so sometimes not sell an object, but this will not be so if the gap between the buyers' and seller's valuation is large.

[9] This argument assumes that the seller does not set a reserve price for the first object and that one of the buyers must receive it even if he bids zero. It is shown in the Appendix that even if this is not the case, the auction is still inefficient.

[10] With more than two bidders, even the existence of equilibrium is problematic.

[11] One can also extend the optimality argument in the Appendix.

Bidding is as before, except that now the buyer with second-highest valuation is indifferent between winning the second object and the first object when the price of the first object is given by[12]

$$p = v_2 - \phi(v_2) + \phi(v_3). \tag{4}$$

Since bidders with higher valuations enjoy a relatively large surplus, one might expect $v_2 - \phi(v_2)$ to be large compared to the typical difference in valuations between the two auctions and hence for there to be price-to-estimate decline on average.

To see this, let k be the estimate for the first object and $\tilde{k}$ the estimate for the second object. From (4) it follows that

$$\frac{p}{k} - \frac{\phi(v_3)}{\tilde{k}} = \frac{v_2 - \phi(v_2)}{k} - \frac{k - \tilde{k}}{k}\frac{\phi(v_3)}{\tilde{k}}.$$

Hence

$$\epsilon\left(\frac{p}{k}\right) - \epsilon\left(\frac{\phi(v_3)}{\tilde{k}}\right) > 0$$

(that is, the price-to-estimate ratio declines in expectation) if and only if

$$\epsilon(v_2 - \phi(v_2)) > (k - \tilde{k})\frac{\epsilon\phi(v_3)}{\tilde{k}}. \tag{5}$$

When $\phi(v) = \alpha v$, the ratio of valuations for the two objects is independent of v, so it is natural to suppose that $\tilde{k} = \alpha k$. In this case, (5) holds trivially (indeed, there is always price decline). With the current more general specification, however, it is less obvious what to assume about these estimates. One plausible interpretation of the estimate is that it is an estimate of what the object would sell for if sold independently, that is, neglecting considerations of order. (As noted above, estimates are made before order is known.) Now in an English auction, the object will sell at the valuation of the second-highest bidder. Hence k and $\tilde{k}$ would be an estimate of the second-order statistic of a sample of bidders (possibly of random size). Hence it might be reasonable to assume that $k = \epsilon v_2$ and $\tilde{k} = \epsilon\phi(v_2)$. Under these assumptions, (5) always holds, since $v_2 > v_3$ implies $\epsilon(\phi(v_2)) > \epsilon(\phi(v_3))$. More generally, there will certainly be price-to-estimate decline provided $\epsilon(v_2 - \phi(v_2))$ exceeds $k - \tilde{k}$, which seems reasonable, as people with higher valuations have relatively large preferences for the first object, and $\tilde{k}$ is not too much smaller than $\epsilon\phi(v_3)$.

Our model assumes that valuations of the objects are perfectly correlated. The results should generalize to some imperfect correlation, but the analysis is harder, as the second-highest bidder in the first auction need not be the winner of the second.

Our analysis assumes that each buyer wishes to only buy one object. In other words, we think of art buyers as being rapidly satiated by paintings. If buyers were to continue to bid, this would tend to mitigate the downward pressure on prices.

A practical reason why buyers may buy only one painting is the existence of cash constraints: they might like to buy two paintings but cannot afford to! Our model cannot

[12] Since $v - \phi(v)$ is increasing, the highest-valuation bidder prefers to win the first object at price p, rather than let the second-highest-valuation bidder win the first object and win the second object at price $\phi(v_3)$. Hence this is indeed an equilibrium.

strictly be interpreted as one with cash constraints, as whether these bind depends on the realized prices of paintings, but one would expect similar results to hold if cash constraints were modelled explicitly.

