How Informed are Sellers of Nonhomogeneous Goods?: Market Structure and Pricing Behavior in the South African Art Auction Market, 2009 - 2013*

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Abstract

In a novel data set of 7553 auction lots from an art market, an auction house with dominant market share provides more conservative pre-sale price estimates than a competitor auction house. Analysis of strategic interaction between sellers of assets and a dominant and competitor auction house shows that: with informed owners auction houses have an incentive to provide valuations convergent to owners' payoff maximizing prices; with myopic owners the competitor auction house is forced to mark up valuations over the dominant auction house's valuation.

JEL Codes: D2, D4, D8, L1, L8.

Keywords: nonhomogeneous goods; uncertainty of asset valuation by owners; market structure; art markets.

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1 Introduction

Begin with an empirical puzzle: in a regional fine art market, characterized by the presence of a dominant and competitor auction house as defined by market share, the competitor provides price estimates for auction at a markup over the price estimates the dominant auction house provides. The puzzle bites since there is compelling evidence that the auction houses have recourse to a common pool of expertise in valuation, eliminating information asymmetries across the houses as an explanation, and since the prior in economics is that owners of assets of value have an incentive to be informed of the value of their assets, creating the expectation of a market discipline on the price evaluations of the auction houses.

How can this divergent pricing behavior be explained?

The explanation presented in this paper is that the sellers of nonhomogeneous assets such as art may plausibly be myopic after all. The theory of this paper demonstrates that where sellers of nonhomogeneous assets are informed, auction houses have an incentive to provide valuations as close as possible to the price the seller expects will maximize payoff, irrespective of market structure. By contrast, in the presence of myopic sellers, market structure becomes important: the competitor is forced to operate at a markup on the price estimate that the dominant auction house provides the seller. Therefore, conditional on myopic sellers and the presence of market structure in the auction market, pricing behavior across auction houses is rationally divergent rather than convergent.

As a result both theory and empirical results of this paper stand in contrast to most of the literature that examines art auction markets. Focus of the literature has been principally on the pricing mechanism of art works in general, without distinguishing which intermediary (auction house) sold the art work, whereas this paper emphasizes the importance of market structure between auction houses. In terms of prior empirical findings, Ashenfelter (1989) finds no evidence of bias in auction house estimates relative to hammer price. Generally the literature confirms this finding, though there is some evidence of bias on particular types of art work (Beggs and Graddy, 1997), or by auction house (Bauwens and Ginsburg, 2000; Chanel et al, 1996).

While the present paper is explicitly framed in terms of art auctions, and uses data from a specific art market (South Africa), the reach of the paper is more general. First, the analysis is not applicable only to art markets, but extends to any assets, goods or services that are characterized by a low degree of homogeneity.

Second, consideration is on the impact of having dominant and competitor auction houses (hence market structure). Third, what is demonstrated is that in the presence of market structure, information asymmetries affecting owners of assets become particularly salient to market equilibrium in terms market intermediary behavior. Fourth, the focus is on pre-sale price estimates by auction houses, rather than the features of the bidding process in auction itself. To the best of my knowledge, these first four claims to generality also imply novelty, in the sense that these questions have not been examined in the literature to date. Fifth, the emergence of regional loci to the art market, especially the growth of art markets specific to emerging economies, is likely to lead to a greater diversity of market structures than has been analyzed to date in the context of art markets, in contrast to the international art market which is characterized by auction houses that do not manifest markedly divergent market power (eg. Sotheby's, Christie's, Phillips). Studies that explore the significance of market structure on the art market will therefore gain in significance. As a consequence the theoretical framework and empirical methodology developed for this paper, will likely carry insight for other contexts. Finally, while as yet the analysis of emerging art markets is relatively rare - though see Taylor and Coleman (2011), Kraeussl and Logher (2010) and Seckin and Atukeren (2006) - increased economic prosperity in emerging markets is likely to raise the importance of these regional art markets. This paper adds understanding to the South African case.

The paper establishes the empirical puzzle in section 2, and section 3 explains why myopia of sellers rather than information asymmetries across auction houses provides a plausible starting point for an explanation. The theoretical explanation then follows in section 4. Conclusions and evaluations follow in section 5.

2 Establishing the Empirical Puzzle

The foundational empirical claim here is that a dominant auction house, as defined by market share, is providing pre-sale price estimates on auction lots that are lower than those of a competitor auction house, for the same piece of art. Given that art works in principle lay claim to uniqueness, the challenge of establishing this empirical claim is that *prima facie* it rests on a nonobservable counterfactual: how auction houses would have valued the art work that they did not bring to market. Since they did not bring the art to market, the price evaluation they may have provided to sellers is not directly observable.

To establish the puzzle, first the presence of a dominant and competitor auction house in the market examined in this paper is confirmed. Then estimated coefficients from two hedonic price estimations derived from the auction lots each auction house in fact brought to market, are employed to infer counterfactual price estimates that each auction house *would have* offered on the art work auctioned by the rival auction house.[1] This methodology confirms lower pre-sale price estimates by the dominant than the competitor house.

2.1 Data

The novel data set of this paper consists of prices and characteristics of 7,553 art works created by South African artists[2] presented for auction by the two largest South African art auction houses over the 2009-13 period. Of these 5,329 sold, while the remainder were bought in (were unsold). All data points were hand coded using the catalogue of all the fine art auctions that took place in Cape Town and Johannesburg between 2009 and 2013.

Price estimates of the lots are provided directly by the catalogued data of the art auction houses. These estimates are in the form of a low and high estimated price, recorded as the mean of the two limit values in the data set.[3] The hammer price including the buyer's premium is employed to measure the market value of artworks. Where the hammer price is below the reserve price, the sale does not occur and the auction house announces this fact, in common with all major auction houses after a New York State law was passed in the 1980s requiring full disclosure of no sales.

Each auction lot item includes a portfolio of information, such as the biographical information of the artist (the name, birth, death, age), the size of the art object, the date of signature if signed, the material, the theme, the commercial packaging (exhibitions, literature related to the work, presentation format in the catalogue, etc.), and other information. This constitutes the range of variables that constitute the characteristics of the art work itself.[4]

[1] Note that the literature has identified a number of alternative approaches to art work valuation. One focusses on expert judgment. A second common approach is the repeated sales method - see Goetzmann (1993), Locatelli-Biey and Zanola (1999), Mei and Moses (2002), Pesando and Shum (1999). Third is the use of hedonic price equations - see Ashenfelter and Graddy (2003), Chanel et al. (1994, 1996), Chanel (1995), and Gerard-Varet (1995).

[2] This includes artists who were born outside South Africa, but spent the preponderance of their creative life in South Africa.

[3] The minimum expected price is generally viewed as being systematically related to the seller's undisclosed reserve price. Ashenfelter and Graddy (2003) argue that the rule of thumb for art auctions seems to be that the reserve price is 80% of the minimum price estimated by the auction house. For an examination of reserve prices and their relation to expert appraisal, see McAndrew et al (2014).

[4] Note that all information available from catalogues was coded; this does not imply that this is a comprehensive list of

The data set identifies 584 separate artists whose work has been presented at auction, of whom 102 did not report sales. Estimations control for the identity of artists,[5] their life status (alive, dead), their year of birth as well as of death (if deceased), and the age of the artist at the time of the auction.[6] Artist identity is controlled for by three sets of categorical variables. First Tier artists are those for whom more than 50 works have been sold in the market, who are controlled for with individual categorical variables (denoted by individual artist names). Second tier artists are those for whom between 10 and 50 works have been sold. Third tier artists are those for whom less than 10 works have been sold. Both second and third tier artists are controlled for by collective categorical variables for all second ($Tier2$), and all third tier ($Tier3$) artists. The artist for whom there are exactly 50 sales records (Stanley Pinker) serves as reference category.

A range of physical, medium and thematic characteristics of the art works are controlled for. These include the size of the art work (height, width, depth, diameter, if applicable) by means of its area or volume ($Area$), and its non-linear transform ($Area^2$).[7] Additional controls are for whether the artwork is signed, numbered or dated, by three categorical variables (*Signed*, *Numbered*, *Dated*). The medium of the art work is classified in terms of 12 categorical variables: *Oil*, *Water Proof Pigment*, *Watercolor*, *Water Soluble Pigment*, *Mixed Media*, *Diverse Media*, *Ceramic*, *Dish*, *Sculpture*, *Print*, *Photo*, and *Others*,[8] with *Dish* serving as reference category. The theme of the art work is classified in terms of 7 categories: *Portrait*, *Nude*, *Figures*, *Miniature*, *Landscape*, *Abstract*, and *Sketch*, with *Abstract* as reference category.

Additional variables capture how art works are presented in the auction house catalogues. These categorical variables include whether the art work appears on the cover of a pre-sale catalogue ($Cover$), whether the catalogue specifies whether the art work was present in important shows ($Exhibited$), and whether the auction catalogue of the sale catalogue specifies whether the art work was illustrated in relevant art literature

hedonic characteristics relevant to the valuation of the art. It is, however, all that is available for this paper.

[5] Use of artist identity may capture not only an inherent market value that may be associated with specific artists, but may serve as an indirect control for the likely style and subject of the work - see the discussion in Grampp (1989). Estimations here control for artist identity not style.

