ANGLO-DUTCH PREMIUM AUCTIONS IN EIGHTEENTH-CENTURY AMSTERDAM *

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January 11, 2017

ABSTRACT. An Anglo-Dutch premium auction (ADPA) is a two-stage auction, with a cash premium paid to the first-stage winner. We study such auctions used in the secondary securities market in 18th-century Amsterdam – among the first uses of a structured market-clearing mechanism in any financial market. Analysis of 16,854 securities sales in the late 1700s shows an empirical connection between greater uncertainty in the security's value and greater likelihood of a second-stage bid; a simple theoretical model of equilibrium bidding predicts the same connection. We argue the ADPA appears well-suited for the particular challenges of this environment, and represented an effective solution to a complex early market design problem.

JEL CLASSIFICATION: D44, N23

KEYWORDS: history of auctions, history of market design, Anglo-Dutch auctions, premium auctions

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1 Introduction

The revolt against Spain (1572-1648), which led to government borrowing, and the foundation of the East India Company (1602), which issued equity and debt, both spurred the growth of the primary market for financial securities in the Dutch Republic. As for the secondary market, while the Amsterdam Exchange provided a centralized marketplace where securities could be traded, it was used mainly as a commodity exchange; only securities for which transparent and liquid markets existed (VOC shares and, later, English public debt) traded there. Other securities, most notably Dutch public debt (Gelderblom and Jonker 2004), traded bilaterally through brokers. These brokers were generally able to accommodate small incidental trades, but were not equipped to trade large volumes all at once, such as when a trustee wanted to liquidate an entire portfolio (Van Bochove 2013). The Amsterdam securities market thus required a platform for trading securities that were relatively illiquid or whose market value was not well-established. Uninformed sellers had to be convinced, moreover, that they would not fall victim there to buyers' private information and collusion. The presence of a relatively small group of well-informed professional brokers in the market meant that such behavior was not implausible.[1] It was against this backdrop that auctions began to be used regularly to resell securities.

With no clear precedents for the use of auctions in financial markets the organizers of the Amsterdam market could not simply import a solution from another financial market. They could draw, however, on extensive experience with various auction formats used for other goods.[2] Beginning around 1700, they chose to use the Anglo-Dutch premium auction.[3] An Anglo-Dutch premium auction has two rounds of (possible) bidding, an ascending-price round and a descending-price round. In the first round, bidders bid against each other as in a standard English auction; the high

[1] Brokers were sometimes hired to estimate the value of securities for division among heirs (Van Bochove 2013). Koudijs (forthcoming) documents strategic behavior and use of information by professional sellers and buyers in the 18th century, which may have been a concern for uninformed buyers at auctions.

[2] For timber, see Schillemans (1947), Middelhoven (1978), Van Prooije (1990), Ebeling (1992). For wine: Wegener Sleeswijk (2006, 2007). For colonial trade: Philips (1924), Glamann (1956), Liu (2007). For art: Mak van Maay (1936), De Marchi (1995), Montias (2002), Blondé and Lyna (2012), Jonckheere (2008). For books: Cruz (2007), Lankhorst (2001). For tulips: Goldgar (2007). See also ACA, Willige verkopingen; ACA, Koopmanschappen; ACA, Houtwaren; ACA, Scheepsverkopingen. For auction mechanisms, see Kröhne (1907), Philips (1924), Wegener-Sleeswijk (2007) for some examples. Merchant manuals of the time describe specific auction techniques and their use in detail: for an example of such a description of the Anglo-Dutch premium auction, see Le Moine de l'Espine (1694-1801) and Ricard (1722).

[3] As in Klemperer (2002), "Anglo-Dutch" refers to an English auction followed by a Dutch auction; as in Goeree and Offerman (2004) and Hu, Offerman, and Zou (2010), "premium auction" refers to an auction where a cash bonus is paid to one or more bidders. Hence the name "Anglo-Dutch premium auction."

bidder in the first round receives a pre-set cash prize (the premium), regardless of what happens in the second round. In the second round, all bidders are still eligible to bid; beginning at a high price, the auctioneer calls out lower and lower prices, and the first bidder to bid wins the object being auctioned. If there are no new bids before the price reaches the level set in the first round, the first-round winner wins the object at that price. This type of auction can be documented as early as 1529,[4] and it was used throughout the Dutch Republic in the 18th and 19th centuries to sell real estate, goods from intercontinental trade, timber, wine, and financial securities.[5] In this paper, we aim to answer two questions: why was this particular auction format chosen, and how did it perform?

To answer the first question, we argue that the two most common auction formats, English and Dutch auctions, each have clear advantages and disadvantages, and conjecture that the Anglo-Dutch premium auction was an attempt to combine the advantages of both. In particular, based on a range of different theoretical auction models, we note that English auctions generally perform better – aggregating disperse information and raising more revenue – when bidders are symmetric and in genuine competition, while Dutch auctions perform better when some bidders are weaker than others or when collusion is a risk. The combination of the two formats might therefore be hoped to combine the informational and revenue properties of an English auction with the robustness to asymmetries and collusion of a Dutch auction.

To answer the second question, we analyze the Anglo-Dutch premium auction both empirically and theoretically. Remarkably good archival data has been preserved on the securities being sold in these auctions and the outcome of each sale; we examine data on 16,854 securities sold at auction between 1766 and 1783. One of the key patterns we find in the data is that the propensity of bidders to bid in the second round of the auction varied systematically with the characteristics of the security for sale: securities issued by less reliable borrowers, denominated in foreign currencies, traded during the winter, or traded after the financial crisis of 1773 were associated with substantially more second-round bidding. To rationalize this pattern, we introduce a simple theoretical model of equilibrium bidding in this setting, and establish a theoretical link between the level of uncertainty about the

[4]Noordkerk (1748). We are not aware of any evidence of the use of this type of auction during the Middle Ages.

[5]This type of auction is still used today for real estate auctions in Amsterdam; see http://www.mva-makelaars.nl/veilingx/english.shtml. Goeree and Offerman (2004) note that similar auction formats are used in other towns in the Netherlands and Belgium. A similar, though not identical, mechanism is used for fire sales of bankrupt companies in the United States; see LoPucki and Doherty (2007).

value of a security (or the amount of private information each buyer has) and the likelihood of a bid in the second round, exactly the relationship we found empirically. We also find a clear price discovery effect: when identical securities were sold one after another, each successive auction had a significantly lower likelihood of a second-round bid. Since second-round bidding is associated with greater uncertainty, this implies that with each successive auction, the amount of private information held by buyers, and the uncertainty about the true value of the security, was shrinking in a substantial, measurable way. Together, these give at least suggestive evidence that the auctions worked well: that bidding appeared consistent with equilibrium behavior (and therefore that buyers were in genuine competition with each other), and that the auctions succeeded in drawing out bidders' private information.[6]

These findings contribute to the literature, first of all, by filling a lacuna. The literature dealing with microstructure of financial markets from the 17th century onward – see Neal (1990), Carlos and Neal (2011), Petram (2011), and Gelderblom and Jonker (2004, 2011), among many others – combines descriptive observations of market institutions with empirical work mainly related to price series, but does not make use of a formal institutional analysis. The work on formal institutional analysis, on the other hand, has focused on individual case studies during the Late Middle Ages, and has focused more on (informal) reputation mechanisms and their impact on markets rather than on formal market institutions (Greif 1993, 1994, 2006; Greif, Milgrom and Weingast 1994).[7] The literature on historical auctions, furthermore, is mainly descriptive and/or takes a rather holistic or sociological approach towards understanding auctions (Wegener Sleeswijk 2006, 2007);[8] the theoretical literature on auctions has, to our knowledge, not studied the Anglo-Dutch premium auction as it was practiced historically.[9]

[6] The second round of the Anglo-Dutch format also provides an informal sort of verification that a security was appropriately priced: if nobody bid in the second round, this might signal that conditional on the information that was revealed in the first round, nobody believed the security to be significantly underpriced. In the auctions we study, fewer than one-quarter of the securities sold attracted a bid in the second round, again suggesting that these auctions were pricing securities correctly.

[7] For recent attempts in historical market design studies with a formal institutional analysis see Boerner and Quint (2016) or Boerner and Hatfield (2014).

[8] Methodologically closer to our research are the work by Engelbrecht-Wiggans and Nonnenmacher (1999) and de Marchi (1996), who study the implementation of different auction mechanisms historically, look into their theoretical economic properties, and analyze their economic performance based on empirical studies.

[9] Papers on other, related two-stage auction formats are Klemperer (2002), Āzacis and Burguet (2008), Goeree and Offerman (2004), Hu, Offerman and Zou (2010), McLean and Postelwaite (2004), and Levin and Ye (2008), but we have not found any models containing the two key features of the ADPA as practiced in this market: a fixed premium paid to the winner of the first round, and all bidders still eligible to bid in the second round.

In addition to understanding this particular auction format, this paper contributes to an understanding of the long-run evolution of market mechanisms in general. Economic historians have claimed that by the 18th century, markets already worked rather well (North and Weingast 1989, Neal 1990). We do not dispute this. But we argue that this need not have occurred by chance, or solely via Adam Smith's invisible hand or self-organizing institutions in the Hayekian sense. Rather, we argue this often occurred through thoughtful, deliberate implementation and monitoring of market platforms with specific allocation mechanisms. Our findings are in line with recent work in market design, which claims that markets need to be engineered and efficiently designed (see for example Milgrom 2011, Roth 2002, 2008, O'Hara 1995, 2003, 2007 and Duffie, Gârleanu and Pedersen 2005). Our case study documents one historical use of such deliberate market engineering, and offers some suggestive evidence that it may have worked reasonably well.

Prior to the 18th century, centrally organized financial markets consisted simply of a designated time and location, where buyers and sellers would assemble to trade among themselves or through brokers;[10] the Amsterdam securities market was among the first, and may have been the very first, financial market to make use of a formal, centralized market-clearing mechanism. This specific auction platform was thus an early step in the evolution of financial markets from medieval-style gathering places toward more structured, centralized clearing mechanisms; as we discuss below, auctions and auction-like mechanisms started appearing in many other financial markets in the late 18th and early 19th century. If, as we believe, these auctions led to a reasonably liquid, transparent, well-functioning secondary market for these securities in Amsterdam in the early 18th century, this could well have contributed to Amsterdam's later rise as the leading issuer of debt and equity for foreign sovereigns, private companies and overseas plantation-owners, and contributed to its international success in finance in the latter half of the 18th century.

The rest of the paper is structured as follows. Section 2 gives some history of the Anglo-Dutch premium auction, and details its use in the securities market we study. Section 3 gives a theoretical discussion of why this auction format may have been chosen. Section 4 describes our data, explains our empirical approach, and presents our empirical findings. Section 5 presents a simple model of equilibrium bidding in Anglo-Dutch premium auctions, and relates the theoretical predictions

[10] Boerner and Quint (2016) study the regulations placed on brokers (for both financial products and other goods) in European merchant towns up to the end of the 17th century.

to our empirical findings. Section 6 discusses our findings and places them in a broader historical context; Section 7 concludes. The results in Section 5 are proved in the appendix.

2 History and Use of the Anglo-Dutch Premium Auction

The use of the Anglo-Dutch premium auction can first be documented in housing auction regulations from 1529. Its first use outside of real estate seems to have been for ships and shipping gear during the 17th century;[11] from the middle of the 17th century onwards it was also used to sell timber, wine, brandy, and colonial goods.[12]

It was around 1700 that Anglo-Dutch premium auctions were gradually adopted in Amsterdam to sell financial securities as well.[13] The use of these auctions in the Amsterdam securities market continued throughout the 18th and 19th centuries.[14] Archival sources suggest that auctions were primarily used to sell off estates.[15] Auctions were not the only way to sell securities – brokers often arranged private sales – but auctions offered the advantage of usually liquidating the entire offering at once and of revealing information about prices.[16]

Auctions were public events, and as such, the whole process was regulated and controlled by the city of Amsterdam. Auctions were held on Mondays at 3 p.m. in a well-known and exclusive hotel, the Oude Zijds Heeren Logement, in the center of Amsterdam. This starting time was likely tied to the hours of the nearby Exchange, which closed at 1 p.m. (Scheltema 1846, p. 46f). Dates

[11] Noordkerk (1748).