4. Declining prices and presale estimates

■ The above model suggests that ordering by value should produce price decline relative to the estimate throughout the auction. In this section we test this empirical implication. As a formal test of whether there are predictable differences in the auction price, the presale estimate, and the auction price relative to the presale estimate over the sequence of an auction, we regress the log of the bid price, the log of the presale estimate, and the log of the bid price controlling for the presale estimate on numerical order of sale, with dummy variables for the different auctions. We also present estimates where we restrict the coefficient on the presale estimate to be one and regress the log of the ratio of the price to presale estimate on order. In all cases this restriction is rejected, though we continue to present the results for comparison. We present separate regressions for the dataset consisting of Contemporary Art and the dataset consisting of Impressionist and Modern Art. The order used in the dataset for Contemporary Art is the true order in which the items appear in the auction, since the dataset contains all items. The order used in the dataset for Impressionist and Modern Art is the order in which the different items created by the 58 artists in the selected sample appear in each auction.

In columns 1–8 of Table 5, we present these regression results for the Contemporary Art dataset, and in columns 9–12 of Table 5, we present results for Impressionist and Modern Art. For Contemporary Art, in columns 1–4, all items are used and the highest quote stated by the auctioneer is used as the bid price. In columns 5–8, only sold items are used. Column 1 indicates that for Contemporary Art, the bid price decreases about .51% per unit sold and column 2 indicates that the presale estimate decreases about .43% per unit sold. Column 3 indicates that even controlling for the presale estimate, the bid decreases about .09% per item sold, and the restricted estimates in column 4 indicate a decrease of .082% per item sold. As there are on average 69 items included in a Contemporary Art auction, these numbers represent a presale estimate decline of approximately 30% throughout the auction and a bid decline, relative to the estimate, of approximately 6.21% throughout the auction. The regression estimates using only sold items, as in columns 5–8, are similar to the estimates using all items.

The regression results using Impressionist and Modern Art are similar in nature. The data indicate that the bid decreases about 1.28% per unit sold and the presale estimate decreases about 1.27% per unit sold. As there are on average 73 items sold in this selected sample per auction, these numbers represent a presale estimate decline of approximately 92% throughout the auction. This is a very large decline, though perhaps not surprising considering the large declines between sessions, as indicated by Table 3. Column 11 shows that when controlling for the log of the estimate, the log of the bid price decreases about .05% per unit sold. This represents a price decline, relative to the estimate, of approximately 3.5% throughout the auction. When the coefficient on the log of the presale estimate is restricted to be one, the log of the ratio of the price to presale estimate decreases about .012% per item sold, but is not quite significant.

The above estimates indicate that the price relative to the average estimate decreases throughout an auction. One reason that could explain the decline is that the auctioneer may be altering the estimates for types of paintings that come later in an auction. For example, the auctioneer may be overvaluing more-recent works of art.

The price relative to the estimate decline could be taking place because of the overvaluation and not because of the structure of the auction order.

Biased valuation should in itself be of interest to economists. Milgrom and Weber (1982a) show that it is in an auctioneer's best interest to present the true valuation.[13] This is consistent with the intuition given that since these auctions are repeated again and again, it would be difficult to justify systematic misvaluation.

The empirical framework we use to test for valuation bias is to include painting characteristics in the regressions of bids and estimates on order. Significance of these characteristics in a regression of the log of the bid price on the log of the estimate may indicate that valuation bias is occurring. If the negative coefficient on the order variable disappears when these covariates are included, this result would indicate that the valuation bias is driving the price decline relative to the estimate.

In addition to including painting characteristics as regressors, we also include the logarithm of the difference between the auctioneer's low estimate and the auctioneer's high estimate. The spread is clearly correlated with order in that items with higher valuations have a higher spread. For example, lot number seven of the June 1994 auction of Contemporary Art had a low estimate of £40,000 and a high estimate of £60,000, whereas lot number 47 had a low estimate of £27,000 and a high estimate of £35,000. However, an additional concern is that perhaps auctioneers place items that are more difficult to value toward the end of the auction, and likewise increase the spread for items the auctioneers consider "risky." Hence, even after controlling for the estimate, the spread could be correlated with order and could possibly affect the price-to-estimate ratio. For example, during the December 1985 auction, the low estimate for lot number 56 was £3,500 and the high estimate was £4,000, and for lot number 57, the low estimate was £2,500 and the high estimate was £3,500.[14] We therefore include the logarithm of the spread in the regressions.