[6] For deceased artists, the recorded age is the age at the time of death. Higgs and Worthington (2005) suggest that the price of an artwork is often expected to increase once an artist has died when all other variables keep constant, though Grampp (1989) demurs.

[7] Bigger may be better, but for private buyers there may be a limit to the size of art work that can be reasonably accommodated.

[8] Note that this classification is directly the reported classification of the auction house catalogues. Accuracy of specification is therefore contingent on the accuracy and consistency of auction house classification.

(*Illustrated*), or discussed in relevant art literature (*Literature*).

2.2 The South African Art Market: The Presence of a Dominant and Competitor Auction House

One advantage of employing the South African (henceforth SA) art market is that it has a degree of historical depth that is unusual for an emerging market - see the discussions in Welz (1976, 1996), Woodward (1974), Berman (1975), and Stevenson (2002). The established domestic SA art auction houses are primarily located in Johannesburg and Cape Town.[9] Among the indigenous auction houses, Strauss & Co. (henceforth SC) and Stephan Welz & Co. (henceforth SWC) are the principal representatives of SA fine art auction houses, and have handled the vast preponderance of sales in recent years, such that all other auction houses constitute at best fringe participants in the market.

Both SC and SWC follow the English auction style with a secret reserve price, minimum bids, and hence an open, ascending auction, where the winner pays the highest bid,and if the hammer price of an artwork fails to reach the reserve price the artwork is bought in. Evidence from auctions for the 2009-13 period, suggests that the South African art auction market has a clear dominant player amongst the auction houses. Table 1 gives the data of how the two principal South African auction houses have performed. Of the two auction houses, SC has a dominant position, both in terms of the number of auction lots sold (55% of sales), and even more so in terms of market valuation of the auction lots sold (83% of total market value). Thus while SC sold 547 more lots than SWC out of a total of 5345 sold lots, the market value of the lots sold by SC was approximately 500% of that realized by SWC, which is reflected in mean and median value ratios per art work of 4:1 and 3:1. This confirms that the SA art market is characterized by the presence of a dominant and competitor auction house in terms of market share.

[9] These include Ashbey's Galleries Fine Art Auctioneers, Bernardi's, Dales Bros Auctioneers, the Fifth Ave Auctioneers, Old Church Auction Galleries, Rudds, Sandton Auctioneers, Strauss & Co., Stephan Welz & Co., and Whale Rock Auctioneers. Internationally, Bonhams in London remains the only major auction house with a dedicated SA art department, though there is some emergent competition from Sotheby's and Christie's. Claims by the latter two auction houses to have representation in South Africa is technically correct, but these offices do not reflect a systematic and sustained presentation of South African art for auction - certainly not in dedicated region-specific auctions.

	Strauss & Co	Stephan Welz & Co	Total
Art Work Presented for Auction:			
Total Estimated Value	612,342,700	531,083,200	1,143,416,900
Number	3,751	3,802	7,533
Mean Value	163,248	139,685	151,387
Median Value	40,000	14,000	25,000
Variance	5.21×10^{11}	2.40×10^{13}	1.24×10^{13}
Standard Deviation	721,948	4,902,580	3,515,133
Art Work Sold at Auction:			
Total Value	586,468,891	119,227,166	705,696,057
Number	2,946	2,399	5,345
Mean Value	199,140	49,699	132,053
Median Value	44,560	15,680	28,964
Variance	7.33×10^{11}	2.56×10^{10}	4.21×10^{11}
Standard Deviation	856,401	160,130	648,962
Note: Values are in South African Rand (ZAR)			
Source: Own data collection from auctions, 2009 - 2013.			

Table 1: The South African Art Market

2.3 Counterfactual Evaluation of Auction House Price Estimates for Art Works they did not Market

The fundamental empirical claim of this paper is that a competitor auction house adopts higher valuations of art work auction lots than a dominant auction house. Testing whether this is in fact the case suffers from a counterfactual limitation: in the absence of repeat sales of the same art work by different auction houses, any art work sold by a given auction house does not have recorded valuation data from the alternative auction house, precluding a one-on-one comparison of the valuations provided by the two auction houses. Since only the catalogued information can be coded, there is no means of capturing any valuations that may have been provided to sellers by the auction houses. However, such a comparison can be approximated by using hedonic price equations loading on art work characteristics. By estimating the hedonic price equation for each auction house, the price estimate any auction house would have provided can be inferred on any art work of specified characteristics, including art works, given their catalogued characteristics, brought to market by the rival auction house.

The standard hedonic pricing approach employed here regresses the estimated catalogued price of each work on a set of observable characteristics of the painting, such as the artist, the size of the painting, its

medium and material. This provides us with the following specification:

$$P^{e}_{i,h} = \alpha_0 + \sum_{j=1}^{m} \alpha_{j,h} X_{i,j,h} + \varepsilon_{i,h},\ h \in \{SC, SWC\} \tag{1}$$

where $P^{e}_{i,h}$ denotes the price estimate (not hammer price) of art work i auctioned by auction house h, and the $X_{i,j}$ denote the range of j characteristics of the $i'th$ art work auctioned by house h that we control for.

The fundamental empirical claim of this paper is then that (a.) if the dominant firm were to use its estimated hedonic price equation on the art work presented for auction by the competitor, it would on average predict a lower price, and (b.) if the competitor were to use its estimated hedonic price equation on the art work presented for auction by the dominant house, it would on average predict a higher price. Thus:

$$P^{e}_{i,SC}\left(X_{i,j,SWC}\right) < P^{e}_{i,SWC}\left(X_{i,j,SWC}\right)\ and\ P^{e}_{i,SC}\left(X_{i,j,SC}\right) < P^{e}_{i,SWC}\left(X_{i,j,SC}\right) \tag{2}$$

i.e. that the hedonic price estimate of SC (dominant) should lie below that of SWC (competitor), irrespective of whether the auction houses are provided with the details of the art works that SC markets, or those that SWC markets. Note that the association would hold for all work presented for auction, rather than sold art work, since for the latter the market valuation of the work would bias downward any evidence for inflated price estimates (art work with inflated prices will have an above average buy-in rate), hiding any overvaluation that the SWC competitor may be pricing into its evaluations. Estimation is thus on the totality of all 7,553 lot records, both sold and unsold, for which all 584 artists appearing in the data are included in the specification, with artists who are unsold classified as $Tier3$. The (1) specification is estimated for both auction houses separately, in order to derive predicted prices for the auction lots presented by the rival auction house. Since the hedonic pricing model in itself is not the object of this study, estimation results are reported without further comment in Table 3 of Appendix 1.

The relevant evidence for our purposes is presented in Table 2. Employing the hedonic price relationship estimated for SC, to provide counterfactual price estimates for SC (dominant) on the art work in fact presented for auction by SWC (competitor): the predicted average price for all 3803 art works presented for auction by SWC computed from the estimated SC hedonic price equation, is ZAR95,852 (mean),

$P^e_{i,SC}$ vs. $P^e_{i,SWC}$		
Dominant and Competitor Price Estimates		
Strauss & Co. (SC) Welz & Co. (SWC)		Total
		Mean
SC on SC	Hedonic	164,275
	SC Recorded Estimate	164,401
SWC on SWC	Hedonic	174,968
	SWC Recorded Estimate	139,869
SC Hedonic Estimate on SWC Lots	Hedonic	95,852
SWC Hedonic Estimate on SC Lots	Hedonic	505,161

Table 2: Counterfactual Price Estimates

well below the ZAR139,869 (mean) value obtained from the SWC actual recorded price estimate, or the ZAR174,968 (mean) value obtained from the SWC hedonic price evaluation. This confirms the expectation that $P^e_{i,SC}(X_{i,j,SWC}) < P^e_{i,SWC}(X_{i,j,SWC})$, that dominant provides lower price estimates than competitor on any given art work. Symmetrically, employing the hedonic price relationship estimated for SWC, to provide counterfactual price estimates for SWC (competitor) on the art work in fact presented for auction by SC (dominant): the predicted average price computed for all 3751 art works presented for auction by SC computed from the SWC hedonic price equation, is ZAR505,161 (mean), well above the ZAR164,401 (mean) value obtained from the SWC actual recorded price evaluation, or the ZAR164,275 (mean) value obtained from the SWC hedonic price evaluation. This confirms the expectation that $P^e_{i,SC}(X_{i,j,SC}) < P^e_{i,SWC}(X_{i,j,SC})$, that dominant provides lower price estimates than competitor on any given art work.

Note that this evidence suggests that the two auction houses are not segmenting the market, by focussing on alternative types of art. A plausible explanation for the competitor auction house reporting lower realized mean values per lot, and lower aggregate sales values, is that the competitor is specializing on less prestigious (in the value terms) art work, with the dominant auction house cornering the market for high-value assets. But if this is the case, the counterfactual hedonic price estimates should report the reverse ordering to that found in our evidence: competitor should generate lower estimates on dominant's lots, not higher, since any given characteristic should map into less value than for the dominant house.

Also worth noting is that for sold art works market discipline on prices is evident. For a repeat exercise of inferred counterfactual prices on sold art works alone, the overvaluation of the SWC competitor disappears - and in fact shows that the competitor generates *lower* prices than the dominant in art works that in fact

sell. This is consistent with the expectation that the competitor overvalues lots presented at auction, at the expense a higher buy-in rate at auction.