[12] Ricard (1722); Le Moine de l'Espine (1694-1801); Philips (1924); Wegener Sleeswijk (2007).

[13] Since auctions were initially used infrequently, it is difficult to determine decisively when they were first used to sell securities. The earliest example that we found dates from 1701 (ACA, Willige verkopingen, inv.nr. 67, 21 March 1701). The ADPA was already being used in Utrecht to auction securities in 1678 (UCA, Notarissen, inv.nr. U065b001 (notary D. Woertman), deed 107, 5 November 1678). Whether the Anglo-Dutch premium mechanism was suggested in Amsterdam by the securities brokers is unclear; but the same group of brokers was already using the ADPA for real estate, so they were familiar with the mechanism and its properties. Petitions to the city government contain an example of timber brokers who complained about the prevailing auctioning mechanism, providing at least some support for the idea that brokers expected the city government to provide a listening ear. (ACA, Schout en schepenen, inv.nr. 714, deed 15) Furthermore Baasch (1902), in his analysis on the use of auctions for merchandise in early 18th-century Hamburg, neatly documents the role of different interest groups, including brokers and merchants, who tried to influence the city government in allowing or restricting auction sales for different products.

[14] We sampled the December issues of the financial newspapers to establish the latter. Editions of the *Prijs-courant der Effecten* (12 December 1842), *Amsterdamsch Effectenblad* (17 December 1869), and *Nieuw Algemeen Effectenblad* (24 December 1897) all included lists of auctioned securities; the December 1901 issues of the *Prijscourant*, however, did not contain such lists. This might indicate the disappearance in the early 20th century.

[15] See ACA, Willige verkopingen, inv.nr. 296, for auction booklets (e.g. auctions on 3 September 1742 and 23 August 1745), and inv.nr. 130 (auction on 24 March 1766) for an example in the auction records kept by the town secretaries. For the town of Utrecht, see UCA, Notarissen.

[16] Van Bochove (2013).

were set well in advance and licensed brokers, who alone were allowed to offer lots at auctions, had to apply to the government for permission to participate on one of these dates. Frequently, they used standardized forms for this.[17] The next step seems to have been for the brokers to inform the town government about the specific securities they wished to auction.[18] Once a broker was granted permission he used newspaper advertisements, which were published several weeks in advance, and auction booklets to describe his lots in detail. Potential bidders were thus informed about the type, issuing party, issuing date, and other details of each security up for sale. Advertised securities could be withdrawn from the auction if the seller found a buyer before the auction was held.[19]

Bidding took place through the Anglo-Dutch premium mechanism introduced above – an English auction, followed by a Dutch auction, with the winner of the first round receiving a separate premium (and winning the security if there were no higher bids in the second round). This format is documented for merchandise in general and wine in particular in Ricard (1722) and Le Moine de l'Espine (from 1744 onwards).[20] These authors do not mention whether the auctioneer called out successive price levels or whether bidders called out their own bids. In our data, nearly all winning bids were in increments of 0.25% of the face value of the security, but a very small number were in increments of 0.125% or some other amount. While bids were being made during the auction's first round, the cash premium, or *plokpenning*, was placed in front of the auction desk such that everybody could see it.[21] The premium's size was not recorded separately for each auction, but we believe it was typically a constant fraction of the face value of the security for sale. Le Moine de l'Espine (1801) stressed, for instance, that the size of the premium was in proportion to the value of the auctioned asset ("near de waerdije der geveilde Goederen"). Archival evidence shows that in Amsterdam the premium was 0.25% of the security's face value.[22]

[17] See *Mercurius* 35, p. 240 (December 1773), for the auction dates of 1774, for example; ACA, Scheepsverkopingen, inv.nrs. 63-72, for brokers' requests; Le Moine de l'Espine (1801), p. 308, for offering lots.

[18] ACA, Willige verkopingen, inv.nrs. 296-298.

[19] On rare occasions, a security was withdrawn by the seller after the auction was held, or even during the auction. This happened in less than 0.5% of cases, so we assume bidders did not view this as a major concern and exclude it from the formal model. ACA, Willige verkopingen, inv.nrs. 75 (12 May 1721, 25 June 1721, 29 December 1721), 79 (26 April 1728), 120 (16 March 1761, 25 May 1761).

[20] Additional detail about the format comes from the source materials, such as ACA, Willige verkopingen, inv.nrs. 75 (23 March 1722) and 88 (29 August 1740) on the details of the second round.

[21] The premium is sometimes also referred to as *trekgeld* or *strijkgeld* (Mak van Waay 1936, pp. 24-25, and Le Moine de l'Espine 1801, pp. 283 and 286).

[22] ACA, Remonstrantse Gemeente, inv.nr. 337, page 165 (auction of 9 July 1759); ACA, Desolate Boedelkamer, inv.nr. 2896 (auction of 22 December 1777). The premium was one of several transaction costs, which summed up to about 1.5-2% of the face value of the security, and was split between the buyer and the seller. Other costs included payments to the auctioneer, the town crier, the printer of the bills and booklets, the agent who posted these in town,

Bidding was open to anybody. While any private buyer was free to participate, many of the bidders were themselves brokers, who were buying securities for their customers.[23] Collusion among bidders may have been a concern: there was a group of regular bidders who participated and won frequently, making it at least a possibility. There was often overlap between brokers bidding on securities and those selling – 20% of securities were won by one of the organizers of that day's auction. New regulations covering other auctions that passed in 1677 explicitly banned collusion under penalty of corporal punishment,[24] suggesting it was perceived to at least be a possibility. Besides serious bidders, there is also evidence of participation by "premium hunters" – people who hoped to win the first-round premium and be outbid in the second round, but had no interest in actually winning the security.[25]

Securities sold by the same broker were offered one after another; within that group, securities from the same issuer were sold consecutively.[26] Each auction also specified how sales had to be settled. Payments, for instance, had to be made within a certain number of days, and with coins of a sufficiently large denomination. Sellers unfamiliar with a buyer's reputation could ask him to name two guarantors. If he failed to name them, the security could be re-auctioned immediately,

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and the notary, a commission to the broker representing the seller, and advertising costs. For securities auctions we have detailed information from the ledgers of Vlaer & Kol (UCA, Vlaer & Kol, inv.nrs. 691 (folio 297) and 694 (folio 139)), who managed securities portfolios for their clients in Utrecht. Detailed information about the Amsterdam wine auctions can be found in Le Moine de l'Espine (1734, pp. 299-300). The auction records from the nearby town of Utrecht report that in most cases there, the premium was 0.275% of the security's face value; some exceptions – usually for securities with odd denominations – were also noted. See UCA, Notarissen, inv.nr. U217a012 (notary W. van Vloten), deed 121 (28 April 1770); inv.nr. U247a009 (notary D.W. van Vloten), deed 108 (19 May 1770); inv.nr. U247a021 (notary D.W. van Vloten), deed 55 (1 October 1785); inv.nr. U227a013 (notary J.T. Blekman), deed 20 (10 September 1785). We have no reason to believe that in Amsterdam the premium varied systematically across sales other than with the size of the security; our empirical approach implicitly assumes that any variation in the premium (as a fraction of the security's face value) was independent of our explanatory variables.

[23] If a security was purchased by a broker, he had to provide the name of his client within a few days. ACA, Willige verkopingen, inv.nrs. 1-266.

[24] The new regulation applied to real estate auctions, and stated that "...no one, and especially not brokers, may cause any commotion, confusion, disorder, assembling or collusion or other actions, leading to the disruption of the sale, or to depress [the prices] of Goods and Merchandise, directly or indirectly, on the penalty of corporal punishment..." (Translation ours.) The real estate auctions were organized by the same brokers as the securities auctions, and certain other regulations applied to both, though we don't have evidence that this one did. See Noordkerk (1748).

[25] This can be documented in regulations (Noordkerk 1748) meant to deal with bidders who were not able to pay for the object in the event that they won. Offenders could be imprisoned, receive corporal punishment, or even be banned from the city. The regulations and other sources (e.g. Le Moine de l'Espine 1801, pp. 316-317) refer to such bidders as "sheep." Their names and punishments were recorded in the "sheep book" (ACA, Schout en Schepenen, inv.nr. 138). See Faber (1971) for a discussion of this book.

[26] The order of the sellers was determined by the order in which they had petitioned the government to participate, or via lottery (Le Moine de l'Espine 1801, pp 310-311). ACA, Willige verkopingen, inv.nr. 130 (deed 24 March 1766) shows how one broker ordered the securities he was selling for his clients.

at the first buyer's expense.[27] At the day of the auction, town secretaries were present to record auction outcomes.[28]

3 Appeal of the Anglo-Dutch Premium Auction

In this section, we use theory to address the question of why the Anglo-Dutch premium auction might have appealed to those designing 18th-century financial markets, and briefly consider how it might have performed. We conjecture that the Anglo-Dutch premium auction was an attempt to combine the benefits of two standard auction formats, the English and the Dutch. Thus, we begin by considering the advantages of each of these auction types.[29] To do this, we draw on insights from a number of different theoretical models of auctions in different environments to build a broad, impressionistic view of the appeal of this particular mechanism. (In Section 5 below, we will introduce our own model of equilibrium bidding in this particular setting.)

3.1 Advantages of English Auctions

English (or ascending) auctions typically have three main advantages over Dutch auctions:

Greater information revelation. Because English auctions allow multiple bidders to bid against each other, bidders have a chance to infer their opponents' views of the value of the object, and incorporate this information into their own bidding. This helps to mitigate the winner's curse, and thus reduces the likelihood of ex post regret by winners.[30] In a Dutch auction, on the other hand, bidders gain no information from their opponents' actions until it is too late to act on that information, so only a single bidder's information can be built into the final price. English auctions also reveal more information about how many bidders are interested in a particular prize – information which might be hidden in a Dutch auction, and which might help bidders to correctly account for the winner's curse.

[27] ACA, Willige verkopingen, inv.nrs. 1-266. The auction on 17 October 1746 (inv.nr. 95) has an example of a security being auctioned for a second time, although this does not appear to have happened often.

[28] The identity of the winner, the high bid in the first round, and the increase in the second round bid (if there was one) were recorded. Le Moine de l'Espine (1801), pp. 311-312; ACA, Willige verkopingen, inv.nrs. 1-266.

[29] Note that descending (Dutch) auctions are strategically equivalent to first-price sealed-bid auctions. Most of the insights we describe below comparing English to Dutch auctions originally considered sealed-bid rather than Dutch auctions, but the results apply equally.

[30] In a simple model, such ex post regret does not hurt the seller. But in a setting where the winning bidder might attempt to back out of the deal, or where a dissatisfied bidder might stop participating in future auctions, this could impose a cost on the seller as well.

Higher revenue when bidders are symmetric. Based largerly on losing bidders' information being revealed through their bidding, Milgrom and Weber (1982) show that ascending auctions yield higher expected revenue than any other standard auction format in a symmetric model with affiliated information and interdependent values.[31]

Greater efficiency when bidders are asymmetric. In an asymmetric private-values setting, an English auction always leads to the efficient allocation (the buyer with the highest valuation always wins); due to asymmetry in bidding strategies, in a Dutch auction, the winner may not be the bidder with the highest valuation (Maskin and Riley 2000).

3.2 Advantages of Dutch Auctions

On the other hand, Dutch auctions have three advantages over English auctions:

Less vulnerability to collusion. Klemperer (2002) points out that Dutch auctions make it harder for a bidding ring to sustain a collusive arrangement.[32] More significantly in our setting, a bidding ring would be more vulnerable to entry by an outsider. If all the "regular" bidders were in a collusive agreement to keep prices artificially low, they would be "protected" in an English auction format, since an outsider who arrived and bid against the ring could still be outbid, and would therefore face little incentive to take on the ring in the first place. In a Dutch auction, however, the new entrant would be able to win at least one auction at a low price before the ring could react – giving him an incentive to show up in the first place.

More advantageous to weak bidders. Even without collusion, we can imagine there might have been some set of "strong" bidders who were committed to participating, and some additional marginal or weak bidders who might or might not. Dutch auctions have been shown to give more surplus than English auctions to weak bidders in a variety of environments.[33] By offering less disadvantage to marginal entrants, Dutch auctions might lead to greater participation.