Table 6 presents regressions with covariates. Column 1 of Table 6 presents a regression of the logarithm of the bid price on the numerical order in which the works of art were sold in a particular auction, controlling for painting characteristics and dummy variables for each different auction, again using the dataset of Contemporary Art. Because observations on length, width, medium, and painting date do not exist for all items, there are now only 2,801 observations in each regression. Column 1 indicates that the bid decreases about .07% per unit sold. While the decrease in the bid remains significant when covariates are included, the decrease in the estimate is far from significant and is of magnitude of approximately .015%. In both columns 3 and 4, when the estimate is controlled for, the bid decreases about .056%. This is about 60% of the decrease when covariates were not included, and it indicates a 3.8% decline throughout the auction. The F-statistic for the included covariates is 4.65 for column 3 and 4.64 for column 4, indicating that these variables are jointly significant.

In the specifications in columns 5–8, we perform similar regressions for Impressionist and Modern Art. There are now only 8,792 items, due to lack of observations on some item characteristics. Column 5 of Table 6 indicates that when item characteristics are controlled for, the bid still decreases about .11% per item sold. The estimate also continues to decrease about .06% per unit sold, and the coefficient on order is statistically significant. In column 7, when the bid is regressed on order, and the estimate along with other covariates are included in the regression, the bid still declines approximately .054% per unit. The F-statistic testing the joint significance of the covariates is 7.79, again strongly indicating joint significance. This estimate is very similar

[13] They do, however, assume symmetric bidders with no collusion and that estimates do not affect entry, which may be strong assumptions in the context of art auctions.

[14] It is not always the case that spreads increase with order.

TABLE 5 Order Regressions Without Covariates

	Contemporary Art							
	All Auction Items				Auction Sale Items			
	1 Bid	2 Estimate	3 Bid	4 Bid/ Estimate	5 Bid	6 Estimate	7 Bid	8 Bid/ Estimate
Order	−.00514 (.00044)	−.00432 (.00041)	−.00090 (.00017)	−.00082 (.00016)	−.00538 (.00048)	−.00456 (.00047)	−.00098 (.00018)	−.00082 (.00018)
Estimate			.98312 (.00593)				.96547 (.00637)	
Auction dummies (F-statistic)	37 99.05	37 110.93	37 22.56	37 22.65	37 74.48	37 76.55	37 16.96	37 16.38
R^2	.458	.4851	.9234	.1571	.4496	.4558	.9273	.1484
Number of observations	4,558	4,558	4,558	4,558	3,531	3,531	3,531	3,531

Note: Standard errors are in parentheses.

to the estimate without covariates. Finally, in column 8, when the bid-to-estimate ratio is regressed on order and covariates, we find a .048% decline per item, indicating about a 3.5% decline in the bid-to-estimate ratio throughout the auction. The covariates again are jointly significant, with an F-statistic of 7.65.

In the above regressions we used a simple average of the high estimate and the low estimate as the average estimate. We also estimated each of the above specifications using the high estimate as a measure of the estimate and using the low estimate as a measure of the estimate. The results from these regressions are very similar to the results in which we used a simple average. All coefficients on order are very similar in magnitude and significance to the regressions presented in Tables 5 and 6.

As the decline in price relative to the estimate does not disappear when covariates are included, it does not appear that valuation bias is driving the results.

The estimates do indicate that there is some bias in the presale valuations. Columns 3 and 4 of Table 6 indicate that for Contemporary Art, more recently executed art works are overvalued and longer and wider paintings are undervalued. For Contemporary Art, some, though not all, of the decline in the price-to-estimate ratio is probably due to overvaluation of more recently executed works. Columns 7 and 8 of Table 4 indicate that for Impressionist and Modern Art, wider, signed, and monogrammed paintings may be underestimated relative to their value. Medium dummy variables and the artist dummy variables are jointly highly significant, as indicated by the F-statistics reported in the regressions. It is somewhat interesting that more recent works of art appear to be overvalued for Contemporary Art, but there is no such bias (the coefficient is positive, but far from significant) for Impressionist and Modern Art. One explanation may be that recent works of Contemporary Art are very difficult to value because they have been exchanged rarely, if at all. However, the later works of Impressionist and Modern Art are already very well known and have most likely been exchanged in the past.