Two additional pieces of evidence lend further robustness to the claim of divergent pricing estimates across the two auction houses.[10] An examination of the relationship of realized hammer prices to pre-auction price estimates confirms that the implied ratio of hammer price to price estimate for the dominant is greater than for the competitor. Specifically, for the dominant the mean actual hammer price realized at auction lies 12% above its price estimates, while for competitor mean realized hammer price lies 22% below its price estimates. Once we allow for the possible endogeneity of price estimates to inherent market value, by instrumenting on hedonic characteristics of the art work, these divergences change to 24% above the auction house estimate for dominant, and 19% below auction house estimate for competitor. These relationships of hammer price to pre-sale estimate suggest a conservative bias on the part of dominant, and price inflation on the part of competitor, consistent with a markup of competitor price estimate over the estimate of the dominant house. Finally, for any given density of bidder valuations across art work characteristics, if competitor presents more aggressive price estimates than the dominant, we would anticipate a lower probability of sale, hence a higher buy-in rate. This is confirmed for the two auction houses in the data, with dominant consistently maintaining a buy-in rate of 20%, competitor of $30 - 40\%$.

3 Why the Empirical Puzzle has Legs, and Starting Toward a Resolution

So why is price divergence a puzzle? Two sets of considerations explain.

First, the fine art auction houses in South Africa have recourse to a small, well-defined and homogenous pool of expertise. This is directly illustrated by the fact that at the chief executive officer, senior executive team, and the art expert level, there is evidence of churn across auction houses over time.[11] Further, the number of academy-based experts on South African artists is strictly constrained, and consulted by all

[10] The full results underlying the summary results that follow are available from the author on request.

[11] Perhaps the most telling anecotal evidence: the founding chief executive officer of SWC, was also a founding executive of SC, and subsequently its chief executive officer, as well as the front ranking expert on art valuation in the market - see for instance Welz (1996).

auction houses. Quite apart from the presumption of incentives arising from market discipline, information asymmetries across auction houses concerning art work values are thus not a compelling explanation of divergent art work price valuations.

Second, in economics the prior is that for any asset that has value, owners have an incentive to be informed about the underlying value of any asset, for art as for equity, bonds, or real assets. The literature on art markets concurs (see for instance Grampp, 1989). As a result, it is surprising that divergent auction house price estimates should have traction.

This paper suggests that the puzzle can be resolved by nonetheless accepting the possibility of myopia on the part of owners of art work regarding the value of their asset. Art is different from other assets in at least one important respect. In the limit, works of art lay claim to being unique, which is a significant contributor to their value over and above the inherent aesthetic pleasure that they afford. A relevant retort is that while art assets are imperfect substitutes, there are genres of art (eg. cubist), or works of art by the same artist that have sufficient similarity so as to belong to a substitutable class of work. Nonetheless, the degree of homogeneity of works of art is distinct from text book illustrations of competitive market goods homogeneity. Thus, while Grampp (1989) is particularly insistent on substitutability for art, Findlay (2014) and Hook (2013) provide art dealers' perspectives that are strongly contrasting: buyers in particular are strongly motivated by considerations of uniqueness and rarity, to allow for bragging rights amongst other considerations. Since goods with a low degree of homogeneity are associated with information costs, there is at least a plausible question regarding just how well informed sellers are about the value of their nonhomogeneous assets.

Anecdotal evidence supports this premise. Even sellers of exceptionally rare and *a priori* valuable art works do not rely exclusively on private sales, but have recourse to market intermediaries at considerable cost. Thus the sale of *Salvator Mundi* on 17 November 2017 at Christie's New York, attributed to Leonardo da Vinci (with some probability below unity), for a final price of $450,312,500 (Daley, 2017, Ellis-Petersen and Brown, 2017, Isaacson, 2017, Ryburn, 2017), included auction house fees estimated at $50,312,500. If the sellers truly knew the value of the art work, and given the ease of publicizing a work by Da Vinci, why forfeit the non-trivial transactions costs by relying on an auction house? Tales of masterpieces rescued from

obscurity are also sufficiently prevalent to raise further doubts as to sellers being uniformly well informed about the value of their art. This happens to apply to the *Salvator Mundi* Da Vinci, which in 2005 was purchased by a dealer at a regional auction in Louisiana for less than $10,000, since unattributed to Da Vinci at the time. Further, a surprisingly small proportion of art appears to survive depreciation to the point of obsolescence (Grampp, 1989:68, estimates only 1/1000 - 1/10,000 of paintings survive). This implies that the task of determining whether a specific art work is one of those to retain value is nontrivial. More subtly, while some of the survival loss may be due to true obsolescence, the implication that 9,999/10,000 pieces of art offer no utility to anyone at all, seems implausible. The implausibility compounds when one bears in mind that obsolescence has affected the work of "masters" as well as more mundane artists. Instead, it seems feasible that some of the depreciation arises due to poor information on the part of owners of art work. Finally, the existence of art market intermediaries in the form of dealers and auction houses suggests that sellers face information asymmetries in the market significant enough to provide room for specialization in the provision of information relevant to exchange transactions in the market.[12]

Hence the presumption of myopia on the part of sellers appears both feasible and plausible. It is central to the remainder of the analysis of this paper.

4 Auction Markets of Nonhomogeneous Goods in the Presence of Informed and Myopic Sellers

Consider the consequence of a market structure with two auction houses, one of which is the dominant, the other the competitor (henceforth dominant, competitor respectively). Dominant is defined as the auction house with the greatest market share, distributing information to the greatest number of market participants. Possible reasons for dominance may be due to greater expertise in the handling of art works, due to scale advantages, superior knowledge of market conditions, differential cost conditions, or simply historical accident such as being the first market entrant. However, since focus is on the consequences of having a dominant auction house present in the auction market, dominance is taken as given, while its emergence is not explained.

[12] None of this need deny that some sellers may have sound information about the value of their asset, and have recourse to private sales, which by some estimates amount to more than 50% of the art market (see McAndrew, 2008).

The analytical treatment of this market structure is in terms of the strategic interaction between the seller of the art work, and the dominant and competitor auction house, for both informed sellers, and for myopic sellers.

4.1 The Underlying Market Characteristics

The art market is characterized by the presence of sellers of art works, who wish to bring their art assets to market, buyers of the pieces of art, and intermediaries who provide the platform for the demand and supply side of the market to interact. In order to focus on the impact of intermediaries, assume direct private sales between sellers and buyers in the market to be of negligible importance, so that sales of art work take place only through an intermediary. For the sake of simplicity of terminology, intermediaries are termed auction houses, though in reality these would include dealers, galleries, and other forms also.[13]

The underlying market for art works is unusual in the sense that each of the items brought to market lays claim to a significant degree of uniqueness[14] - restricting the supply of the good to a single unit. As such, variation in expected price will influence whether the particular art work will be made available for sale, but cannot further increase the quantity of the good available for supply.[15]

4.1.1 Buyers

On the demand side of the market, associated with each art work is a density of private bidder valuations, $m\left[P\left(S\right)\right]$, in density-price space, that reflects the subjective evaluations of the intrinsic qualities, S, of the object being auctioned (for the sake of compactness, we henceforth suppress the mapping from intrinsic

[13] See the discussion of agents in the art market in Findlay (2014), Hook (2013), Grampp (1989) and Heilbrun and Gray (2001). Since our analysis is of the structure of pre-sale price estimates, it does not extend to the actual bidding process at auction itself. However, note that since art markets generally follow the English open ascending auction model, bidding strategies under this auction structure have long been studied in the literature. Given a characterization of risk-neutral bidders such that their valuations are private, reflect the intrinsic qualities of the object being auctioned, and are independently drawn from the same underlying continuous distribution, the winning bid will belong to the bidder that places the highest valuation on the object, and will reflect the second-highest bidder valuation. As such, the winning bid will reflect the distribution of valuations based on the characteristics of the objects being sold (see Milgrom and Weber, 1982). The extensive literature on auctions has considered the consequences of relaxing symmetry, risk neutrality, independence and private valuations (see for instance Maskin and Riley, 1985, Hendriks and Porter, 1988, Klemperer, 1998, Hong and Shum, 2003).

[14] There may be a degree of substitutability with art work of a similar "type" (however that is defined). As noted in section 3, one of the distinguishing features of art work is that this substitutability is low, making for a low degree of homogeneity of the goods being exchanged. For this reason, the limiting assumption of uniqueness is adopted. Having said which, nothing in the analysis which follows is conditional on absolute uniqueness.

[15] Though forgery may render the supply more elastic, auction houses are assumed to have sufficient expertise to render forgeries negligible in the market - something of an idealization.

qualities, S, into price, P). Valuations of bidders reflect willingness to pay. The cumulative density function of valuations, $\int_0^\infty m(P)\,dP$, then allows for the specification of the probability of a sale of the art object for any price, $M(P)$, declining in price, given by:

$$M(P_i) = 1 - \int_0^\infty m(P)\,dP \tag{3}$$

This renders explicit that higher valuations of art works lower the probability of a sale occurring, with both auction houses and potential sellers of art works aware of the declining probability of sale in price valuation.