[31]However, this result can be reversed when bidders are risk-averse or asymmetric.

[32]His reasoning is that in an English auction, an insider who deviates from the agreement and bids higher than he is supposed to would be detected immediately and could be outbid, while in a Dutch auction, he would have already won the auction (at an artificially low price) by the time his deviation was detected.

[33]Maskin and Riley (2000) show that in an asymmetric, two-bidder private value setting, the weak bidder wins more often, and earns higher payoffs, in a Dutch auction than in an English auction. Klemperer (1998) shows that if values are "mostly common" but one bidder has a slight private-value disadvantage, he can profitably compete in a Dutch auction, but drops out immediately in equilibrium in an English auction. Engelbrecht-Wiggans, Milgrom and Weber (1983) show that in a pure common-values setting where one bidder knows the value of the prize exactly and the others do not, the uninformed bidders can still bid seriously in a Dutch auction and win half the time, while they drop out immediately in an English auction.

Greater revenue when one bidder is stronger than the others. In some environments, when there is only a single "strong" bidder, a Dutch auction leads to substantial revenue, while an English auction does not.[34] And even when bidders are symmetric, common-values English auctions admit multiple equilibria, some of which are very low-revenue, while a Dutch auction lacks such equilibria.

3.3 Motivation for the Anglo-Dutch Premium Auction

Summing up, English auctions tend to outperform Dutch auctions when bidders are equally strong and in genuine competition with each other; while Dutch auctions tend to be better when bidders are asymmetric, when weak bidders might be deterred from participating, and when bidders might be colluding. We conjecture that the motivation for combining the two was to capture the advantages of both formats. Depending on equilibrium behavior, one could hope that the first stage would allow for better information revelation and increase revenue; while the presence of the second stage would encourage entry by marginal bidders and disrupt collusive behavior.

However, given the hybrid format, there remains the question of whether bidders will compete seriously in the first stage, or simply wait to bid in the second round, undermining the point of using a two-stage auction.[35] The two-stage mechanisms considered by Klemperer (2002) and Goeree and Offerman (2004) solve this problem in one way: by limiting participation in the second round to the highest two bidders in the first round. But this comes at a cost: many of the relative advantages of the Dutch auction (robustness to collusion, attractiveness of entry to weaker bidders) might be lost if participation in the Dutch auction was rationed.[36] The payment of a first-round premium is a different way to solve the problem: it offers additional motivation to bid in the first round (and makes very low first-round prices implausible), while still allowing all bidders access to the Dutch part of the auction, potentially disrupting collusion and encouraging entry.

[34]This is true in two common-value models – the Klemperer (1998) model where one bidder has a small private-value advantage over the others, and the Engelbrecht-Wiggans (1983) model where one bidder has better information. In both of these, weak bidders drop out of an English auction at price 0, since at any positive price where the strong bidder allows a weak bidder to win, the weak bidder ends up with a negative payoff. In the Maskin-Riley (2000) asymmetric private value model, however, the revenue ranking of the two formats is ambiguous; Kirkegaard (2012) offers sufficient conditions under which the Dutch auction gives higher revenue.

[35]This appears to be the logic considered by Cassady (1967), who writes, "The attainment of a sufficiently high first-phase bid is so crucial to a successful [Anglo-] Dutch auction that sometimes bidders in the ascending phase are encouraged by means of a small bonus, called in Holland *plok* or *plokgelden*."

[36]Goeree and Offerman show their mechanism performs well when there is a single "strong" bidder and multiple weak bidders; but with just two strong bidders, weak bidders would have little chance of advancing to the second round, and entry by weak bidders would therefore be discouraged.

In total, then, the Anglo-Dutch premium auction seems an attempt to combine the better informational and revenue properties of an English auction with the anticollusive and pro-entry features of a Dutch auction, with the premium required to elicit serious bidding in the first round.

4 Empirical Analysis

Next, we study detailed transaction-level data to see how the Anglo-Dutch premium auction performed in practice. As explained above, we believe the Anglo-Dutch premium auction represented an attempt to capture the relative advantages of both the English and Dutch auction formats. A natural question, then, is whether it succeeded. One key source of insight into how the auction performed is the prevalence, or absence, of second-round bids. The auction did not require a second-round bid: it was entirely possible for all the bidding to occur in the ascending-price stage, and for nobody to then bid in the descending stage. If this were the norm, however, we might wonder whether the auctions were actually getting any benefit from the second round, or whether the auction was for practical purposes simply an English auction. On the other hand, if nearly every sale involved a second-round bid, we might wonder whether the first-round bids were truly competitive, or whether bidders were mostly holding back and concealing their private information to bid in the descending stage; in that case, we might wonder whether the English stage was actually accomplishing its goal.[37]

As we discuss below, in the auctions we study, roughly a quarter ended up including a second-round bid – enough to make the second round meaningful, but few enough that first-round bidding appears to have been serious. More interesting, perhaps, is that different auctions had markedly different likelihoods of having a second-round bid. In this section, we discuss our data, and establish key empirical regularities in that data; in the next section, we will then introduce a simple model of equilibrium bidding to explain those patterns. What we will find – both empirically and theoretically – is that greater uncertainty in the value of the security is associated with a greater likelihood of a bid in the second round.

[37] Further, if second-round bids occurred in nearly every auction, this could be a sign of collusion among bidders. If first-round bids were low enough for a second-round bid to be nearly inevitable, it would seem sensible for a bidder to bid higher in the first round, to capture the premium; not doing so might suggest the bidders were using the premium to reward collusive behavior, or using first-round bids to signal second-round intentions, rather than truly competing for the prize.

4.1 Data

We study primary source data for securities auctioned through the Anglo-Dutch premium mechanism on Amsterdam's secondary market. Our data set covers 469 auction days from January 1766 to December 1783. Auctions were typically held every two weeks, but fewer auctions were held during summer and around Christmas. The number of securities sold on one day ranged from very few up to 289, and the total number of securities sold during our period was 16,854.[38] Securities were auctioned one by one; for each sale, our data includes the identity of the issuer, the face value of the security,[39] and the currency it was issued in, along with the outcome of the auction – the high bid in the first round, the second-round bid if there was one, and the identity of the winner. Nearly one-quarter of the securities in our data were won by the ten most frequent winners (identified in Table 2), and more than half the securities were won by the top 50 winners, but there were also many buyers in the data who won just one security. More detailed information such as when the security was issued, what interest rate it paid, and how many times it had been resold since being issued, is available for a subset of sales.[40]

4.2 Empirical Strategy

While our data include the price (winning bid) for each security, it is hard to link this to any fundamental value or calculate an implied yield, since maturity date and coupon rate are only available for a subset of securities. Instead, we focus on a variable that is unique to our setting: whether or not a particular sale included a second-round bid. Overall, 23% of auctions had a bid in the second round, but this varied significantly across issuers, time, and in relation to various other explanatory variables. Below, we describe the different explanatory variables we use, how they relate to second-round bidding in a simple descriptive way, and how they explain second-round bidding via a binary probit model. Tables 4 and 5 formally define the explanatory variables

[38]The data were recorded by town secretaries during the eighteenth century, and are now stored in the Amsterdam City Archive. Research assistants collected the data from there (ACA, Willige verkopingen, inv.nrs. 70-129) and from *De maandelykse Nederlandsche Mercurius*, where they were published starting in the 1760s. On the latter, see Hoes (1986); Van der Steen (1996); Van Meerkerk (2006). We again thank Oscar Gelderblom and Joost Jonker for access to the data.

[39]Most securities had a face value of 1,000 guilders; this was about three to four times the yearly income of an unskilled worker (De Vries and Van der Woude 1997).

[40]Most securities had been issued between five and twenty years earlier, but a few dated back as far as the late 17th century. Some had changed ownership as many as 27 times. Coupon rates typically ranged from 2.5% to 6%.

and give summary statistics; Tables 1, 2, and 3 show the relationship between certain individual explanatory variables and the likelihood of a second-round bid. Tables 6 and 7 present the marginal fixed effects from various specifications of a binary probit model. The unit of observation is an individual security sale, with the dependent variable being 1 if there was a second-round bid and 0 if not; each column of these tables uses a different combination of explanatory variables. We think of the final column of Table 7 as the "primary" specification, and describe it in the text below, but most effects are consistent (both in magnitude and statistical significance) across the different specifications. Table 8 offers several robustness checks on correlated error terms; again, the results change very little qualitatively.

4.3 Explanatory Variables and Empirical Results

Issuer

Rather than using the specific identity of each issuer, we group them into five broad categories (see Table 1). Securities issued by the province of Holland accounted for more than 5,300 of the sales. Other Dutch government securities issued by the States General, other provinces, cities, and the Navy Boards accounted for about 1,700 sales. Foreign government securities issued by the kings of Denmark, France and Sweden, the Austrian emperor, the Russian tsar, and various German dukes and cities accounted for about 1,900 sales. Private company loans included, among others, debt issued by a Spanish canal building company, a Swedish mining company, a Dutch mutual fund, and the VOC (and very occasionally VOC shares as well). This group accounted for about 1,000 sales. Caribbean and South American plantation loans included loans to owners of plantations in Suriname, Demerara, Essequibo, Berbice, Trinidad and Tobago, Grenada, the Danish West Indies, and other locations. These loans accounted for about 7,000 sales.

The available coupon rates suggest that these five groups of issuers were associated with different levels of risk. The most reputable domestic borrower, the province of Holland, paid a coupon of only 2.5% (Liesker and Fritschy 2004). The Danish case is illustrative for the rates charged to foreign borrowers (Van Bochove 2014): the Danish kings initially paid a coupon of 5%, but this later decreased to 4%. At the same time, however, large Danish corporations (5%) and plantation owners in the Danish West Indies (6%) typically paid higher coupons, to compensate for greater risk.[41]

Winning bids also varied across issuer category. Despite the lower coupon rates, Holland securities usually sold at a premium over face value. Plantation loans, on the other hand, nearly always sold at a discount; the other security types routinely sold both above and below face value.

Simple descriptive statistics suggest that the securities perceived as higher-risk were also more likely to attract a second-round bid at auction. As shown in Table 1, second-round bidding was more than twice as common in auctions for private company loans (34% of auctions) and plantation loans (30%), as in auctions for Holland securities (14%) and foreign government securities (14%), with other Dutch securities falling somewhere in between (20%). These same patterns persist when we move to the probit regressions and include other variables and controls. Relative to Holland securities (the omitted category), and holding other factors fixed, other Dutch securities, plantation securities, and private company securities are all more likely to have a second-round bid, by between 11% and 23%, while foreign government securities are slightly less likely, with all of these differences being statistically significant.

Currency

While most securities in this market were denominated in Dutch guilders, a small number were denominated in foreign currencies. In the sales of securities denominated in a foreign currency, 25% had a second-round bid. While this is close to the overall average in our data (23%), nearly all the securities in foreign currencies were foreign government securities, which typically (see above) had much less second-round bidding. When we include a dummy variable for foreign currency in the regressions, it has a small positive effect, but as more explanatory variables are added, it loses statistical significance.

Historical and Seasonal Effects

Several explanatory variables relate to the historical context of the period. At the end of December 1772 and the beginning of January 1773, Amsterdam experienced a financial crisis that hurried its long-run decline as a financial center in favor of London (Jonker and Sluyterman 2000). The

[41] Recent research suggests that mechanisms existed to keep 18th-century sovereign borrowers committed to repaying their loans (Drelichman and Voth 2014, Van Bochove 2014), likely explaining the lower coupon rates.

crisis was triggered by liquidity problems among major Amsterdam banking houses (Sautijn Kluit 1865, Jonker and Sluyterman 2000), and led to chain reactions and spillovers on financial centers all over Europe and to further business failures. This financial crisis coincided with shocks, such as tornadoes and slave rebellions, affecting the plantations in South America and the Caribbean (Postma 1990; Postma and Enthoven 2003; De Vries and Van der Woude 1997; Van de Voort 1973).

The effect on second-round bidding is striking. Before the crisis, only 9% of auctions had a second-round bid, compared to 26% after the start of the crisis. The change was most dramatic for foreign government securities (from 3% to 17%) and plantation loans (from 5% to 33%), while the increases for the other groups of securities, while significant, were more modest in relative terms (from 10% to 16% for Holland securities, from 11% to 25% for other Dutch securities, and from 19% to 38% for private companies).