The estimates reported above indicate that it is not the case that auctioneers report the true value of an item, which may or may not be intentional. Perhaps most interestingly, in Contemporary Art, the younger pieces appear to be overvalued relative to the older works. One possible reason for this result may be that as the estimates are likely to be less accurate for the most recent paintings, buyers may experience the

TABLE 5 ***Extended***

Impressionist and Modern Art			
Auction Sale Items			
9 Bid	10 Estimate	11 Bid	12 Bid/Estimate
−.01278 (.00024)	−.01266 (.00023)	−.00046 (.00008)	−.00012 (.00007)
		.97326 (.00275)	
152	152	152	152
86.83	87.69	10.74	10.18
.5396	.5422	.9616	.1196
11,544	11,544	11,544	11,544

winner's curse more and hence bid lower. It is also interesting that in columns 4 and 8, the coefficient on spread is negative and significant, which also is consistent with the spread being wider for those items for which the estimates are less accurate, and buyers perhaps experiencing winner's curse for these items.

In the above regressions we have not taken into account possible endogeneity between order and the bid-to-estimate ratio. Although sellers approach auction houses and are given estimates independently, to the extent that the estimator can anticipate order based on painting date or possibly other characteristics, endogeneity could potentially be an issue with order and one that could be quite difficult to address, given the data. Endogeneity that results from the auctioneer's shading the estimates for those paintings that are placed later in the auction is likely to bias the estimates downward. Hence, it is possible that we are underestimating the extent of the bid-to-estimate decline with order. However, as the paintings are far from strictly ordered by painting date and it appears that the auctioneer's estimates are made without taking into account the order of the auction, we believe it is unlikely that endogeneity is significantly affecting the results. In the regressions in which the bid is regressed on order and the estimate is controlled for, there is the possibility of endogeneity between the bid and the estimate. However, for two reasons we think this unlikely to be driving the results. First, since we include both auction dummy variables and artist dummy variables, it is unlikely that endogeneity continues to exist after conditioning on these variables. Second, there is very little difference between the coefficient on order when the bid-to-estimate ratio is regressed on order than when the bid, controlling for the estimate, is regressed on order.

In order to explore the sensitivity of the results to the particular grouping that we used, we also ordered the auctions for Impressionist and Modern Art by auction session, where each session is defined as an auction on a particular day at a particular house. As would be expected, the estimate declines within sessions are about a quarter of the size of the estimate declines when sessions on sequential days are grouped into identical auctions. The ratio of the bid-to-estimate decline when covariates are controlled for is .037% per item, as opposed to .048% per item when sequential sessions are grouped into one auction.

We can perform one final test using the Impressionist and Modern Art data. By positively identifying 230 different paintings that were sold in the same location at the