4.1.2 Sellers

Two types of sellers are distinguished: informed and myopic. Informed sellers do, while myopic sellers do not hold clear subjective views on the underlying value of their art assets. The difference is due to the presence of significant information costs or asymmetries. Myopic sellers rely on market intermediaries, here auction houses, to provide them with information regarding the value of their art. The distinction is thus that informed sellers hold subjective views regarding the density of private bidder valuations, $m[P(S)]$, myopic sellers do not. Importantly, given that auction houses interact closely with sellers, and have extensive knowledge of the market, auction houses know whether sellers are informed or myopic.

The seller of the art work anticipates a return from the sale of the art work, determined by price:

$$E_S(P) = M(P)[P - R(P)] \tag{4}$$

where E_S denotes the mathematical expectations operator for the seller,[16] P price, $M(P)$ is supplied either by the seller themselves (if informed), or is unknown by seller (if myopic) though the general form of (4) is common knowledge even to myopic sellers, and $R(P)$ denotes the commission charged by the auction house conditional on a successful sale, which is a function of the price of the art work sold.[17] The commission

[16] Note that in the event of the sale not occurring with probability $1 - M(P)$ the associated expected value is given by $(1 - M(P))\,0$.

[17] Both the buyer's premium and the seller's commission to the auction house typically vary in price. While there may be additional transactions costs for the seller, such as transport and insurance costs, we suppress these in the analysis since they are likely either symmetrical across the auction houses, or themselves a function of the value of the art work.

structure is known to both auction houses, and to any prospective seller of art works. Objective of the seller is to maximize the expected return form the sale of the art work, i.e. to $\arg\max_{P} (E_S(P))$.

4.1.3 Auction Houses

There are two auction houses, one of which is the dominant, the other the competitor. Dominant is defined as the auction house with the greatest market share, distributing information to the greatest number of market participants. Auction houses, sellers and buyers in the market know which auction house is the dominant, which the competitor.

Auction houses seek to maximize their expected profit from the sale of art objects. The basis of the auction houses' expertise is that they are informed about the density of risk-neutral private bidder valuations, $m(P)$. Then the expected profit function for an auction house is given by:

$$\Pi_i = M(P_i) R(P_i) - C(P_i), \; i = D, T \tag{5}$$

where notation is as defined above,[18] Π_i denotes expected profit by auction house i, P_i denotes the price estimate of auction house i, D and T denotes dominant and competitor respectively, and C is the cost faced by the auction house in effecting the auction for the art work, borne with certainty irrespective of whether the sale occurs. Auction houses face a variable cost of bringing an art work to auction, borne irrespective of whether the sale is successful or not (for instance the art work would have to be curated and catalogued regardless of whether the auction proved successful). While the preponderance of art auction costs may be fixed costs, with rising valuations of art work, there is an increased level of transactions costs that arise from marketing, curating and insurance of significant art work. Thus, in general we anticipate costs to increase in valuations, $\partial C/\partial P > 0$, likely convex, $\partial^2 C/\partial P^2 > 0$.

The analysis proceeds under the assumption that it is unlikely for there to be scope for auction houses to negotiate with sellers on commission, $R(P)$. In the event that an auction house sets commission above marginal cost, other things being equal its rivals have the possibility of offering a lower commission rate. A

[18] For both auction houses, in the event of the sale not occurring with probability $1 - M(P)$, the expected value is given by $(1 - M(P))\,0$.

rational seller, defined by (4), for any projected P and hence $M(P)$, which renders the distinction between informed and myopic sellers irrelevant, would choose the lower $R(P)$, with the only stable equilibrium being defined by a commission defined by the marginal cost of auction service provision.[19,20] Empirically, this is borne out by both the South African and international evidence. Official seller's commissions to auction houses and buyer's premia are closely symmetrical between auction houses. Thus in South Africa both auction houses step from a 15% to a 12% seller's commission at price thresholds that are differentiated by less than US$200, and direct communication with both auction houses confirms that they do not offer commission discounts. Commissions appear to be similarly constant for Sotheby's and Christie's in the more competitive international market - see McAndrew (2008) and Findlay (2014). To reflect the absence of strategic interaction between auction houses on commission, we let the commission be a common function of price:

$$R(P) > 0, 0 < \frac{\partial R(P)}{\partial P} < 1, \frac{\partial^2 R(P)}{\partial P^2} \leq 0 \quad (6)$$

$$R(P) = \theta P,\ 0 < \theta < 1 \quad (7)$$

with (7) the linear special case of (6). Precluded are $\partial R(P)/\partial P > 1$ since this would eliminate the incentive for seller to realize higher prices under (4), and $\partial R(P)/\partial P < 0$ for symmetrical incentive implications for the auction house.

4.2 Strategic Interaction in the Presence of an Informed Seller

4.2.1 Structure of the Interaction between Agents

Since informed sellers have subjective views regarding the density of risk-neutral private bidder valuations, $m(P)$, the specification of $E_S(P)$ in terms of (4) allows sellers to specify the first order condition for maximizing their expected pay-off in terms of the optimal price, P_S^*. Both auction houses then provide

[19] An alternative approach to viewing the commission as fixed, is to view the rational seller as reacting to the *margin* between price and commision, i.e. $P - R(P)$. The analysis of the strategic interaction below would follow symmetrically.

[20] The one caveat to this observation is that it should be viewed as applying to "standard" works. With high profile items, there may be some scope for negotiation, since the very fact that an auction house brings the high profile work to market, serves a marketing and credibility enhancing purpose for the remainder of its activity.

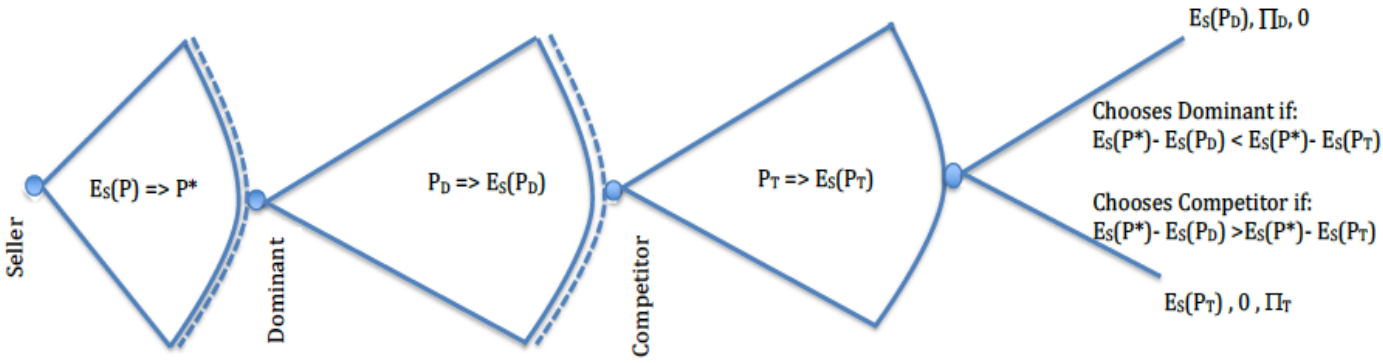

Figure 1: Strategic Interaction between Seller and Two Auction Houses in the Presence of an Informed Seller

their own valuations of the art work, P_D, P_T, for dominant and competitor respectively, allowing the seller to infer the associated expected payoffs, $E_S(P_D)$, $E_S(P_T)$, from (4). Conditional on the informed seller having confidence in their subjective belief regarding $m(P)$, choice of auction house will then be determined by which auction house valuation specifies a price, which minimizes any anticipated loss in terms of the expected value of the sale to the seller, $E_S(P_S^*)$, due to the deviation of the auction house valuation from the pay-off maximizing price anticipated by the subjective beliefs of the seller, $E_S(P_S^*) - E_S(P_i)$, $i = D, T$. The expected profit of the auction house chosen would be determined by (5), with the rival auction house realizing no return. Recall also that auction houses know (can tell) that the seller is informed.

In terms of timing, for informed sellers the distinction between dominant and competitor does not carry any prospects of gaining information about the market. Hence, the seller approaches dominant and competitor simultaneously and independently, requesting a market valuation. Dominant and competitor provide their valuations knowing that the informed seller has their own private subjective beliefs regarding $m(P)$ and hence pay-off maximizing price, but without knowledge of the valuation of the rival auction house, nor of the private valuation provided by the seller. Seller then chooses the auction house with the valuation which minimizes deviation of expected payoffs from the valuation generating the maximized pay-off.

This provides the strategic interaction illustrated by Figure 1.

4.2.2 Market Equilibrium

Informed sellers are defined as having private subjective views concerning the distribution of valuations of potential risk-neutral bidders in the market, reflecting the intrinsic qualities of the object being auctioned - i.e. they hold subjective beliefs concerning $m(P)$, $M(P)$.[21] From the perspective of the seller, the expected payoff maximum of the sale then occurs at the price P^* which satisfies:

$$\begin{aligned} \frac{\partial E_S(P)}{\partial P} &= 0 = \frac{\partial M(P)}{\partial P}[P - R(P)] + M(P) - M(P)\frac{\partial R(P)}{\partial P} \\ &\Longrightarrow \frac{\partial M(P)}{\partial P}[P - R(P)] + M(P) = M(P)\frac{\partial R(P)}{\partial P} \end{aligned} \tag{8}$$

the standard expected marginal return to marginal cost equality condition. Denote the payoff maximizing price obtained from (8) by P_S^*.