The effects are similar in the regression outcomes. When a single "pre-financial-crisis" dummy variable is included, it has a strong, high statistically significant, negative effect on second-round bidding. When separate pre-crisis dummies are used for each category of issuer, all are negative and significant, with plantation and foreign government securities having the largest magnitudes (18% and 15%), and Holland securities having the smallest (6%).

We also consider the effect of the Fourth Anglo-Dutch War (1780-1784), which mainly affected overseas economic activities; and the effect of winter, since during the months of January, February and March, relatively few ships came into the harbor of Amsterdam.[42] War and the commercial off-season would both likely have slowed the arrival of information.

During the period of the Fourth Anglo-Dutch War, second-round bidding was even more common than usual in auctions for plantation loans (39%), but not for other types of securities. Auctions held in winter had only marginally more second-round bidding (24% versus 23%). Both effects were modest, but statistically significant, when included in the regressions.

[42]In the years 1771-1787 the share of annual entries of ships from European points of origin into Amsterdam's port (as measured through the *paalgeld* tax) was 1.5% in January, 1.8% in February and 5.8% in March (Welling 1998). In the years 1766-1769 the share of annual passages through the Sound – northern Europe's most important shipping route – was 0.1% in January, 0.1% in February and 2.6% in March (Soundtoll 2011).

Intra-day Learning

The next set of variables relates to intra-day learning among the auction participants. Securities from the same issuer were often auctioned consecutively. Over the course of several consecutive sales, bidders' opinions about a security would be revealed, and there would be less private information present in each successive sale.

This had a clear effect on second-round bidding, as shown in Table 3. When the security being sold was the first security of a given issuer, 34% of sales attracted a second-round bid. For the second consecutive sale for the same issuer, 26% had second-round bids; for the third, fourth, and fifth sales, 22% had second-round bids. After twenty or more securities of the same issuer had just been sold, only 16% of sales had a second-round bid.

We account for this in the regressions by including the number of securities of the same issuer (or, in the case of plantation securities, securities linked to the same plantation) that had just been sold prior to a particular sale; we include this number separately for each category of issuer. All of these variables get negative coefficients; all but one (foreign government securities) are statistically significant.

"Auction Room Effects"

We also consider several variables considers effects specific to each auction day. While the auctions were usually held every other week, there were occasions when they were less frequent. When there was a longer gap between auctions, there would have been more time for private information and news to accummulate. We therefore include the number of days since the previous auction day; we find it had a positive, and statistically significant, effect on second-round bidding.

We also consider the number of securities sold on an auction day, as we expect days with more securities for sale would likely have attracted more bidders. The effect of the number of securities sold on second-round bidding is inconsistent across specifications, however, and is not statistically significant.

Finally, we control for the mix of bidders we know to have been present on a particular day. We do this because there is significant heterogeneity in bidding behavior across individual bidders, as shown in Table 2. For instance, among the securities won by bidder Van Blomberg, 69% were won with a second-round bid; among the securities won by bidder Heimbach, on the other hand, only 14% were won with a second-round bid. For each auction day, we construct two variables meant to capture the propensity of the bidders present that day to bid, or not bid, in the second round. Obviously, the relationship between these variables and second-round bidding is mechanical (by construction); we are more interested in seeing whether the other effects we measure are robust to controlling for this type of "auction-room heterogeneity".[43]

Other Controls

Since there was often an overlap between the brokers organizing a particular day's auction and those buying securities for their clients, we include a dummy for whether the winning bidder was among that day's organizers. We also control for a linear time trend in some specifications (measured in months), and for four prices taken from the Amsterdam Stock Exchange: two commodity prices (Polish grain and St. Domingo sugar), the Amsterdam exchange rate on Hamburg, and the price of Amsterdam bank money (the agio).[44] We didn't anticipate a particular causal relationship for any of these controls; we simply wanted to ensure that our other results were robust to their inclusion. Comparing Table 7 column (10) (which excludes these controls) to column (13) (which includes them), we see that the coefficients on the other explanatory variables are unchanged.

Summary

As noted earlier, columns (1) through (13) of Tables 6 and 7 offer marginal fixed effects from binary probit regressions with various combinations of explanatory variables.[45] While exact quantitative results vary slightly from specification to specification, nearly all the qualitative takeaways – the signs and statistical significance of each effect – are quite stable. Table 8 gives robustness checks on

[43]The two variables are constructed as follows. We take the 83 most frequent auction winners in our data, each of whom won at least 50 auctions and who together account for 67% of winning bids. For each auction day, we look at those bidders from this group who won at least one security, and therefore who we know were present that day. We then calculate the fraction of those present who were "high-propensity second-round bidders" (won at least 30% of their securities in the second round over the entire sample) and the fraction who were "low-propensity second-round bidders" (won less than 10% of their securities in the second round).

[44]Data from Malinowski (s.a.). These four prices were selected in part based on availability of weekly price data, and partly because of their relevance to different parts of the economy.

[45]All non-binary explanatory variables aside from the time trend are converted to a log scale – by adding one and then taking the natural log – prior to inclusion in the regression. While many of our explanatory variables are binary dummies, each represents a broad category, not the identity of an individual issuer or bidder, so we are not concerned about the incidental parameters problem noted by Neyman and Scott (1948).

correlated error terms. Column (1) is the final regression taken from Table 7, with regular standard errors. Column (2) is the same regression with robust standard errors; column (3) has standard errors clustered by the identity of the winning bidder; and column (4) has standard errors clustered by the auction day. A couple of coefficients lose statistical significance when standard errors are clustered by auction day, but again the qualitative takeaway changes very little across the different treatments.

We summarize the main empirical conclusions as follows:

- Relative to securities of Holland, sales of other (non-Holland) Dutch securities, plantation loans, and loans to private companies had significantly more second-round bidding, while sales of foreign government securities had slightly less.
- Auctions held before the onset of the financial crisis had less second-round bidding than auctions after; the effect was strongest for plantation loans, and weakest for Dutch securities (both Holland and other). Auctions held during the Fourth Anglo-Dutch War had less second-round bidding.
- Auctions held in winter had more second-round bidding.
- Across all issuer types, second-round bidding was less likely when more securities from the same issuer had just been sold.

Nearly all these findings (all but the Anglo-Dutch War) suggest that second round bidding was more likely to occur for riskier assets, or when there was greater uncertainty about the value of the security. Next, we will see whether a simple theoretical model of equilibrium bidding can explain this pattern.[46]

[46] We also examined the effect of the same explanatory variables on the increase in price between the first and second round, looking only at those sales with a second-round bid. Intuitively, the more likely other bidders are to bid in the second round, the higher each bidder must plan to bid in the second round if he wants to win. We would thus expect the variables that predict more second-round bidding, to also predict a larger increase in price. We find exactly that: among sales with a second-round bid, the increase in price was greater on average for other Dutch securities, plantation loans, and private company loans; loans in foreign countries; sales after the onset of the financial crisis (but only for plantation loans and private company loans); auctions held in winter; and the increase was smaller when more identical securities had just been sold.

5 Simple Model of Equilibrium Bidding

In this section, we construct a simple theoretical model of equilibrium bidding in an Anglo-Dutch premium auction, to try to explain the pattern observed empirically: a greater likelihood of second-round bidding in auctions with more uncertainty. The model is not meant to be perfectly realistic, but instead is the simplest we could find that would explain this empirical regularity.

Since the auctions we study are for financial instruments – basically, a series of (uncertain) future cash flows – we model bidder valuations as pure common values. There are N identical bidders, each of whom receives some private signal s_i about the value of a security; given the realizations of all bidders' signals $\mathbf{s} = (s_1, s_2, \ldots, s_N)$, the value of the security is $v(s_1, s_2, \ldots, s_N)$ regardless of the winner.[47] We use a very simple model of valuations:[48] we assume that bidder signals are independent draws from the uniform distribution on $[0, 1]$, and that the value of the security is linear in the average of the bidders' signals,

$$v(\mathbf{s}) \quad = \quad c + \beta \frac{\sum_{i=1}^{N} s_i}{N}$$

The parameter β measures the absolute variability of v (the most it could vary based on all bidders' information), and $\frac{\beta}{N}$ is the share of that variability attributed to each bidder's signal.[49] The constant term c ends up playing no role in the bidding strategies or in our analysis, so we can imagine changing c at the same time as changing β without changing our conclusions, allowing us to isolate the effect of higher variability of valuations separate from simply higher average valuations.[50]

As for the auctions themselves, we follow the theoretical literature and model prices as continuous. We model the ascending round as a continuous-time button auction, as in Milgrom and

[47] Goeree and Offerman (2004) and Hu, Offerman and Zou (2010) model a related, but different, auction using private values, and make the case for their mechanism via asymmetries between bidders. We feel that for the particular case of financial products, common values is the more natural model. Exploring the effect of asymmetrically-informed bidders in our environment would be an appealing extension to our work, but has so far proved beyond us.

[48] In the appendix, we show how some of our results would extend to a more general model of signals and valuations, where bidder signals are correlated and v is symmetric and increasing but otherwise unrestricted. Besides being less complete, these more general results are more notation-heavy and therefore harder to link directly to primitives of the environment; we therefore rely on the more restrictive model shown here to convey the intuition of the results.

[49] The notion of informational size in McLean and Postelwaite (2004) is analogous to β and β/N in our model, though given our simpler model of valuations, our measure is defined differently.

[50] That is, as β varies, we could let $c = A - \frac{\beta}{2N}$, so that the expected valuation $c + \frac{\beta}{N}\frac{1}{2} = A - \frac{\beta}{2N} + \frac{\beta}{2N} = A$ remained constant as β varied. Equilibrium bids all increase one-to-one with an increase in c, so this would not change bidding behavior qualitatively. For this reason, we interpret β as a measure of the variability of uncertainty in valuations, not a parameter related to the *level* of valuations.

Weber (1982): the price rises continuously (as on a clock) from a low level, and each bidder keeps his hand raised as long as he wants to remain active in the auction, then lowers his hand when he chooses to drop out. Bidders all know who is still active at each point and at what prices other bidders have dropped out;[51] the first round ends when the second-to-last bidder drops out. In the second round, the price drops continuously from a high level, and the first bidder to shout "mine!" ends the auction and wins at that price. In the unlikely event of a tie (simultaneous bids in the second round, or all remaining bidders dropping out simultaneously in the first round), a winner is selected at random.

We let ρ denote the value of the premium paid to the first-round winner. *Equilibrium* below refers to Perfect Bayesian equilibrium, the standard equilibrium concept for a dynamic game of incomplete information.

Theorem 1. *For any $N \geq 2$, $\rho > 0$, and $\beta > 0$, an equilibrium exists.*

1. *If $\beta \leq N\rho$, there is a symmetric, pure-strategy equilibrium with only first-round bidding.*

2. *If $\beta > N\rho$, then any* ***symmetric*** *equilibrium (if one exists) must have a positive probability of second-round bidding.*

3. *If $\beta > N(N+1)\rho$, then* ***any*** *equilibrium must have a positive probability of second-round bidding. Further, the probability of a second-round bid must be at least $\frac{1}{c+\beta}\left(\frac{\beta}{N(N+1)} - \rho\right)$ in any equilibrium; this lower bound is increasing in β and decreasing in N.*

Theorem 1 is proved in the appendix.[52] The results can be summarized as follows. When β is small relative to ρ, it's possible for all bidding to occur in the first round. On the other hand,

[51] Thus, we assume that bidders know N as soon as the auction starts. This may be one of the advantages of a two-stage auction relative to a simple Dutch auction: bidders would learn in the first stage how many competitors they faced. (We thank the editor for pointing out this possibility.) Uncertainty about N could lead to more cautious bidding, as bidders would be unsure of the magnitude of the winner's curse. Of course, bidders could choose to conceal their interest by not bidding until the second round, but this would turn out to typically not be in their best interest: more bidders means a stronger winner's curse and therefore lower bids from their opponents.