TABLE 6 Order Regressions With Covariates

	Contemporary Art				Impressionist and Modern Art			
	1 Bid	2 Estimate	3 Bid	4 Bid/ Estimate	5 Bid	6 Estimate	7 Bid	8 Bid/ Estimate
Order	.000708	−.000150	−.000576	−.000558	−.001099	−.000620	−.000539	−.000480
	(.000303)	(.000181)	(.000257)	(.000258)	(.000118)	(.000077)	(.000096)	(.000096)
Painting date	−.161252	−.067855	−.101171	−.093398	.001105	−.003127	.003936	.004232
	(.044541)	(.026609)	(.037856)	(.037921)	(.027077)	(.017589)	(.021901)	(.021963)
Length	.132182	.061281	.077921	.070901	.084168	.067120	.023401	.017048
	(.027114)	(.016198)	(.023080)	(.023084)	(.015444)	(.010032)	(.012524)	(.012527)
Width	.172943	.112680	.073171	.060263	.115891	.074728	.048236	.041164
	(.026750)	(.015981)	(.022932)	(.022775)	(.016160)	(.010498)	(.013110)	(.013108)
Value added tax	−.015502	.017595	−.031081	−.033097				
	(.027241)	(.016274)	(.023128)	(.023193)				
Signed					.116787	.042539	.078274	.074248
					(.018619)	(.012095)	(.015071)	(.015103)
Monogrammed					.047753	.011261	.037557	.036492
					(.013288)	(.008632)	(.010749)	(.010778)
Stamped					.015439	.005098	.010824	.010341
					(.007984)	(.005186)	(.006458)	(.006476)
Estimate			.885444				.905356	
			(.028513)				(.013454)	
Spread	.708864	.853163	−.046564	.144299	.818919	.885967	.016803	−.067048
	(.013460)	(.008041)	(.026876)	(.011459)	(.005994)	(.003894)	(.012868)	(.004862)
Medium dummies	19	19	19	19	11	11	11	11
(*F*-statistic)	8.96	7.34	4.09	3.56	33.48	37.44	8.54	6.65
Artist dummies	255	255	255	255	56	56	56	56
(*F*-statistic)	3.56	2.67	2.74	2.66	11.92	11.13	5.29	4.74
Auction dummies	37	37	37	37	151	151	151	151
(*F*-statistic)	17.92	5.64	17.38	16.89	10.15	7.98	9.73	9.58
R^2	.9246	.9721	.9457	.3734	.9421	.975	.9621	.1674
Number of observations	2,801	2,801	2,801	2,801	8,792	8,792	8,792	8,792

Note: Standard errors are in parentheses.

same auction house but in different auctions between 1980 and 1990, we can difference out the fixed effects of identical paintings.[15] Table 7 presents regressions where the change in the log of the bid is regressed on the change in the order percentile, controlling for the change in the log of the estimate, and the change in the log of the bid-to-estimate ratio is regressed on the change in the order percentile. The coefficient on the change in order percentile is negative and significant in both regression specifications. As the average change in order percentile is .20, this indicates a 9% decline between identical items placed relatively later in an auction with respect to an identical item placed relatively earlier in a different auction.[16] While this is a selected sample and selection bias could be affecting the coefficient on order (in both directions), we interpret these results as supporting the hypothesis that prices decline relative to the estimates throughout the auction.

[15] These paintings have identical titles, medium, artist, and painting date. As many paintings have identical titles, title and artist are not sufficient identifiers.

[16] There are 248 observations, rather than only 230, because some items were sold more than twice during the period.

TABLE 7 Impressionist and Modern Art

	1 Change in Bid	2 Change in Bid/Estimate
Change in order percentile	−.46999 (.15535)	−.45839 (.15570)
Change in estimate	.95535 (.02618)	
Constant	.09446 (.04352)	.09187 (.04366)
R^2	.8467	.034
Number of observations	248	248

Note: Standard errors in parentheses.

5. Alternative explanations

■ The above estimates indicate that art auctions are ordered approximately from highest to lowest value. Furthermore, the price relative to the estimate is higher at the beginning of the auction, where estimates are also higher, than at the end. Declining estimates, however, are not the only possible explanation for price decline relative to the estimate, and we briefly review below the literature on why prices may decline throughout auctions of homogeneous objects.

McAfee and Vincent (1993) suggest that declining prices in auctions of homogeneous goods, such as wine, can be explained by risk aversion. Intuitively, a buyer may be prepared to pay a higher price than the expected price next period if he dislikes risk. The power of this explanation depends on the degree of information revealed in this period. If all bids are observed, there is in fact no uncertainty about valuations, so this explanation has no bite. If, however, the auction is more like a second-price sealed-bid auction or uncertainty about valuations occurs, then risk aversion may be important. An unappealing feature is that a pure-strategy equilibrium exists only when there is nondecreasing absolute risk aversion, which is usually thought implausible. Mixed-strategy equilbria are, with positive probability, *ex post* inefficient.