The seller of the art work does not sell to the market directly, relying instead on the auction houses to do so, since by assumption we preclude private sales. Each of the auction houses generates its own price estimate prior to the sale by way of a valuation of the art work, thus providing the price estimates P_D for dominant, P_T for competitor. Given (4), and P_D, P_T, the informed seller, will have a view of the anticipated payoff under the two valuations, $E_S(P_D)$, $E_S(P_T)$, reflecting the anticipated probability of a sale, the projected price, and commission to be realized under the price estimates of the dominant and competitor auction houses. Given that P_S^* is the seller's payoff maximizing price, for any $P_D \neq P_S^*$, $P_T \neq P_S^*$, of necessity $E_S(P_D) < E_S(P_S^*)$, $E_S(P_T) < E_S(P_S^*)$. A rational seller will allocate the art work to the auction house whose projected price generates an expected payoff that least deviates from the maximizing expected payoff under the informed sellers' subjective view of the distribution of market valuations. Denoting the associated expected payoff under the optimal price as perceived by the seller, P_S^*, as $E_S(P_S^*)$, this provides the expected

[21] Analysis in this section reflects Farber (1980).

payoff for the seller of:

$$E_S(P) = \begin{cases} E_S(P_D) \ if \ E_S(P_S^*) - E_S(P_D) < E_S(P_S^*) - E_S(P_T) \\ E_S(P_T) \ if \ E_S(P_S^*) - E_S(P_D) > E_S(P_S^*) - E_S(P_T) \end{cases} \tag{9}$$

An immediate implication of this market is that the price that maximizes the expected payoff to the informed seller, precludes profit maximization for auction houses. The intuition is that auction houses have an incentive to price more conservatively than sellers, since sellers bear commission costs only when a sale occurs, while auction houses bear the cost of bringing the art work to market irrespective of whether a sale occurs.

Proposition 1 *For an informed seller, the payoff maximizing predicted price lies above the price that would be profit maximizing for an auction house, provided that the elasticity of the auction house commission with respect to price lies below unity.*

Proof. See section 6. ■

A second implication that follows is that in the presence of an informed seller, auction houses have an incentive to try to match their price prediction to the payoff maximizing price expectation of the seller. The intuition is that since a deviation of either auction house price estimate from the price which the seller deems payoff maximizing, the implied payoff loss makes the auction house price estimate less attractive.

Proposition 2 *In the presence of an informed seller, Bayesian Nash Equilibrium (BNE) implies: (A.) That the auction house for which the marginal payoff gain relative to the marginal profit loss, weighted by the gain in probability of having the art work allocated, due to an increase in price estimate by the auction house, is greater than that for its rival, will realize a higher probability of having the art work allocated to it, and will provide a higher price estimate to the seller. (B.) If auction houses share a common belief concerning the distribution of buyers, have a common commission and cost structure, and the informed seller responds symmetrically to price estimate changes by dominant and competitor, then a sufficient condition for BNE is given by $P_D = P_T$, in which case the probability that the art work is allocated to the auction house is symmetrical across the two houses, $(1/2)$, such that the average of the seller's expected payoff associated*

with the P_D, P_T, auction house price estimates, must equal the median of the seller's expected payoff. (C.) Where in addition to having common beliefs as defined above, auction houses have common knowledge of this belief symmetry, symmetry in price valuations by auction houses will converge to the price anticipated by the auction houses to be payoff maximizing to the seller, provided that expected profit meets a nonnegativity constraint.

Proof. See section 7. ■

Proposition 2 confirms that provided that sellers are informed regarding the density of private bidder valuations, auction house price estimates should converge on the price maximizing the seller's expected payoff. In the presence of informed sellers divergence across auction house price estimates is therefore not mandated.

4.3 Strategic Interaction in the Presence of a Myopic Seller

4.3.1 Structure of the Interaction between Agents

Myopic sellers do not have subjective beliefs regarding $m(P)$, and hence cannot determine the expected payoff of (4) with its associated maximand. Instead, myopic sellers have to rely on auction house valuations of the art work. However, the general structure of (3) through (6) is common knowledge in the game. Then rational myopic sellers would know that auction houses have a profit maximizing incentive to recommend auction prices that are below payoff maximizing price, such that $P_i^* < P_S^*,\ i \in D, T$, given only a weak below-unity elasticity requirement, from Proposition 1 directly. Seller begins with a prior probability of allocating the art work to dominant and competitor of $0 \leq \lambda \leq 1$ and $(1-\lambda)$ respectively, which reflect the subjective perceptions of the seller regarding the significance of the market power of dominant vs. competitor. Recall that auction houses know (can tell) that the seller is myopic.

Any signal of dominant or competitor on intensity of effort associated with bringing the art work to market ("our dominant market share reflects greater expertise," "we are number two, so have to work harder") lacks credibility, since both have an incentive to mislead in order to secure the work for auction, and neither claim to expertise and effort can be verified by myopic sellers (there is no P_S^* comparator). The only signal with the possibility of credibility, is the price prediction of the auction house, since given (5), cost is borne by

auction houses directly in relation to price and irrespective of whether the sale occurs, while the revenue of the auction house becomes less likely with rising price predictions.

Since dominant is held to have greater market share, let myopic sellers approach dominant first, to obtain a valuation of the art work (note: the solution to the game provided below is not conditional on the dominant being approached first). Sellers then obtain a valuation from competitor, revealing the valuation of dominant to competitor. Competitor competes by applying a markup $\mu \lessgtr 1$ to the price provided by dominant such that:

$$P_T = \mu P_D,\ \mu \lessgtr 1 \tag{10}$$

Seller allows dominant to revise their valuation, by $dP_D \gtrless 0$, followed by the opportunity for competitor to also revise their estimation, by $d\mu \gtrless 0$, potentially repeatedly. Seller then chooses to allocate the art work to either dominant or competitor and the game ends.

4.3.2 Market Equilibrium

Allow dominant to open its price forecast by means of a choice between two alternatives. Define P_{high} as a "high" price in the sense that it approximates the price beyond which further price increases would eliminate all positive expected return from the sale (from (5) a strict upper bound would be given by the solution to $M(P) = C(P)/R(P)$, which in the event of the linear commission structure of (7) and convex cost structure cP^2, would require $P = \frac{\theta}{c} M(P)$). By contrast, P_{low} is a "low" estimate, in the sense that it is bounded below by the profit maximizing price, so $P_{low} \to P^*_\Pi$ provides a lower bound. Since the myopic seller is not able to determine whether the price estimate they have received from dominant is high or low, competitor is then given the opportunity to provide a price estimate on the art work. Competitor does so by setting $\mu P_{L,k}\ k = high,\ low$, choosing between $\mu \leq 1$ and $\mu > 1$. Seller can repeat the approaches to dominant and competitor. Note that P_{high} may itself be the outcome of an iterative offer process such as that sketched for P_{low}; it can thus be thought of as the upper bound outcome to the alternating auction house estimate process considered for P_{low}.

In the event that competitor does not increase the price estimate of dominant, such that $\mu \leq 1$, seller chooses an auction house to allocate the art work to, and the game ends.

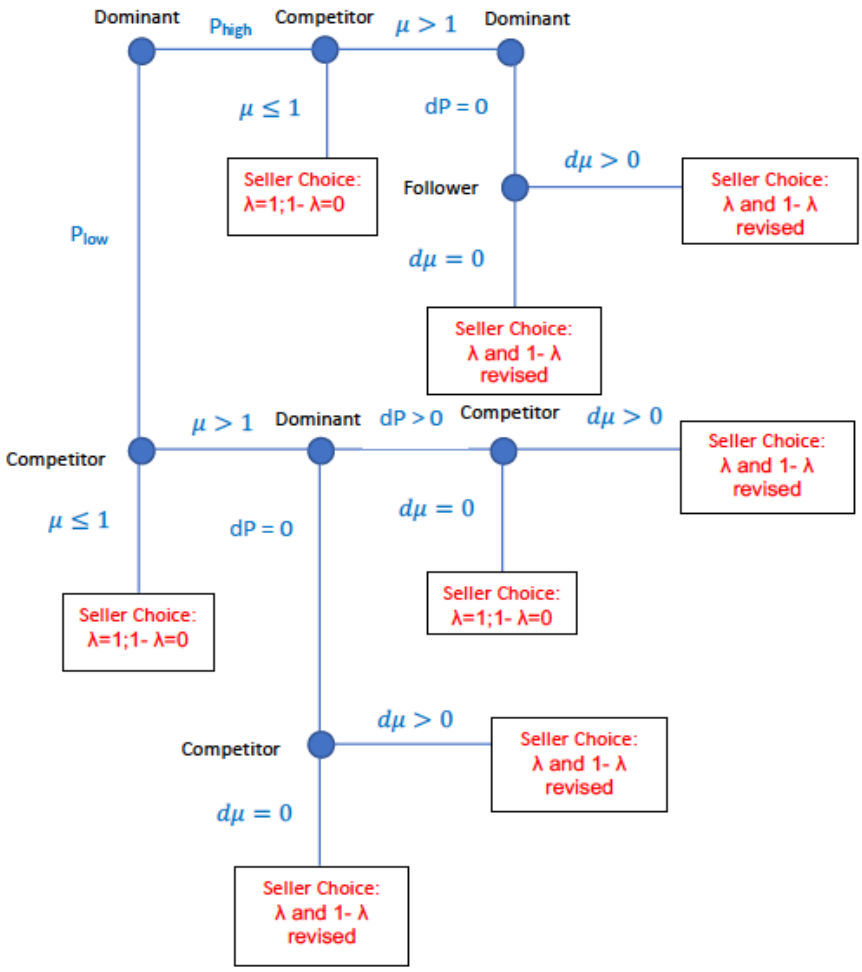

Figure 2: Interaction between Dominant and Competitor Auction Houses, and Seller.