[52] For intuition about the proof, consider what would happen if bidders bid in the first round as if there were no second round. Let s^i denote the i^{th} highest realized signal. Equilibirum bidding strategies in an English auction are described in the appendix, and lead to the bidder who received the highest signal (s^1) winning the first round at a price of $c + \frac{\beta}{N}\left(s^2 + s^2 + s^3 + \cdots + s^N\right) + \rho$. Note that this price is $\rho - \frac{\beta}{N}(s^1 - s^2)$ above the value of the object (without the premium). If $\frac{\beta}{N}$ is small, $\rho - \frac{\beta}{N}(s^1 - s^2)$ will tend to be positive, so losing bidders would have no reason to bid in the second round: since first-round bids were inflated by the premium ρ, they expect the object to be overpriced. Thus, an equilibrium exists with no bidding in the second round. On the other hand, if $\frac{\beta}{N}$ is large relative to ρ, this difference is negative – losing bidders feel the object is still likely underpriced, and so losers would have an incentive to bid in the second round. For this reason, equilibria without any second-round bidding collapse, and all equilibria have some positive likelihood of a bid in the second round.

when β is large relative to ρ, all equilibria involve at least some likelihood of second-round bidding; and the larger is β, the higher must be the probability of second-round bidding in any equilibrium. Thus, in rough terms, we expect second-round bids to be more likely in sales of securities with higher β (greater uncertainty in value),[53] as well as auctions with lower N.[54]

The theory model therefore matches our empirical findings fairly well. While we did not have any reliable empirical proxy for the number of bidders, and therefore could not document the effect of N on auction outcomes empirically,[55] many variables that would logically correspond to higher β predicted a greater likelihood of second-round bidding. As noted above, since we can change the constant term c in valuations without changing the equilibrium, we think of β as a measure of the uncertainty in a security's value, or the amount of private information present, not the level of the security's value. Empirically, characteristics indicating greater risk (riskier issuers, securities denoted in a foreign currency, or the financial crisis) or a reduced flow of information (winter) were associated with more second-round bidding, while characteristics indicating greater certainty about price (more of the same security already having been sold) were associated with less second-round bidding, exactly as the theory would seem to suggest.

Revenue Comparison to Standard Mechanisms

Finally, given our model of equilibrium bidding, it is worth briefly discussing how the equilibrium revenue compares to the revenue from standard auction formats.[56] First, note that in the model presented in the text – independent signals and v linear – a pure Dutch auction and a pure ascending auction would be revenue-equivalent. However, in a more general model of common values with symmetric, affiliated signals (such as the model presented in the appendix), the pure ascending auction would generate higher expected revenue than the pure Dutch auction (Milgrom and Weber

[53] We could alternatively state these results in terms of ρ: that when ρ is large, equilibrium exists with only first-round bidding, but when ρ is small, any equilibrium must have some chance of a second-round bid. In our empirical application, there is no variation in ρ across auctions, while a number of variables in the data relate to β, so we focus on the results in terms of β for fixed ρ.

[54] We cannot, however, state these results as formal comparative statics, in part due to multiplicity of equilibrium. For example, in the case $\beta \leq N\rho$, equilibria exist both with and without second-round bidding. While we hoped to fully characterize the set of equilibria, we have so far been unable to. At the very least, however, as β increases and N decreases, the lower bound on the equilibrium probability of second-round bidding increases.

[55] We had hoped that the number of securities sold on a given day might proxy for N, since bigger auctions might attract more bidders, but the effect was not statistically significant.

[56] Since we employ a common-values model, any auction which always awards the object to *someone* will yield the same level of efficiency. Thus, in terms of overall welfare, our mechanism is exactly as good as a pure ascending auction, or a pure descending auction, or a purely random assignment of the security to one of the bidders.

1982).

For the Anglo-Dutch premium auction, revenue conclusions depend on the equilibrium played. When $\beta \leq N\rho$, the equilibrium considered in the first part of Theorem 1 gives the same revenue as a pure ascending auction.[57] On the other hand, the rather contorted equilibrium constructed in the existence proof in the appendix – in which all meaningful bidding occurs in the *second* round – matches the revenue of a pure Dutch auction, *minus* the premium, which is effectively given away for free. Other equilibria with second-round bidding may exist, and we do not know how they perform; in general, holding β and N fixed, we suspect equilibrium revenue will tend to be higher in equilibria with less second-round bidding.[58]

The revenue result therefore depends on equilibrium selection. When β is small relative to ρ, one equilibrium matches the (high) revenue of a pure English auction – and does so in a way that is likely more robust to collusion (and may not have alternative low-revenue equilibria). But for any values of β and ρ, an equilibrium exists which does strictly worse than the (lower) revenue of a pure Dutch auction.[59] This does suggest one possible policy recommendation: to ensure that the "good" equilibrium is at least a possibility, the auctioneer should take care to make the premium large enough relative to the uncertainty in the value of the object, although this concern is mitigated when there are sufficiently many interested bidders.[60]

6 Discussion

From these results, we can think about three natural questions. First, what do we learn about the Anglo-Dutch premium auction? Second, what do we learn about the secondary securities market

[57] Each bidder bids ρ higher in the first round of the Anglo-Dutch than they would have in a regular ascending auction with no premium, and nobody bids in the second round, so the premium ρ is exactly paid for by the increase in the winning bid.

[58] In any equilibrium where a second-round bid occurs with probability r, equilibrium expected revenue is at worst $r(c+\beta)+\rho$ less than the expected value of the security, although this bound is not tight.

[59] Getting away from the button auction modeling convention, the first round of the Anglo-Dutch premium auction might also be vulnerable to jump bidding. Avery (1998) shows that common-value English auctions admit multiple equilibria, some with jump bids, which can reduce revenue from the English-auction level down to the Dutch-auction level. Jump bidding would be more complicated here, since jump bids might signal information which would then alter bidders' beliefs entering the second round. Even if Avery's results extended to our setting, we already know that the range of possible equilibrium revenue extends below the revenue of a pure Dutch auction, so jump bidding may not alter our results at all – although it may work against our optimism about the "good" equilibrium being played when it exists.

[60] In fact, as noted above, a larger premium (0.275% versus 0.25%) was typically used in Utrecht, where auctions were smaller, than in Amsterdam, where they were larger, although other differences between the two markets may have accounted for the difference.

in Amsterdam in the 18th century? And third, what do we learn more generally about market design in history?

In terms of the auction mechanism itself, its selection appears consistent with aims of generating competition, discouraging collusion, and inducing auction participants to reveal their private information. Our empirical analysis offers suggestive evidence that the design may have succeeded. As noted above, nearly all our empirical findings are consistent with the prediction that greater uncertainty should accompany a higher likelihood of second-round bidding. At least by this measure, then, it is plausible that bidding behavior may have been be consistent with non-cooperative equilibrium play – suggesting these auctions may have succeeded in generating genuine competition. Further, the "price discovery" effect suggests that these auctions did succeed in drawing out bidders' private information in a significant and measurable way. To our knowledge, both our theoretical predictions about behavior in the Anglo-Dutch premium auction, and our empirical findings consistent with those predictions, are unique.

Next, we consider the impact of these auctions on the Amsterdam securities market in general. At the time these auctions were run, decentralized trade through brokers persisted as well; the two types of trades existed side by side. We can assume that a broker in a bilateral bargaining situation was under little pressure to disclose his private information to a private customer. Thus, the auction platform can be thought of as an outside option for private customers, particularly appealing to customers with limited trading knowledge.[61] Since professional brokers participated in the auctions as both buyers and sellers, it is likely that the best-informed agents contributed to the price discovery process. Information on past prices (from both auctions and bilateral sales) was initially sold privately by brokers, and from the 1760s onwards auction results were published in the newspaper *Mercurius*; this suggests both that such information was valuable, and that it was available to serve as a reference point for other transactions. Thus the revelation of the auction results might have added a constraint on how much surplus a broker might extract from a private seller. Similar auctions for securities appeared elsewhere in the Dutch Republic during the 18th century, so we can assume that these platforms had a similar effect all over the Republic. We

[61] This interpretation is in line with the observations of Le Moine de l'Espine (1734, pp 300-301), who notes that relative to private sales, the greater transparency and open competition in an auction protect brokers from being suspected of dealing dishonestly, but that "one will resort to an auction only when the goods can bear the costs" (translation ours).

can also guess at the approximate share of these auctions in the market as a whole. While these numbers are rather speculative, Van Bochove (2013) estimates that in Utrecht, these auctions account for between 5 and 15% of all traded securities. Even at this relatively limited size, the auctions could have had an impact on the whole market by serving as a public reference point for prices. Further, as noted in the introduction, the availability of these auctions gave a transparent, liquid way to sell debt should it be necessary later; the availability of this secondary market could have helped encourage the primary market as well, contributing to Amsterdam's subsequent growth as an international financial center.

Finally, we can put the implementation of the auction mechanism in a long run perspective. As noted in the introduction, this market was an early step – possibly the first step – in the evolution of financial markets from medieval-style gatheringplaces toward more structured, centralized clearing mechanisms. London and Amsterdam were the two most developed financial markets of the 17th and 18th centuries (Neal 1990), and thus the two most natural candidates for such an advance. In London, like in Amsterdam, auctions were commonly used to sell commodities by the 17th century; it is not clear at exactly what point auctions began being regularly used in London financial markets.[62] Thus, it is not completely clear whether the securities market we study was the very first use of a formal mechanism to clear a financial market, and if so, for how long it was the only one; but it seems to have been the first financial market to so regularly and prominently use such a mechanism.[63]

If the Amsterdam securities market was unique (or nearly unique) for a time, however, it would not be forever. By the 1790s, the New York and Philadelphia exchanges were using auctions to sell securities (Sobel 2000; Vitiello and Thomas 2010). Auction-like mechanisms were introduced in Paris around 1801 for public debt (Hautcoeur and Riva 2011), and in Berlin later in the 19th century

[62] In commodity auctions run by the (English) East India Company starting in the 17th century, shares of the Company were occasionally sold as well (Scott 1912), but there is no evidence that these auctions provided a regular market for such securities (Chaudhuri 1965). In the mid-18th century, regular auctions for commodity goods were held in various London coffee houses (Dickson 1967 p. 505). Securities were also traded in these coffeehouses; research to date does not inform us as to whether they were ever sold via auction. Dickson (1967 p. 225) cites a 1746 source suggesting that securities should be sold via auction if they could not be sold otherwise; Michie (1994) concludes that infrequently-traded securities eventually sold by auction. Thus, the motivation for the use of auctions in London financial markets appears to have been the same as in Amsterdam: to allow trade in otherwise-illiquid securities.

[63] The clearing technique for bills of exchange and derivatives of VOC shares called *rescontre* (and known since the late Middle Ages) was a way to offset liabilities, not a mechanism to buy and sell financial products, and was therefore not a clearing mechanism in our sense. See Boerner and Hatfield (2014) and Petram (2011).

for stocks (Burhop and Gelman 2011).[64] The open outcry system in the Amsterdam Exchange was most likely adopted in the 1830s.[65] On the other hand, the use of Anglo-Dutch premium auctions in the Amsterdam securities market declined by the late 1800s, apparently vanishing around 1900. In the early 19th century, the Dutch public debt was amalgamated – centrally-issued debt replaced debt issued separately by each province. This led to a more liquid market for Dutch public debt, which promptly vanished from the auctions; thereafter, the auctions were used almost entirely for foreign and private domestic issues.[66] We conjecture that more generally, as market depth and price information improved, auctions were no longer necessary to aggregate liquidity and solve informational problems, and trade migrated to the open outcry system at the Exchange.

Thus, our takeaway from this case study is not that this particular mechanism would be useful for any financial market in any place and time, but that it appears to have been well-chosen for the particular environment. From the 18th century onwards, we observe highly sophisticated and centralized market designs used to clear financial markets. Thus we identify a dimension of market microstructure which needs further attention and examination – particularly if one believes that market institutions are important for economic growth.

7 Conclusion

This paper studies Anglo-Dutch premium auctions used for the resale of sovereign and other securities in 18th-century Amsterdam, Europe's financial capital at the time. We conjecture that the auction format was chosen to try to capture the relative advantages of two different auction formats. We analyze data on 16,854 sales of securities from the late 18th century, and find an empirical pattern linking uncertainty in the value of a security to the likelihood of a bid in the second round. We then introduce a simple theoretical model of bidding behavior, and find that this occurs naturally in equilibrium. This gives at least suggestive evidence that bidding behavior may have been consistent with equilibrium play, suggesting bidders were indeed bidding competitively. We also find that uncertainty about value dropped measurably when identical securities were sold in succession, suggesting that this market was indeed drawing out bidders' private information,

[64]In both markets, lists of buy and sell orders were submitted by brokers and matched to determine a single market-clearing price.