Bernhardt and Scoones (1994) and Engelbrecht-Wiggans (1994) show by example that prices may decline in a series of auctions if buyers' valuations are not perfectly correlated between auctions even if the objects are stochastically equivalent (that is, buyer's valuations are drawn from identical and independent distributions for each object). They assume that buyers do not know their own future valuations, which seems implausible for art sales. Gale and Hausch (1994) again consider a model with stochastically equivalent objects but assume that buyers know their future valuations, which may be correlated with their current valuations. They consider only the case of two bidders and show by example that prices may decline. They do not give a general condition in terms of the primitives of the model for there to be price decline.[17,18]

Much of the above work was driven by the empirical literature that indicates declining prices for homogeneous bottles of wine or condominiums. While some of the above explanations, primarily risk aversion, could be applicable in the art market,

[17] They give a condition in terms comparing revenue from the sequential auction and a right-to-choose auction.

[18] For other explanations of price decline for homogeneous objects, see Black and de Meza (1992) and von der Fehr (1994).

declining estimates as the driving force for price relative to estimate decline is in some ways more intuitively appealing. As opposed to risk aversion, declining estimates will still produce a price-to-estimate decline in pure English auctions, where all valuations are observed. Furthermore, a decline in the price relative to the estimate resulting from declining estimates, as shown above, is *ex post* efficient.

Our model suggests that if items remain substitutes, a larger decline in the estimate throughout the auction should result in a larger decline in the price relative to the estimate. In some ways this may be difficult to test. The result that a very cheap item may not be a substitute for an expensive item may override the price decline relative to estimate suggested by the model. For example, since Impressionist and Modern Art is both more expensive and has a higher standard deviation in price than Contemporary Art, it may be reasonable to presume that individuals are less willing to substitute between Impressionist paintings than between works of Contemporary Art.

If our model is taken literally and all items are substitutes, one would expect a rational auctioneer to auction items in exact decreasing order of value. This does not happen in practice. One explanation is that all items are not substitutes. For example, when van Gogh's *Portrait of Dr. Gachet* was sold at Christie's in New York in 1990 for a record \$69 million, it is unlikely that the buyer would consider another painting as a substitute. Concerns by the auctioneer relating to seller and buyer relations may also discourage the auctioneer from ordering exactly by value. Finally, the belief by the auction house (as related by the representatives) that time is needed to build an exciting atmosphere and that people get tired toward the end of an auction discourages exact ordering by value.

6. Conclusion

■ In this article we have shown that the presale estimate declines with order in auctions of Contemporary Art and in auctions of Impressionist and Modern Art. Furthermore, we have shown that the price relative to the presale estimate also declines with order. While theories of price decline in sequential auctions of homogeneous items may also apply to our findings, in a simple theoretical model we show that valuation decline throughout the auction may also induce price decline relative to the presale estimate. Furthermore, our model indicates that ordering an auction from highest to lowest value is an optimal strategy for an auctioneer.

Appendix

■ This Appendix outlines a proof of the optimality of sequential sales in order of declining valuation in the current model. All the arguments are variants on standard ones, so some are only sketched, and the reader is referred to, for example, Myerson (1981) for details.

It is assumed that there are n buyers, with $n \geq 2$, for the two objects. A buyer with valuation v for the first object has valuation αv for the second object, provided the first object was not acquired (and zero if it was), where $0 < \alpha \leq 1$. Valuations are drawn independently from the interval $[\underline{v}, \overline{v}]$ with density function $f(v)$ and distribution function $F(v)$ for all buyers. The seller has valuation zero for the object ($\underline{v} > 0$).

It will be shown that sequential sales are optimal in the class of all incentive-compatible mechanisms. By the revelation principle, one need only consider direct revelation mechanisms, that is, those in which the seller asks buyers to reveal their true valuations and it is optimal for buyers to do so truthfully (see Myerson, 1981). Such a mechanism in this context is specified by the probability with which each buyer receives each object and the payment he must make as a function of buyers' announcements. Suppose that buyers 1 to n claim that their valuations are $s_1, \ldots, s_n$. Let $p_i^1(s_i, s_{-i})$ be the probability that agent i receives object 1 and object 1 alone if his message is s_i and the vector of other messages is s_{-i}. Similarly let $p_i^2(s_i, s_{-i})$ be the probability that he receives object 2 alone. In principle, an agent might receive both objects, but as he wants only one, it is clear that this cannot be optimal; to save notation, this probability will be set to zero throughout. Let $T_i(s_i, s_{-i})$ be the payment buyer i must make with messages s_i and s_{-i}. The mechanism will be denoted by the pair (p, T).