In the event that competitor does increase the price estimate of dominant, such that $\mu > 1$, seller reverts to dominant to allow dominant the choice to revise its price estimate upward ($dP > 0$), or not ($dP = 0$). In either event, competitor is also given a further opportunity to revise its price estimate, either by raising its markup ($d\mu > 0$) or keeping it constant ($d\mu = 0$), in the light of the revised estimate provided by dominant. Figure 2 illustrates.

Under this form of market interaction, market equilibrium will require that competitor marks up price over dominant ($\mu > 1$). The intuition is immediate from the realization that since a rational seller knows that auction house profit maximizing price estimates lie below price estimates maximizing seller expected payoff (Proposition 1 is common knowledge), $E_S(\mu P_D) \leq E_S(P_D)\ \forall \mu \leq 1$, so that seller will never allocate the

art work to competitor for any price estimate below dominant, given the superior market reach of dominant given its market greater share. This forces competitor to set $\mu > 1$.

Proposition 3 *There are multiple possible equilibria to market pricing. However, all equilibria will preclude pooled equilibria in which auction houses provide the same price estimates ($\mu = 1$), and all separating equilibria in which the competitor provides lower price estimates than the dominant ($\mu < 1$). Instead, all equilibria are separating equilibria in which competitor provides a markup over the price estimate of the dominant ($\mu > 1$).*

Proof. See section 8. ■

Myopic sellers start with views regarding the importance of dominant vs competitor market status in allocating their art work, which issues in a probability λ, $(1-\lambda)$, of allocating the work to dominant and competitor respectively. If markup $\mu < 1$, since seller knows (Proposition 1) that auction houses have an incentive to price below the seller's expected payoff maximizing price (for any $M(P)$), seller has no incentive to allocate to competitor, and hence the allocation probabilities change to $\lambda = 1$, $(1-\lambda) = 0$; this precludes $\mu < 1$ as a rational play for competitor since they will never be allocated the art work and thus cannot participate in the market, and confirms all such plays as off-equilibrium path. By contrast, for $\mu > 1$ (recognizing the possibility of a series of upward price revisions by both houses), this may result in $d\lambda \gtreqless 0$, but does not preclude $\lambda < 1$. For this reason any PBE equilibrium that exists, must be consistent with $\mu > 1$.

Separating play between the auction houses is effectively the outcome of seller seeking to extract information from the auction houses, inducing them to raise price estimates above P^*_Π, on the basis of the common knowledge of all players that $E_S(\mu P_D) \leq E_S(P_D)\ \forall \mu \leq 1 \mid \mu P_D \leq P^*_S$. Critically, multiple (possibly mixed) separating equilibrium strategies are feasible reflecting the prior probability of allocating the art work to dominant and competitor, λ, $(1-\lambda)$, and any changes to λ in the light of price revisions by the two auction houses. This is the crucial insight: since pooled equilibria are not, and only separating equilibria for which competitor marks up on dominant ($\mu > 1$) are feasible, any equilibrium that emerges is a separating equilibrium, such that $P_T = \mu P_D,\ \mu > 1$.

Note that while for informed sellers, auction houses have an incentive to provide estimates that replicate

the views of the seller, in the presence of myopic sellers, since sellers have to rely on a bidding contest between auction houses designed to extract market information for the seller, price estimates for myopic sellers may be driven upward so that they may to come to lie *above* rather than below the price which maximizes the payoff to seller. The only limit is provided by the upper bound given by the solution to $M(P) = C(P)/R(P)$, beyond which auction houses face a loss on bringing the art work to market. With myopic sellers the bidding contest between auction houses can produce too much of a good thing, in the form of price valuation increases beyond the point maximizing expected returns to sellers.

Finally, note that in the event that dominant does adopt the price estimate provided by the solution to $M(P) = C(P)/R(P)$, such that no abnormal profits remain, competitor has no choice but to either forgo pursuing bringing the art work to market, or to bring it to market at a price estimate generating an expected loss. The implication is that once an auction house establishes itself as dominant, in the presence of myopic sellers any competitor auction house will be subject to extreme competitive disadvantage. In the limit it may be forced to rely on informed sellers alone.

4.4 Empirical Implications of the Theory

The analysis has differentiated between two distinct cases: strategic market interaction in the presence of informed and myopic sellers, given the presence of a dominant and competitor auction house.

A number of empirical implications follow from the theory. Proposition 2 suggests that in the presence of informed sellers, auction houses have an incentive to provide price estimates that conform to the payoff maximizing price expectation of the seller, conditional on a weak elasticity condition, and common market conditions for the auction houses. Proposition 3 suggests that in the presence of myopic sellers and market structure in the auction markets, the competitor auction house has an incentive to provide a mark-up price estimate relative to the dominant auction house. Informed sellers thus predict price estimate convergence, myopic sellers price estimate divergence.

For the case of myopic sellers, since competitor markup is constrained to be above unity ($\mu > 1$), we can add that the observed divergence between auction houses should be such that the competitor provides *higher* price estimates on art work than the dominant auction house. Further, given higher price targets at

auction by competitor, for a given distribution of bidder valuations, the probability of sale, $M(P)$, should be lower for competitor than dominant as evidenced by higher buy-in rates (proportion of lots unsold) at auction, and realized hammer price relative to price estimate should on average be lower for the competitor than for the dominant auction house.

Note that the features of the empirical puzzle noted in section 2 of the paper, strictly conform to these empirical implications of the theory.

5 Conclusions and Evaluation

Faced with informed sellers of nonhomogeneous assets, market intermediaries such as auction houses have an incentive to provide sellers with pre-sale price estimates that replicate the asset owner's payoff maximizing price expectation, given only weak elasticity and market homogeneity conditions. The presence of market structure, in the form of a dominant and competitor market intermediary as defined by market share, is immaterial to this outcome. Instead, where the sellers are myopic regarding the distribution of private bidder valuations for the asset, any competitor auction house is forced to provide pre-sale price estimates on the asset that mark up on the estimate of the dominant intermediary. The contrast is immediate: informed sellers predict price convergence, myopic sellers price divergence in the valuation of nonhomogeneous assets provided by market intermediaries.

This is the main insight of this paper: the presence of myopia on the part of asset owners regarding the value of their assets, a plausible consequence of assets being nonhomogeneous, renders market structure in auction markets material, with dominant and competitor auction houses showing distinct pricing behavior. While the application of the present paper is to the fine art market, the analysis applies to any market for nonhomogeneous assets. Since the dominant auction house can provide aggressive price estimates, the competitor house may be consigned to permanent weakness in the market, with pricing that generates low expected profits and poor market credibility due to high buyin rates (failure to sell auction lots due to overpricing). By way of a conjecture, this might help explain why market structure may persist over time, at least in markets for nonhomogeneous assets - competitor firms face a deep disadvantage in terms of rational pricing strategy.

These insights are consistent with the empirical observation with which this paper began: divergent pre-sale price estimates across two auction houses in a regional fine arts market. The observation was established by reference to hedonic price equations for the two auction houses in the market to generate *predicted* prices for the art works that were brought to market by the rival auction house, which are then compared to the actual price estimates provided by the rival auction house. On average, the dominant auction house provides lower price estimates than its competitor.

The analysis of the paper thus provides a methodology to examine how knowledgeable owners of nonhomogeneous assets are about the market valuation of their assets. It provides insight into the consequences of market structure, defined by market share, across auction houses. Certainly regional fine art markets have a marked tendency to include dominant and competitor auction houses (this paper illustrates South Africa, but Canada, Australia, for instance are similar), but this can extend to other nonhomogeneous assets also. From the analysis of this paper it follows that taking into account such market structure in auction markets is essential to the analysis of market behavior.