[65]Jonker (1996), pp. 145-147 and 308-309, and private communication.

[66]This is based on the auction outcomes recorded in the 1820 and 1830 issues of the *Prijs-courant*.

allowing it to be incorporated into prices. By the early 1700s, auctions had been widely used to sell a variety of goods for some time, and so the designers of the securities market in Amsterdam had many possible auction formats to choose from, and considerable experience to guide that choice. In this paper, we find evidence that they seem to have chosen wisely.

Our results suggest a number of interesting avenues for future work. With better data, one would love to compare the prices and outcomes reached in the Amsterdam securities auctions to those reached when similar securities were traded by brokers or on the Amsterdam Exchange, in order to better understand the tradeoff faced in introducing auctions into financial markets. This would help shed light on the causes, and welfare effects, of the evolution of financial markets from unstructured meeting places to formal, centralized market-clearing mechanisms. It would likewise be interesting to understand why this change spread from market to market in the way that it did, and to compare the performance of the various types of mechanisms introduced in different markets. While descriptive information is available about many of these markets, formal institutional analysis is yet to be done. By studying this one market in detail – in particular, beginning to understand why it was designed the way it was, and what that design allowed it to accomplish – we feel our paper is a first step in that direction.

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Appendix – Proof of Theorem 1

We postpone the proof of equilibrium existence to the end.

A.1 Benchmark Equilibrium

Consider the following strategy for first-round bidding, which we will refer to as "simple bidding":

- At any history where nobody has dropped out yet, given signal s, keep bidding up to the price $v(s, s, s, \ldots, s) + \rho$
- At a history where the first bidder dropped out at price p^N, define s^N implicitly by $p^N = v(s^N, s^N, s^N, \ldots, s^N) + \rho$; at such a history, keep bidding up to price $v(s, s, s, \ldots, s, s^N) + \rho$
- At a history where the second bidder dropped out at price p^{N-1}, define s^N as above and s^{N-1} by $p^{N-1} = v(s^{N-1}, s^{N-1}, s^{N-1}, \ldots, s^{N-1}, s^N) + \rho$; at a history where one bidder dropped out at p^N and another at p^{N-1}, keep bidding up to price $v(s, s, s, \ldots, s, s^{N-1}, s^N) + \rho$
- And so on – at each history, bid as if all dropped-out bidders had revealed their types and all remaining bidders' signals match your own

This is well known to be an *ex post* equilibrium of a (one-stage) ascending auction for a good worth $v(\mathbf{s}) + \rho$. (See, e.g., Milgrom (2004) p 196.)

A.2 Theorem 1 Part 1

We claim that if $\beta \leq N\rho$, all bidders bidding simply in the first round, and not bidding in the second round, is an equilibrium of the two-stage auction; and if $\beta \leq \frac{1}{2}N\rho$, it's an *ex post* equilibrium.

If $\frac{\beta}{N} \leq \frac{1}{2}\rho$, this is an ex post equilibrium.

We show the latter first. Let s_1 be bidder 1's signal, and $y^1 \geq y^2 \geq \ldots \geq y^{N-1}$ the re-ordered signals of his opponents. Following the equilibrium strategy, bidder 1 will win both the security and the premium whenever $s_1 > y^1$, and pay the price at which his last opponent drops out, for a payoff of

$$c + \frac{\beta}{N}\left(s_1 + y^1 + \textstyle\sum_{i>1} y^i\right) + \rho - \left[c + \frac{\beta}{N}\left(y^1 + y^1 + \textstyle\sum_{i>1} y^i\right) + \rho\right] \quad = \quad \frac{\beta}{N}(s_1 - y^1)$$

when $s_1 > y^1$, and a payoff of 0 when $s_1 \leq y^1$. Any other first-round strategy will give either the same payoff or a payoff of 0, so the only potential deviation would involve second-round bidding.

If bidder 1 is the second-to-last bidder to drop out, and drops out at a price revealing s_1 to be x, the first round ends at price $c + \frac{\beta}{N}\left(x + x + \sum_{i>1} y^i\right) + \rho > c + \frac{\beta}{N}\left(x + y^2 + \sum_{i>1} y^i\right) + \rho$. If bidder 1 drops out with at least two opposing bidders still active and reveals s_1 to be x, the first round ends at price $c + \frac{\beta}{N}\left(x + y^2 + \sum_{i>1} y^i\right) + \rho$. So either way, the price reaches at least $c + \frac{\beta}{N}\left(x + y^2 + \sum_{i>1} y^i\right) + \rho \geq c + \frac{\beta}{N}\left(y^2 + \sum_{i>1} y^i\right) + \rho$. So by bidding in the second round and winning the security, bidder 1's payoff is at most

$$c + \frac{\beta}{N}\left(s_1 + y^1 + \sum_{i>1} y^i\right) - \left[c + \frac{\beta}{N}\left(y^2 + \sum_{i>1} y^i\right) + \rho\right] \quad = \quad \frac{\beta}{N}\left(s_1 + y^1 - y^2\right) - \rho$$

Since $s_1 + y^1 \leq 2$, if $\frac{\beta}{N} \leq \frac{1}{2}\rho$, this is nonpositive. So simple bidding, followed by no bidding in the second round, is an ex post equilibrium when $\beta \leq \frac{1}{2}N\rho$.

If $\frac{\beta}{N} \leq \rho$, this is an equilibrium.

Consider the bidding in the first round up to a particular point where bidder 1 is still active. The history up to that point can be described by the number of bidders (including bidder 1) who are still active, K; the signals revealed by those bidders who have already dropped out, $y^K \geq y^{K+1} \geq \ldots \geq y^{N-1}$; and the lower bound on the signals of the remaining bidders (assuming simple bidding), $\underline{s}$, which is the solution to

$$P \quad = \quad c + \frac{\beta}{N}\left(K\underline{s} + y^K + y^{K+1} + \ldots + y^{N-1}\right) + \rho$$

where P is the current price. Conditional on equilibrium play up to that point, the signals of the remaining active bidders are independent uniform draws on the interval $[\underline{s}, 1]$, which will allow us to calculate bidder 1's expected payoff from various strategies. We will show that at any history $h = (K, (y^K, y^{K+1}, \ldots, y^{N-1}), \underline{s})$, if $s_1 > \underline{s}$, straightforward bidding offers a higher expected continuation payoff than dropping out immediately with the option to bid in the second round if that would be profitable; and if $s_1 < \underline{s}$, no strategy offers a strictly positive payoff, so bidding higher in the first round than simple bidding would suggest is never profitable.

If $s_1 > \underline{s}$ and bidder 1 plans to follow the simple bidding strategy, he will win whenever $s_1 > y^1$, earning a security worth $c + \frac{\beta}{N}\left(s_1 + y^1 + \sum_{i>1} y^i\right) + \rho$ at a price $c + \frac{\beta}{N}\left(y^1 + y^1 + \sum_{i>1} y^i\right) + \rho$ for profit of $\frac{\beta}{N}(s_1 - y^1)$. Starting at history h, then, his expected continuation payoff from following this strategy is

$$E_{y^1|h} \max\left\{0, \frac{\beta}{N}\left(s_1 - y^1\right)\right\} = \frac{\beta}{N}\int_{\underline{s}}^{s_1}(s_1 - x)dF_1(x|h)$$

where $F_1(\cdot|h)$ is the probability distribution of y^1, conditional on history h. Conveniently, since the signals of 1's remaining active opponents are independent uniform draws from the interval $[\underline{s}, 1]$, $F_1(x|h) = (\frac{x-\underline{s}}{1-\underline{s}})^{K-1}$, so we can evaluate this integral, which turns out to be $\frac{\beta}{NK}\frac{(s_1-\underline{s})^K}{(1-\underline{s})^{K-1}}$.

If $K = 2$ (only one opponent besides bidder 1 is still active at history h), then by dropping out immediately, bidder 1 would end the first round immediately, at price $c + \frac{\beta}{N}\left(\underline{s} + \underline{s} + \sum_{i>1} y^i\right) + \rho$. The remaining opponent's signal would then be a uniform draw from the interval $[\underline{s}, 1]$, so by bidding in the second round, bidder 1 could in expectation earn at most

$$c + \frac{\beta}{N}\left(s_1 + \frac{1+\underline{s}}{2} + \sum_{i>1} y^i\right) - \left[c + \frac{\beta}{N}\left(\underline{s} + \underline{s} + \sum_{i>1} y^i\right) + \rho\right] = \frac{\beta}{N}\left(s_1 + \frac{1+\underline{s}}{2} - 2\underline{s}\right) - \rho$$

If $\beta \leq N\rho$, then, the gain from dropping out now instead of sticking to the equilibrium strategy is at most

$$\begin{aligned}
&\frac{\beta}{2N}\left(2s_1 + 1 + \underline{s} - 4\underline{s}\right) - \rho - \frac{\beta}{2N}\frac{(s_1-\underline{s})^2}{1-\underline{s}} \\
&\leq \frac{\beta}{2N}\left(2s_1 + 1 + \underline{s} - 4\underline{s}\right) - \frac{\beta}{N} - \frac{\beta}{2N}\frac{(s_1-\underline{s})^2}{1-\underline{s}} \\
&= \frac{\beta}{2N}\left(2(s_1 - \underline{s}) - 2\underline{s} - (1 - \underline{s}) - \frac{(s_1-\underline{s})^2}{1-\underline{s}}\right) \\
&= \frac{\beta}{2N}\frac{1}{1-\underline{s}}\left(-(1-\underline{s})^2 + 2(s_1 - \underline{s})(1 - \underline{s}) - (s_1 - \underline{s})^2 - 2\underline{s}(1 - \underline{s})\right) \\
&= \frac{\beta}{2N}\frac{1}{1-\underline{s}}\left(-(1 - s_1)^2 - 2\underline{s}(1 - \underline{s})\right) \\
&\leq 0
\end{aligned}$$

If $K > 2$, then by dropping out immediately, bidder 1 would "reveal" his signal to be $s_1 = \underline{s}$, and he would have the option of bidding in the second round after learning the realizations of $(y^2, y^3, \ldots, y^{K-1})$ (but not y^1). The first round would end at price $c + \frac{\beta}{N}\left(\underline{s} + y^2 + \sum_{i>1} y^i\right) + \rho$. Since, conditional on y^2, $y^1 \sim U[y^2, 1]$, the expected value of the security at that point would be $c + \frac{\beta}{N}\left(s_1 + \frac{1+y^2}{2} + \sum_{i>1} y^i\right)$. By bidding a tiny bit above the reserve whenever this expected value is greater than the first-round price, bidder 1 could at best achieve a payoff of

$$\begin{aligned}
&\max\left\{0, c + \frac{\beta}{N}\left(s_1 + \frac{1+y^2}{2} + \sum_{i>1} y^i\right) - \left[c + \frac{\beta}{N}\left(\underline{s} + y^2 + \sum_{i>1} y^i\right) + \rho\right]\right\} \\
&= \max\left\{0, \frac{\beta}{N}\left(s_1 - \underline{s} + \frac{1-y^2}{2}\right) - \rho\right\}
\end{aligned}$$

and so bidder 1's maximal expected payoff from dropping out at history h is

$$E_{y^2|h} \max \left\{0, \tfrac{\beta}{N}\left(s_1 - \underline{s} + \tfrac{1-y^2}{2}\right) - \rho\right\}$$

which (if it is ever strictly positive) can be written as

$$\frac{\beta}{2N} \int_{\underline{s}}^{\min\{1, 2s_1 - 2\underline{s} - 2\frac{\rho N}{\beta} + 1\}} \left(2s_1 - 2\underline{s} - \frac{2N\rho}{\beta} + 1 - x\right) dF_2(x|h)$$

where $F_2(\cdot|h)$ is the distribution of y^2 conditional on h. Since the remaining opponents have signals which are independently $U[\underline{s}, 1]$, when $K \geq 3$, $dF_2(x|h) = (K-1)(K-2)\frac{1}{1-\underline{s}}\frac{1-x}{1-\underline{s}}(\frac{x-\underline{s}}{1-\underline{s}})^{K-3}$. If $\beta \leq N\rho$, the upper limit of the integral is less than 1, so the expected payoff from dropping out is no more than

$$\frac{\beta}{2N}\frac{(K-1)(K-2)}{(1-\underline{s})^{K-1}} \int_{\underline{s}}^{2s_1 - 2\underline{s} - 2\frac{\rho N}{\beta} + 1} \left(2s_1 - 2\underline{s} - \frac{2N\rho}{\beta} + 1 - x\right)(1-x)(x-\underline{s})^{K-3}\, dx$$