Let $\overline{U}_i(s, v)$ be the expected surplus of buyer i if his valuation is v and he claims it is s. That is,

$$\overline{U}_i(s, v) = v\overline{p}_i^1(s) + \alpha v\overline{p}_i^2(s) - \overline{T}_i(s),$$

where $\overline{p}_i^1$ is the marginal probability that he wins object 1, similarly for $\overline{p}_i^2$, while $\overline{T}_i$ is his expected payment if he announces s. All expectations are taken under the assumption that all other players announce their valuations truthfully.

In order that players wish to participate, they must be guaranteed an average payoff of at least zero (their outside option), which is the individual rationality (IR) constraint, that is,

$$\overline{U}_i(v, v) \geq 0 \tag{IR}$$

for all v and i. In addition, it must be optimal to tell the truth (the incentive constraint (IC)), that is,

$$\overline{U}_i(v, v) \geq \overline{U}_i(s, v) \tag{IC}$$

for all s, v, and i. Let $S_i(v) = U_i(v, v)$ be player i's payoff from telling the truth.

Using (IC) and (IR) one obtains, as in the standard case,

Lemma A1. A mechanism (p, T) satisfies (IR) and (IC) if and only if

$$\overline{p}_i^1(s_i) + \alpha\overline{p}_i^2(s_i) \tag{A1}$$

is increasing in s_i,

$$S_i(v_i) = S_i(\underline{v}) + \int_{\underline{v}}^{v_i} [\overline{p}_i^1(s) + \alpha\overline{p}_i^2(s)]\, ds \tag{A2}$$

for all i and v_i and

$$S_i(\underline{v}) \geq 0 \tag{A3}$$

for all i.

It is easy to check that in an optimal mechanism, $S_i(\underline{v}) = 0$ for all i, so using (A2) one obtains

$$\overline{T}_i(v) = \overline{p}_i^1(v)v + \alpha\overline{p}^2(v)v - \int_{\underline{v}}^{v} [\overline{p}_i^1(s) + \alpha\overline{p}_i^2(s)]\, ds.$$

$\overline{T}_i(v)$ is expected revenue i from buyer i if his valuation is v_i. Summing over all i and taking expectations, one obtains

Lemma A2. Expected revenue from a mechanism (p, T) is given by

$$\int_V \left(\sum_i p_i^1(v)\left(v_i - \frac{1 - F(v_i)}{f(v_i)}\right) + p_i^2(v)\alpha\left(v_i - \frac{1 - F(v_i)}{f(v_i)}\right)\right) f(v)\, dv. \tag{A4}$$

V denotes the n-fold product of $[\underline{v}, \overline{v}]$, v the vector $(v_1, \ldots, v_n)$ and $f(v)$ the product of $f(v_i)$ over i. It follows that in order to maximize revenue, one must choose p to maximize (A4). p is subject to the following constraints:

$$0 \leq \sum_i p_i^1(v) \leq 1 \qquad 0 \leq \sum_i p_i^2(v) \leq 1 \tag{A5}$$

for all i and v, and

$$0 \leq p_i^1(v) + p_i^2(v) \leq 1 \tag{A5}$$

$$p_i^1(v),\ p_i^2(v) \geq 0 \tag{A7}$$

for all i and v. That is, the probability that each object goes to someone is at most one, the probability that each person receives an object is at most one, and these probabilities must be nonnegative. Note that T does not enter (A4) explicitly. Any mechanism (p, T) with the same probability vector p yields the same revenue.