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6 Proof of Proposition 1

From (5) profit maximization would require the expected equivalence of expected marginal revenue and marginal cost condition:

$$\begin{aligned} \overbrace{\frac{\partial M(P_i)}{\partial P_i} R(P_i) + M(P_i) \frac{\partial R(P_i)}{\partial P}}^{E(MR)} - \overbrace{\frac{\partial C(P_i)}{\partial P_i}}^{MC} &= 0 \\ \therefore\ M(P_i) &= \frac{\partial C(P_i)/\partial P_i + m(P_i) R(P_i)}{\partial R(P_i)/\partial P_i} \end{aligned} \tag{11}$$

By contrast, payoff maximization to seller, from (8) requires:

$$M(P) = \frac{m(P)[P - R(P)]}{1 - \frac{\partial R(P)}{\partial P}} \tag{12}$$

It follows that:

$$\begin{aligned} \frac{m(P)[P - R(P)]}{1 - \frac{\partial R(P)}{\partial P}} &< \frac{\partial C(P)/\partial P + m(P) R(P)}{\partial R(P)/\partial P} \\ m(P)[P - R(P)] \frac{\partial R(P)}{\partial P} &< \left(1 - \frac{\partial R(P)}{\partial P}\right)\left(\frac{\partial C(P)}{\partial P} + m(P) R(P)\right) \\ m(P) R(P)\left[\frac{\partial R(P)}{\partial P}\frac{P}{R(P)} - \frac{\partial R(P)}{\partial P}\right] - m(P) R(P)\left(1 - \frac{\partial R(P)}{\partial P}\right) &< \left(1 - \frac{\partial R(P)}{\partial P}\right)\left(\frac{\partial C(P)}{\partial P}\right) \\ \Longrightarrow m(P) R(P)\left[\frac{\partial R(P)}{\partial P}\frac{P}{R(P)} - 1\right] &< \left(1 - \frac{\partial R(P)}{\partial P}\right)\left(\frac{\partial C(P)}{\partial P}\right) \end{aligned} \tag{13}$$

since $R(P) > 0$, $P > 0$, $0 < m(P) < 1$, $\partial C(P)/\partial P > 0$ (see (5)), and $\frac{\partial R(P)}{\partial P} < 1$, (from (6)), provided only that $\frac{\partial R(P)}{\partial P}\frac{P}{R(P)} \leq 1$ ensures $\left[\frac{\partial R(P)}{\partial P}\frac{P}{R(P)} - 1\right] \leq 0$, $\left(1 - \frac{\partial R(P)}{\partial P}\right)\left(\frac{\partial C(P)}{\partial P}\right) > 0$. Thus, denoting the price point which satisfies payoff maximization (from (12)) as P_S^*, that which satisfies profit maximization (from (11)) as P_Π^*, $M(P_S^*) < M(P_\Pi^*)$. Given (3), $P_S^* > P_\Pi^*$ follows for the general case. This can be immediately illustrated for the linear case of (7), since then (13) is given by:

$$m(P) R(P)\left[\frac{\theta P}{\theta P} - 1\right] = 0 < (1 - \theta)\left(\frac{\partial C(P)}{\partial P}\right)$$

7 Proof of Proposition 2

Given that the informed seller forms $E_S(P)$ under subjective beliefs, only the seller knows P_S^* for sure. However, provided that the $\frac{\partial R(P)}{\partial P}\frac{P}{R(P)} \leq 1$ condition is met, the two auction houses know that $P_S^* > P_\Pi^*$. Thus the auction houses know that $E_S(P_\Pi^*) < E_S(P_S^*)$, and that $P_i \to P_S^* \Longrightarrow E_S(P_i) \to E_S(P_S^*)$, $i = D, T$, under monotonicity of $M(P)$ over the $[P_\Pi^*, P_S^*]$ interval. Since the seller wishes to maximize payoff, allocation of the art work for auction will go to whichever satisfies $\min_{P_D, P_T}[E_S(P_S^*) - E_S(P_D), E_S(P_S^*) - E_S(P_T)]$, so that:

$$\begin{aligned}
\Pr\{P_D \text{ chosen}\} &= \Pr\{E_S(P_D) > E_S(P_T) \mid P_D \leq P_A^*\} \\
\Pr\{P_T \text{ chosen}\} &= 1 - \Pr\{E_S(P_D) > E_S(P_T) \mid P_T \leq P_A^*\}
\end{aligned}$$

where P_A^* is the seller's payoff maximizing price from (8) projected by auction houses derived from the auction houses' $M(P)$. Since $P_i > P_A^*$ would serve to lower auction house profit, auction house anticipated $E_S(P_i)$, and hence $\Pr\{P_i \text{ chosen}\}$, there is no incentive to increase price above P_A^*. Then, denoting $\Pr\{E_S(P_D) > E_S(P_T) \mid P_D \leq P_A^*\}$ by $\Pr\{P_D, P_T\}$ for compactness, from (5) the expected profit of the auction houses is given by:

$$\Pi = \Pi_D \Pr\{P_D, P_T\} + \Pi_T [1 - \Pr\{P_D, P_T\}]$$

Any BNE must therefore satisfy:

$$\begin{aligned}
\Pi_D^* &= \arg\max_{P_D} [\Pi_D \Pr\{P_D, P_T\} + \Pi_T^* [1 - \Pr\{P_D, P_T\}]] \\
\Pi_T^* &= \arg\max_{P_T} [\Pi_D^* \Pr\{P_D, P_T\} + \Pi_T [1 - \Pr\{P_D, P_T\}]]
\end{aligned}$$

where Π_D^*, Π_T^*, denote best responses. Hence for dominant:

$$\left(\frac{\partial \Pi_D}{\partial P_D}\right) \Pr\{P_D, P_T\} + \Pi_D^* \left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_D}\right)\left(\frac{\partial E_S(P_D)}{\partial P_D}\right) - \Pi_T^* \left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_D}\right)\left(\frac{\partial E_S(P_T)}{\partial P_D}\right) = 0$$

$$\therefore (\Pi_T^* - \Pi_D^*)\left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_D}\right)\left(\frac{\partial E_S(P_D)}{\partial P_D}\right) = \left(\frac{\partial \Pi_D}{\partial P_D}\right) \Pr\{P_D, P_T\}$$

and for competitor:

$$\Pi_D^* \left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_T} \right) \left(\frac{\partial E_S(P_T)}{\partial P_T} \right) + \left(\frac{\partial \Pi_{FT}}{\partial P_T} \right) [1 - \Pr\{P_D, P_T\}] - \Pi_T^* \left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_T} \right) \left(\frac{\partial E_S(P_T)}{\partial P_T} \right) = 0$$

$$\therefore \ (\Pi_T^* - \Pi_D^*) \left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_T} \right) \left(\frac{\partial E_S(P_T)}{\partial P_T} \right) = \left(\frac{\partial \Pi_T}{\partial P_T} \right) [1 - \Pr\{P_D, P_T\}]$$

Hence BNE requires:

$$\frac{\left(\frac{\partial \Pr\{P_D, P_T\}}{\partial P_D} \right) \frac{\left(\frac{\partial E_S(P_D)}{\partial P_D} \right)}{\left(\frac{\partial \Pi_D}{\partial P_D} \right)}}{\left(\frac{\partial \Pr\{P_D P_T\}}{\partial P_T} \right) \frac{\left(\frac{\partial E_S(P_T)}{\partial P_T} \right)}{\left(\frac{\partial \Pi_T}{\partial P_T} \right)}} = \frac{\Pr\{P_D, P_T\}}{[1 - \Pr\{P_D, P_T\}]} \tag{14}$$

Over the $[P_\Pi^*, P_A^*]$ interval $(\partial E_S(P_i)/\partial P_i) > 0$, $(\partial \Pi_i / \partial P_i) < 0$, $(\partial \Pr\{P_D, P_T\}/\partial P_i) > 0$, $i = D, T$. The implication of (14) is that if the marginal payoff gain relative to the marginal profit loss, weighted by the gain in probability of having the art work allocated, due to an increase in price estimate for dominant, is greater than that for competitor, then $\frac{\Pr\{P_D, P_T\}}{[1-\Pr\{P_D, P_T\}]} > 1 \Longrightarrow P_D > P_T$; symmetrically, if the seller's marginal payoff gain relative to the auction house's marginal profit loss, weighted by the gain in probability of having the art work allocated, due to an increase in price estimate for dominant, is less than that for competitor, then $\frac{\Pr\{P_D, P_T\}}{[1-\Pr\{P_D, P_T\}]} < 1 \Longrightarrow P_D < P_T$. The intuition is that the auction house which has a stronger probability weighted payoff gain to profit loss for price increases, has the stronger incentive to increase price valuations of the art work, and will realize a higher probability of being awarded the sale. This establishes 2.A. It also follows that if dominant and competitor share a common belief concerning the distribution of buyers, $M(P)$, have a common commission, $R(P)$, and cost, $C(P)$, structure, and the informed seller responds symmetrically to price estimate changes by dominant and competitor (in $\partial \Pr\{P_D, P_T\}/\partial P_i, \ i = D, T$), then a sufficient condition for BNE is given by $P_D = P_T$, in which case $\frac{\Pr\{P_{LD}, P_T\}}{[1-\Pr\{P_D, P_T\}]} = 1 \Longrightarrow \Pr\{P_D, P_T\} = 1/2$, such that the average of the seller's expected payoff associated with the P_D, P_T, auction house price estimates, must equal the median of the seller's expected payoff. This establishes 2.B. Where in addition to having a common $M(P)$, $R(P)$, $C(P)$, and $\partial \Pr\{P_D, P_T\}/\partial P_i, \ i = D, T$, auction houses have common knowledge of this symmetry, $P_D = P_T \rightarrow P_A^*$ is also necessary, since any $P_i > P_j$ would be known to result in $E_S(P_i) > E_S(P_j)$, hence the certainty of allocation of the art work to auction house i rather than j. The

incentive to increase price valuations to the price anticipated by the auction houses to be payoff maximizing to the seller follows provided that expected profit meets the $\Pi_i \geq 0$ constraint. This establishes 2.C.

8 Proof of Proposition 3

Consider the possible pooled and separating equilibria in the strategic interaction. There are separating equilibria arising from $\mu < 1$ and from $\mu > 1$; pooled equilibria arising from $\mu = 1$.