After some algebra, this integrates to

$$\frac{\beta}{NK}\frac{Z^K}{(1-\underline{s})^{K-1}} - \frac{\beta}{2NK}\frac{Z^{K-1}}{(1-\underline{s})^{K-1}} K(1-\underline{s}+Z)$$

where $Z = 2s_1 - 2\underline{s} - 2\frac{\rho N}{\beta} + 1 - \underline{s}$. Now, if $\beta \leq N\rho$, then $2\frac{N\rho}{\beta} \geq 2 \geq (s_1 - \underline{s}) + (1 - \underline{s})$, or $0 \geq (s_1 - \underline{s}) - 2\frac{N\rho}{\beta} + (1-\underline{s})$, which in turn implies $s_1 - \underline{s} \geq Z$, so

$$\tfrac{\beta}{NK}\tfrac{(s_1-\underline{s})^K}{(1-\underline{s})^{K-1}} \quad \geq \quad \tfrac{\beta}{NK}\tfrac{Z^K}{(1-\underline{s})^{K-1}} \quad \geq \quad \tfrac{\beta}{NK}\tfrac{Z^K}{(1-\underline{s})^{K-1}} - \tfrac{\beta}{2NK}\tfrac{Z^{K-1}}{(1-\underline{s})^{K-1}} K(1-\underline{s}+Z)$$

and the payoff to dropping out now (followed by optimal play) cannot be better than sticking to simple bidding.

Finally, at a history h with $s_1 \leq \underline{s}$, the first round is guaranteed to end at a price no lower than $c + \frac{\beta}{N}\left(\underline{s} + y^2 + \sum_{i>1} y^1\right) + \rho$, so bidder 1's payoff from bidding in the second round can be no more than

$$\begin{aligned} c + \tfrac{\beta}{N}\left(s_1 + y^1 + \textstyle\sum_{i>1} y^i\right) - \left[c + \tfrac{\beta}{N}\left(\underline{s} + y^2 + \textstyle\sum_{i>1} y^1\right) + \rho\right] \quad &= \quad \tfrac{\beta}{N}\left(s_1 - \underline{s} + y^1 - y^2\right) - \rho \\ &\leq \quad \tfrac{\beta}{N} - \rho \end{aligned}$$

which is nonpositive if $\beta \leq N\rho$. So neither dropping out of the first round earlier than simple bidding would suggest, nor remaining active later, would be a profitable deviation; so simple bidding, followed by no bidding in the second round, is an equilibrium.

A.3 Theorem 1 Part 2

We want to show that if $\beta > N\rho$, there cannot be a symmetric equilibrium with no second-round bidding on the equilibrium path.

No equilibrium that's outcome-equivalent to simple bidding

First, note that any strategies which are outcome-equivalent to the simple-bidding equilibrium proven above cannot be an equilibrium when $\beta > N\rho$. This is because:

- In the event that $y^1 = \epsilon \approx 0$, such strategies would need to end the first round at a price close to $c + \rho$; so in the event that $y^2 \approx 0$, all bidders but bidder 1 and one opponent must drop out at prices close to $c + \rho$
- Once that happens, in the event that $s_1 = 1 - \epsilon \approx 1$, bidder 1 knows he will win with probability close to 1, at a price close to $c + \frac{\beta}{N} 2y^1 + \rho$, which has expected value $c + \frac{\beta}{N} + \rho$; so by following the supposed equilibrium strategy, his expected payoff would be $c + \frac{\beta}{N}(1 + \frac{1}{2}) + \rho - \left[c + \frac{\beta}{N} + \rho\right] = \frac{\beta}{2N}$
- However, by dropping out immediately and then bidding $\epsilon \approx 0$ above the current price in the second round, bidder 1 could win the security (without the premium) at a price close to $c+\rho$, for expected payoff $c + \frac{\beta}{N}(1 + \frac{1}{2}) - [c + \rho] = \frac{3\beta}{2N} - \rho$
- If $\beta > N\rho$, $\frac{3\beta}{2N} - \rho > \frac{\beta}{2N}$, so this would be a profitable deviation.

No symmetric, separating equilibrium

Next, we show that any symmetric, *separating* equilibrium (i.e., any symmetric equilibrium with strictly monotone strategies in each part of the auction, as used in Bikchandani, Haile and Riley (2002)) in which there are no second-round bids on the equilibrium path must lead to the same price as simple bidding, and therefore such an equilibrium cannot exist when $\beta > N\rho$. Bikchandani et. al. show that this would be true if there was no second round: that is, that any symmetric, separating equilibrium of a pure ascending auction would lead to the same price as simple bidding. So if there were a symmetric, separating equilibrium of the two-stage mechanism with no second-round bidding which led to a different outcome, those same strategies would not be an equilibrium in a pure ascending auction. Suppose such an equilibrium existed, and call those strategies B.

Since B is an equilibrium of the two-stage mechanism but B restricted to the first round of bidding is not an equilibrium of an ascending auction, that means some bidder must have a deviation from B which would be profitable in a pure ascending auction but not in the two-stage mechanism. This is only possible if that deviation would be "punished" by second-round bidding in the two-stage mechanism. Since by assumption, B does not have second-round bids on the equilibrium path, it must be that this deviation would therefore be recognized as an off-equilibrium-path play. However, in a symmetric, separating equilibrium, a bidder with the highest possible signal never drops out in equilibrium; so a unilateral deviation by any one bidder could not be detected until he dropped out. But at the point where the deviation calls for him to drop out, he is guaranteed a payoff no worse than 0, the same as in a pure ascending auction; so if the deviation is profitable in the pure ascending auction, the same first-round deviation (followed by no second-round bid) would be profitable in the two-stage auction. So there is no equilibrium of the two-stage auction with no second-round bidding on the equilibrium path which does not conclude at the same price as simple bidding; so when $\beta > N\rho$, no symmetric, separating equilibrium can exist with no second-round bidding on the equilibrium path.

No symmetric, non-separating equilibrium

All that is left, then, is potential symmetric equilibria which are not separating, i.e., potential equilibria where either some range of types playing mixed strategies with overlapping supports, or some range of types pooled at the same pure strategy.

Suppose first that at some history, there is some range of signals at which bidders play a mixed strategy whose supports have common overlap. Since there is some probability that all remaining bidders have types within that range, strategies at the top of that overlap must have strictly higher probability of winning then strategies at the bottom of that overlap. But bidder payoffs have strictly increasing differences in the signal and the probability of winning; so multiple signals can't make a bidder indifferent between two of those strategies.

What is left to rule out are equilibria where multiple types pool on the same pure strategy. Since strict single-crossing implies equilibrium strategies must be weakly monotonic, the potential equilibria to consider are those where at some history, some range of types (s_*, s^*) pool and drop out at a common price P. Note that since there is a chance all remaining bidders have types within that range, pooling gives a positive probability less than 1 of winning at that price. Now, in such an equilibrium, at that history...

- If $s^* < 1$, then any pooling types who strictly prefer to win at that price could remain in slightly longer and win with discontinuously higher probability; such a deviation would not appear to be "out of equilibrium" since higher types stay in longer, so it could not be "punished" by being outbid in the second round. If no pooling types strictly prefer to win, then some pooling types strictly prefer to lose, in which case they would drop out before the pooling price. So the pooling range must be $(s_*, 1]$.
- If bidders with signals $s_i = 1$ strictly prefer to win at the pooling price, then the only way to rule out a deviation of staying in past that price is if another bidder would "punish" such a deviation by outbidding it in the second round with a high probability. But in that case, the bidders at the bottom of the pooling range could benefit by exceeding the pooling price, winning the premium, and then being outbid in the second round. (The lowest pooling type must be indifferent about winning the security *and the premium* at the pooling price, otherwise types below the pooling range would also pool; but this means winning the premium but likely losing the security is even better!)
- What's left is if the pooling range is all types. Then no information is revealed in the first round, and all bidders play the same strategy and drop out at the pooling price.
- In that case, to rule out a bidder with a high signal wanting to bid in the second round if he loses in the first, the pooling price must be at least $c + \frac{\beta}{N}\left(1 + \frac{N-1}{2}\right)$. But since $\frac{\beta}{N} > \rho$ by assumption, this is strictly more than $c + \frac{\beta}{N}\left(0 + \frac{N-1}{2}\right) + \rho$; so by staying in until the pooling price, a bidder with a type close to 0 would get negative expected payoff; so such an equilibrium cannot exist.

A.4 How Parts 1 and 2 Extend to a More General Model

Parts 1 and 2 have analogs in a much more general common values model, but at the cost of more notation and less easily-interpreted results. Suppose bidder signals s_i are potentially correlated, but their distribution is symmetric and has support $[0, 1]^N$; and $v(\mathbf{s})$ is any symmetric, strictly-increasing function. (This nests the standard affiliated-signals model where $(V, S_1, S_2, \ldots, S_N)$ are affiliated, since we can let $v(\mathbf{s}) = E(V|(S_1, \ldots, S_N) = \mathbf{s})$.

Let $\mathbf{y} = (y^2, y^3, \ldots, y^{N-1})$ denote all but the highest of 1's opponents. We define two measures Δ_1 and Δ_2 relating to the variability of $v(\mathbf{s})$: let

$$\Delta_2 = \max_{\mathbf{y}} \left\{ v(1, 1, \mathbf{y}) - v(0, y^2, \mathbf{y}) \right\}$$

and Δ_1 the value of ρ that solves

$$0 \;=\; \max_{h} \; \max_{s_1 \geq \underline{s}} \left\{ \begin{array}{r} \underset{\mathbf{y}|h,s_1}{E} \max \left\{ 0, \underset{y^1|\mathbf{y},s_1}{E} \{ v(s_1, y^1, \mathbf{y}) - v(\underline{s}, \max\{\underline{s}, y^2\}, \mathbf{y}) - \rho \} \right\} \\ \\ - \underset{\mathbf{y}|h,s_1}{E} \; \underset{y^1|\mathbf{y},s_1}{E} \max \left\{ 0, \; v(s_1, y^1, \mathbf{y}) - v(y^1, y^1, \mathbf{y}) \right\} \end{array} \right\}$$

Note that in the independent-linear model presented in the text, $\Delta_2 = \frac{2\beta}{N}$ and $\Delta_1 = \frac{\beta}{N}$.[67] Parts 1 and 2 of Theorem 1 extend to the more general model in the following way:

- If $\rho \geq \Delta_2$, then simple bidding in the first round, followed by no bidding in the second round, is an ex post equilibrium of the two-stage mechanism. If $\rho < \Delta_2$, then no ex post equilibrium exists for the two-stage mechanism with no second-round bidding.
- If $\rho \geq \Delta_1$, then simple bidding in the first round, followed by no bidding in the second round, is an equilibrium of the two-stage mechanism. If $\rho < \Delta_1$, then no symmetric, separating equilibrium exists for the two-stage mechanism with no second-round bidding.

The last part of Theorem 1, however, has no analog when bidder signals are not independent.

A.5 Theorem 1 Part 3

We need to show that in the independent, linear model, if $\frac{\beta}{N(N+1)} > \rho$, then in any equilibrium, the probability of a second-round bid is bounded below by $\frac{1}{c+\beta}\left(\frac{\beta}{N(N+1)} - \rho\right)$.