Conversely, given a probability vector p satisfying (A1), one can construct a mechanism $(p, \hat{T})$ that yields the revenue in (A4) by setting

$$\hat{T}_i(v) = p_i^1(v) + \alpha p_i^2(v) - \int_{\underline{v}}^{v_i} [p_i^1(s, v_{-i}) + \alpha p_i^2(s, v_{-i})]\, ds. \tag{A8}$$

This clearly satisfies (A2) and (A3) and so is implementable. Summarizing,

Proposition A1. If p maximizes (A4) subject to (A1), (A5), (A6), and (A7) and T is given by (A8), then (p, T) is an optimal mechanism. Any mechanism with the same probability vector that gives a buyer with valuation $\underline{v}$ zero surplus yields the same expected revenue.

If one neglects constraint (A1), then the objective function is linear, as are the constraints. In this relaxed problem it is easy to check that one should set $p_i^1(v) = 1$ if v_i gives the largest value of

$$G(v) = v - \frac{1 - F(v)}{f(v)} \quad \text{and} \quad p_j^2(v) = 1$$

if j gives the largest but one value, so long as these values are positive. If either one is negative, the corresponding value of p is zero. This corresponds to setting a reserve price. The following regularity (R) assumption is standard:

$$v - \frac{1 - F(v)}{f(v)} \quad \text{is increasing in } v. \tag{R}$$

$1 - F(v)/f(v)$ decreasing, that is, F has an increasing hazard rate, is sufficient but not necessary for (R). Under this assumption, the solution of the relaxed problem is equivalent to $p_i^1(v) = 1$ if v_i is the largest value of v and $p_j^2(v) = 1$ if v_j is the largest but one value, provided the values exceed $G^{-1}(0)$. If not, the corresponding probabilities are zero. If $G(v)$ is positive for all v in $[\underline{v}, \bar{v}]$, then $G^{-1}(0)$ is understood to be $\underline{v}$ and it is always optimal to sell. It is straightforward to check that (A1) is automatically satisfied. This therefore establishes

Proposition A2. If (R) holds, then any mechanism that gives the first object to the bidder with highest value with probability one and the second to the bidder with highest value but one, provided these exceed $G^{-1}(0)$, and gives a buyer with valuation $\underline{v}$ zero surplus is optimal.

If the seller employs the sequential English auction of the text and sets reservation price $G^{-1}(0)$ in the first auction and $\alpha G^{-1}(0)$ in the second, then this will ensure that the objects are indeed allocated to the highest and highest bar one value bidders respectively and that buyers with valuation $\underline{v}$ have zero surplus. Hence one has

Proposition A3. If (R) holds, then a sequential English auction in descending order of estimate with appropriate reservation prices is optimal.

Note that the reserve prices derived are optimal if the auctioneer can commit himself to them in advance (which is plausible, since reserve prices are set in advance). If the auctioneer learns that bidders' valuations are in fact low, then he might wish to lower the reserve price, but such lack of commitment would make him worse off.

Finally, consider the case of the English auction in ascending order of quality. Attention is restricted to the case of two bidders. To be efficient, such an auction must satisfy the conditions of Proposition A2. In particular, since the first object is supposed to go to the bidder with lower valuation, the auctioneer must set a reserve price of $\alpha G^{-1}(0)$ for the first object and $G^{-1}(0)$ for the second. It will be assumed that if neither buyer bids for the first object it will be withdrawn and the second auctioned off.

Consider the case when both valuations exceed $G^{-1}(0)$. In such a case, efficiency requires that both objects be sold with probability one, with the first object going to the bidder with lower valuation with probability one. It will be shown that this cannot be the case. It is clear that neither buyer will offer more than $\alpha G^{-1}(0)$ for the first object. If both offer this amount, assume that the object is allocated randomly.

Suppose that time is continuous and that if no acceptable offer is received up to and including time T, the first object is to be withdrawn. Since each player prefers the other to win the object, it can only be an equilibrium for a player to bid before T if the other never bids. This cannot be efficient, as the first object then need not go to the player with lower valuation. The only other possibility is that they bid simultaneously at T. In order that the object always be sold then, conditional on his valuation exceeding $G^{-1}(0)$, at least one buyer must bid with probability one. In this case, the other buyer will not bid, and again the object need not go to the player with lower valuation. The auction therefore cannot be efficient.

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