There are three possibilities of pooled equilibria: (a.) The case in which dominant chooses P_{low}, and competitor responds by $\mu = 1$, such that we have a pooled play on a low price estimate by both auction houses. (b.) The case in which dominant chooses P_{low}, competitor responds by $\mu > 1$, dominant revises its price estimate upward ($dP > 0 \rightarrow P_D = P_T$), and competitor undertakes no further upward revision of their price estimate ($d\mu = 0$). This provides a pooled play on an upwardly revised price estimate by both auction houses. (c.) The case in which dominant chooses P_{high}, and competitor responds by $\mu = 1$, such that we have a pooled play on a high price estimate by both auction houses.

There are also three possibilities of separating equilibria in which competitor offers a lower price estimate than dominant: (a.) The case in which dominant chooses P_{low}, and competitor responds by $\mu < 1$, such that we have a separating play on a low price estimate by both auction houses. (b.) The case in which dominant chooses P_{low}, competitor responds by $\mu > 1$, dominant revises its price estimate upward ($dP > 0 \rightarrow P_D > P_T$), and competitor undertakes no further upward revision of their price estimate ($d\mu = 0$). This provides a separating play on an upwardly revised price estimate by both auction houses. (c.) The case in which dominant chooses P_{high}, and competitor responds by $\mu < 1$, such that we have a separating play on a high price estimate by both auction houses.

At this point seller is faced by fixed price estimates, and must choose between dominant and competitor for the allocation of the art work. Seller does not know where the price estimates are on the "low" to "high" spectrum. However, since seller knows that the profit maximizing price of any auction house, P^*_Π, lies below the seller payoff maximizing price P^*_S, by Proposition 1, $E_S(\mu P_D) \leq E_S(P_D)\ \forall \mu \leq 1$. Given $E_S(\mu P_D) \leq E_S(P_D)\ \forall \mu \leq 1$ and the greater market share of the dominant auction house, hence its greater reach to more potential bidders, it is not rational for seller to allocate the art work to competitor, such

that the posterior probability of allocation of the art work to dominant and competitor are $\lambda = 1$ and 0 respectively. As long as $\Pi_T = M(\mu P_D) - C(\mu P_D) > 0$, it is therefore irrational for competitor to play $\mu \leq 1$, such that either pooled play on low, intermediate or high price estimates, or any separating play under $\mu < 1$, cannot constitute a Perfect Bayesian Equilibrium (PBE).

There are also five possible separating equilibria in which competitor offers a higher price estimate than dominant: (a.) The case in which dominant chooses P_{low}, competitor responds by $\mu > 1$, dominant does not revise its price estimate upward ($dP = 0$), and competitor undertakes no further upward revision of their price estimate ($d\mu = 0$), such that we have a separating play on a low price estimate by the auction houses. (b.) The case in which dominant chooses P_{low}, competitor responds by $\mu > 1$, dominant does not revise its price estimate upward ($dP = 0$), and competitor undertakes a further upward revision of their price estimate ($d\mu > 0$), such that we have a separating play on a low price estimate by the auction houses - more strongly separating than in the preceding case. (c.) The case in which dominant chooses P_{low}, competitor responds by $\mu > 1$, dominant revises its price estimate upward ($dP > 0 \rightarrow P_D > P_T$), and competitor undertakes a further upward revision of their price estimate ($d\mu > 0 \rightarrow P_D < P_T$), such that we have a separating play on an upwardly revised low price estimate by the auction houses. (d.) The case in which dominant chooses P_{high}, competitor responds by $\mu > 1$, dominant does not revise its price estimate upward ($dP = 0$; since $P_{high} \Longleftarrow M(P) = C(P)/R(P)$), and competitor undertakes no further upward revision of their price estimate ($d\mu = 0$), such that we have a separating play on a high price estimate by the auction houses. (e.) The case in which dominant chooses P_{high}, competitor responds by $\mu > 1$, dominant does not revise its price estimate upward ($dP = 0$; since $P_{high} \Longleftarrow M(P) = C(P)/R(P)$), and competitor undertakes a further upward revision of their price estimate ($d\mu > 0$), such that we have a separating play on a high price estimate by the auction houses - more strongly separating than in the preceding case.

Seller is now again faced by fixed price estimates, and must choose between dominant and competitor for the allocation of the art work. Since the only absolute constraint on price estimate increases by auction houses is that $\Pi_i = M(P_i) - C(P_i) > 0,\ i = D, T$, all of $P_D, \mu P_D < P_S^*$, $P_D, \mu P_D > P_S^*$, $P_D < P_S^*, \mu P_D > P_S^*$ are feasible, so that $dP \geq 0$ and $d\mu \geq 0$ are potentially consistent with with any of $d\lambda \gtreqless 0$, rendering multiple (possibly mixed) separating equilibrium strategies and hence PBEs feasible.

9 Appendix 1: Estimated Hedonic Price Equations

Dep Var.: $P^e_{i,h}$	(1:h=SWC)	(2: h=SC)			(1:h=SWC)	(2: h=SC)
Battiss_WW	−166674.8	−129168.4		Age	−133.9	−88.27
	(0.12)	(1.49)			(0.12)	(0.47)
Boonzaier_GJ	−143255.7	−117488.1		Signed	133653.4	−6865.0
	(0.10)	(1.26)			(0.24)	(0.15)
Pierneef_JH	−52315.4	258248.4		Dated	73555.0	10709.9
	(0.03)	(2.73)			(0.29)	(0.45)
Skotnes_CEF	−488533.9	−15316.8		Numbered	41945.5	34990.9
	(0.27)	(0.16)			(0.08)	(0.75)
Sumner_MFE	−14925.4	−129921.3		Oil	232459.3	128507.0
	(0.01)	(1.33)			(0.52)	(3.64)
Laubser_Maggie	−241554.7	−135933.9		WaterProof	137778.3	52653.8
	(0.16)	(1.32)			(0.22)	(0.70)
deJongh_MJ	−403866.4	−176043.8		Watercolor	−143921.6	70383.8
	(0.27)	(1.42)			(0.27)	(1.54)
Naude_PH	−341670.7	−156768.7		WaterSol	−128754.4	−201371.7
	(0.20)	(1.43)			(0.18)	(2.81)
McCaw_TJ	−442166.8	−234320.2		MixedMedia	−150385.6	−4710.2
	(0.29)	(2.06)			(0.25)	(0.09)
Stern_Irma	18246112.6	1945558.6		DiverseMedia	−201035.5	−63130.2
	(9.87)	(18.58)			(0.60)	(2.56)
Hodgins_RG	−254712.2	−176846.5		Sculp	80074.0	15942.2
	(0.16)	(1.72)			(0.12)	(0.34)
Coetzer_WH	−410495.1	−203809.6		Print	−143790.9	−76211.7
	(0.25)	(1.89)			(0.25)	(1.57)
VanHeerden_P	−396012.9	−174093.7		Photo	66115.8	28890.9
	(0.17)	(1.73)			(0.04)	(0.09)
Boyley_ES	−399570.5	−182371.0		Others	−6565.5	−54962.2
	(0.26)	(1.50)			(0.01)	(0.54)
Claerhout_FM	−335825.3	−159366.1		Exhibited	−550054.8	124166.6**
	(0.22)	(1.36)			(0.47)	(2.68)
Krige_F	−286586.7	−171943.5		Literature	417483.8	169897.9***
	(0.20)	(1.05)			(0.43)	(4.20)
VanEssche_MCL	−217193.2	−155233.8		Illustrated	−213304.4	105548.7
	(0.13)	(1.36)			(0.82)	(0.31)
Innes_AR	−138332.4	−128657.2		Cover	−1664104.9	1389281.1
	(0.08))	(1.16)			(1.09)	(22.28))
Baker_K	−578973.9	−223576.5		Still_Life	−253434.7	−18066.9
	(0.40)	(0.74)			(0.49)	(0.39)
Coetzee_C	−396976.2	−185858.9		Nude	−461939.8	−31696.9
	(0.22)	(1.53)			(0.55)	(0.33)
Catherine_NC	−219443.5	−89312.7		Figures	−131168.6	−81015.1
	(0.14)	(0.76)			(0.38)	(2.55)
Büchner_CA	−479107.2	−211073.8		Portrait	316234.9	145871.3
	(0.27)	(1.80)			(0.16)	(1.11)
Villa_ED	−208550.2	−96886.7		Miniature	−68429.3	−44948.0
	(0.07)	(0.89)			(0.09)	(0.10)
Boshoff_AH	−371928.7	−151274.5		Landscape	−206807.1	−92366.5
	(0.22)	(1.16)			(0.60)	(2.62)
Meintjes_JP	−383276.4	−238932.5		Illustrations/Cartoon	−18183.2	−110341.6
	(0.18)	(2.15)			(0.02)	(1.10)
Tier2	−343775.7	−142147.7		Constant	3410981.7	12604.4
	(0.28)	(1.91)			(0.29)	(0.01)
Tier3	−360559.0	−173067.4		N	3154	3423
	(0.30)	(2.24)				
Death	−1517.6	92.22		adj-R^2	0.08	0.31
	(0.26)	(0.18)				
Figures in round parentheses denote t-statistics						

Table 3: Hedonic Price Estimations 2009-13