To prove this, we first show that in any equilibrium, ex-ante combined bidder payoffs must be at least $\frac{\beta}{N(N+1)}$. Let $U_i(s_i)$ denote the equilibrium payoff of bidder i with signal s_i, and $Q_i(s_i)$ the probability he wins the security in equilibrium. For any $s_i' > s_i$,

$$U_i(s_i') - U_i(s_i) \quad \geq \quad Q_i(s_i) \frac{\beta}{N} (s_i' - s_i)$$

since a bidder with type s_i' could always imitate the equilibrium strategy of s_i but the security

[67] The former is easy to see, as the maximum is achieved at $\mathbf{y} = (0, 0, \ldots, 0)$. The latter maximum is achieved at $s_1 = 1$, at the history where all but one of bidder 1's opponents have signals 0 and have just dropped out, so that $K = 2$ and $\underline{s} = 0$, although showing that no other history exceeds this value of the maximand is nontrivial.

would be worth $\frac{\beta}{N}(s_i' - s_i)$ more whenever he wins it. So for any ϵ,

$$U_i(s_i) \quad \geq \quad U_i(s_i - \epsilon) + \tfrac{\beta}{N}\epsilon Q_i(s_i - \epsilon) \geq \quad U_i(s_i - 2\epsilon) + \tfrac{\beta}{N}\epsilon Q_i(s_i - \epsilon) + \tfrac{\beta}{N}\epsilon Q_i(s_i - 2\epsilon) \quad \geq \quad \cdots$$

and taking $\epsilon \to 0$, $U_i(s_i) \geq \frac{\beta}{N}\int_0^{s_i} Q_i(t)dt$. Let U_i denote bidder i's ex-ante equilibrium expected payoff; then

$$U_i \quad = \quad E_{s_i}U_i(s_i) \quad \geq \quad E_{s_i}\frac{\beta}{N}\int_0^{s_i} Q_i(t)dt \quad = \quad \frac{\beta}{N}\int_0^1 \int_0^{s_i} Q_i(t)dtds_i$$

Reversing the order of integration,

$$U_i \quad \geq \quad \frac{\beta}{N}\int_0^1 \int_t^1 Q_i(t)ds_idt \quad = \quad \frac{\beta}{N}\int_0^1 (1-t)Q_i(t)dt$$

Let $q_i(s_1, s_2, \ldots, s_N)$ denote bidder i's probability of winning the security at a particular signal profile (given equilibrium play by all bidders), and s_{-i} the signals of bidder i's opponents; then

$$U_i \quad \geq \quad \frac{\beta}{N}\int_0^1 (1-s_i)E_{s_{-i}}q_i(s_i, s_{-i})ds_i \quad = \quad \frac{\beta}{N}\int_{[0,1]^N} (1-s_i)q_i(\mathbf{s})d\mathbf{s}$$

Summing over i,

$$\sum_i U_i \quad \geq \quad \frac{\beta}{N}\int_{[0,1]^N}\left(\sum_i (1-s_i)q_i(\mathbf{s})\right)d\mathbf{s} \quad \geq \quad \frac{\beta}{N}\int_{[0,1]^N}\left(\min_i\{1-s_i\}\right)\left(\sum_i q_i(\mathbf{s})\right)d\mathbf{s}$$

Since the auction always awards the security to somebody, $\sum_i q_i(\mathbf{s})d\mathbf{s} = 1$, so

$$\sum_i U_i \quad \geq \quad \frac{\beta}{N}\int_{[0,1]^N}\left(\min_i(1-s_i)\right)d\mathbf{s} \quad = \quad \frac{\beta}{N(N+1)}$$

Next, we use this to rule out equilibrium with no second-round bidding. Let h be the history of first-round bids. If there is no second-round bidding, then ex post payoffs given h are the expected value of the security, $E(v|h)$; plus the premium, ρ; minus the price at which the first round ended, which we label $p(h)$. By iterated expectations,

$$E_h\left\{E(v|h) + \rho - p(h)\right\} \quad = \quad \textstyle\sum_i U_i \quad \geq \quad \frac{\beta}{N(N+1)}$$

If $\frac{\beta}{N(N+1)} > \rho$, then $E_h\left\{E(v|h) - p(h)\right\} > 0$; so at some histories, the security (in expectation over all the signals that produce those first-round bids) is worth more than the first-round price. Then in a supposed equilibrium where nobody was planning to bid in the second round (and there was therefore no additional winner's curse), any losing bidder (provided his own signal was good relative to his range given h) could gain by bidding in the second round.

Next, we put a lower bound on the probability of a second-round bid. Let (h,t) denote the first-round bidding history h, followed by nobody bidding in the second round before or at price $p(h)+t$. Thus, $(h,0)$ denotes a first-round outcome followed by nobody bidding in the second round. Let $E(v|(h,0,s_i))$ denote the expected value of the security conditional on both $(h,0)$ and on the actual value of bidder i's signal.

Suppose we are in any equilibrium, and consider a particular first-round history h. Pure strategies for the second-round game consist of a price $t(s_i)$ such that bidder i, given signal s_i, plans to bid in the second round at price $p(h)+t(s_i)$ if nobody has bid by then. $t(s_i)=0$ means a plan not to bid. By strict dominance, we can assume $t(s_i)\in[0,\overline{v}]$; mixed strategies are allowed.

Claim 1. *Second-round equilibrium strategies satisfy strict single crossing: if both are reached with positive probability, if bidder i weakly prefers t' to $t<t'$ at signal s_i, he must strictly prefer t' to t at any signal $s_i'>s_i$.*

This is straightforward, since the probability of winning is monotonic in t, and $t'>t$ can only be as good if the win probability is strictly higher. This leads to equilibrium strategies being weakly monotonic; which means that the conditional expected value of the security can only go down as the second round progresses, except at the moment when someone bids.

Claim 2. *In any equilibrium, for any h, if the history $(h,0)$ is reached on the equilibrium path, $E(v|(h,0))\leq p(h)$.*

Suppose this were false – that is, suppose for some history h, $E(v|(h,0))-p(h)>0$. Consider second-round strategies following that history. Let s_i^* denote the highest signal consistent with h at which losing bidder i chooses $t(s_i)=0$ with positive probability. We claim $E(v|(h,0,s_i^*))\leq p(h)$. If it was not, let $\epsilon=E(v|(h,0,s_i^*))-p(h)>0$. By bidding at price $p(h)+\frac{\epsilon}{2}$, bidder i would get a payoff of $E(v|(h,\frac{\epsilon}{2}),s_i^*)-(p(h)+\frac{\epsilon}{2})\geq E(v|(h,0),s_i^*)-p(h)-\frac{\epsilon}{2}=\frac{\epsilon}{2}$, so not bidding would be dominated. So for all s_i such that $E(v|(h,0,s_i))>p(h)$, bidder i must plan to bid at some point (although he could mix over the time). So if he lets time run out, we know $E(v|(h,0,s_i))\leq p(h)$. So then taking the expectation of s_i over the signals at which he doesn't bid, we're done.

Claim 3. *At any history $(h,0)$, expected ex post winner surplus is no more than ρ.*

It's $E(v|(h,0)) + \rho - p(h) \leq \rho$. If we now take expectations over h such that no bid happens in the second round, the expected ex-post payoff to a first-round winner is no more than ρ.

Claim 4. *Let r be the probability of a second-round bid; then $r \geq \frac{1}{c+\beta}\left(\frac{\beta}{N(N+1)} - \rho\right)$.*

Let $E(no)$ denote expected ex-post payoffs conditional on no second-round bid being placed, and $E(yes)$ expected ex-post payoffs conditional on a second-round bid. By iterated expectations, $\sum_i U_i = (1-r)E(no) + rE(yes)$. We just showed that $E(no) \leq \rho$; since bids are non-negative, the highest payoffs ever achievable are $c + \beta + \rho$, so

$$\frac{\beta}{N(N+1)} \leq \sum_i U_i = (1-r)E(no) + rE(yes) \leq (1-r)\rho + r(c+\beta+\rho) = \rho + r(c+\beta)$$

and so $\frac{\beta}{N(N+1)} - \rho \leq r(c+\beta)$. □

A.6 Proof of Equilibrium Existence

To prove existence, we construct a particular (asymmetric) equilibrium that exists for all values of β and ρ. Here, we present the equilibrium strategies for the case $N \geq 4$; for brevity, the proof that these strategies constitute an equilibrium, and the modified strategies for the cases $N = 3$ and $N = 2$, are in a separate, online-only appendix.

Overview

On the equilibrium path, in the first round, bidders $2, 3, \ldots, N$ all drop out immediately, ending the first round at a price of 0 and allowing bidder 1 to win the premium. Since no information is revealed in the first round, beliefs in the second round match prior beliefs, and all bidders bid in the second round as they would bid in the symmetric equilibrium of a pure Dutch auction.

To make first-round play (in particular, dropping out immediately) a best-response, we construct a continuation game where a bidder who deviates and bids in the first round is "punished" by a combination of other bidders' beliefs, continued first-round bidding by bidder 1, and bidding in the second round. To make the punishment "credible", we construct another continuation game where bidder 1 is "punished" if he fails to properly punish bidder 2.

First Round Strategies

Define

$$P^* = \begin{cases} c + \frac{\beta}{N}\frac{N+1}{2} + \rho & if \quad \rho \geq \frac{\beta}{2N} \\ c + \frac{\beta}{N}\left(1 + \frac{N}{2}\left(\frac{2N\rho}{\beta}\right)^{\frac{1}{N}}\right) & if \quad \rho < \frac{\beta}{2N} \end{cases}$$

and

$$P^{**} = \begin{cases} c + \frac{\beta}{N}\frac{N+2}{2} + \rho & if \quad \rho \geq \frac{\beta}{2N} \\ c + \frac{\beta}{N}\left(2 + \frac{N-1}{2}\left(\frac{2N\rho}{\beta}\right)^{\frac{1}{N-1}}\right) & if \quad \rho < \frac{\beta}{2N} \end{cases}$$

Although it's not obvious, $P^{**} > P^*$ for all $\beta > 0$. First-round strategies and beliefs for player 1 are:

- Do not drop out at $P = 0$
- At any history where $P > 0$ and there is one other active bidder, believe that he has signal $s_i = 1$, and
  - If $P < P^*$, remain active
  - If $P \geq P^*$, drop out

First-round strategies and beliefs for each player $i \neq 1$ are:

- Drop out at $P = 0$
- At any history where $P > 0$ and bidder i is still active along with bidder 1,
  - If $P \leq P^*$, believe $s_1 \sim U[0,1]$; remain active if $s_i = 1$ (and drop out if $s_i < 1$)
  - If $P^* < P < P^{**}$, believe $s_1 = 1$; remain active if $s_i = 1$ (and drop out if $s_i < 1$)
  - If $P \geq P^{**}$, drop out immediately

Since all bidders $i \neq 1$ are expected to drop out immediately, any history not addressed above (and not addressed in the discussion of second-round play below) can only be reached via simultaneous deviations by multiple bidders; such a history cannot affect play on the equilibrium path, and we therefore do not specify the strategies played at such histories.

Second Round Beliefs and Strategies On the Equilibrium Path

On the equilibrium path, bidders $2, 3, \ldots, N$ all dropped out immediately regardless of their signals, so no information was revealed. Thus, all bidders' beliefs match the prior belief that $s_i \sim U[0,1]$

for all i. Each bidder i then bids in the second round according to the bidding function

$$b(s_i) \quad = \quad c + \tfrac{\beta}{N}\left(\tfrac{N-1}{N}s_i + (N-1)\tfrac{s_i}{2}\right)$$

Should bidder 1 choose to drop out at $P = 0$ along with the other bidders, so that the first-round winner is chosen by a random tiebreaker, second-round beliefs and strategies are unchanged.

Second Round Beliefs and Strategies After a First-Round Deviation By Bidder $i \geq 2$

For ease of exposition, if a single player $i \geq 2$ deviates in the first round by not dropping out immediately, we will assume it is bidder 2. The equilibrium is symmetric in the identities of bidders $2, 3, \ldots, N$.

So, suppose bidder 2 failed to drop out at price $P = 0$, but bidder 1 played his equilibrium strategy, so either bidder 2 dropped out at some price $P \leq P^*$, or bidder 1 dropped out at price P^*. In this event, all bidders commonly believe that $s_2 = 1$, and $s_1 \sim U[0, 1]$. Strategies are:

- Bidder 2 does not bid (regardless of his actual type)
- If $P \geq c + \frac{\beta}{N}\left(1 + \frac{N}{2}\right)$, then nobody bids
- If $P \in \left(c + \frac{\beta}{N},\, c + \frac{\beta}{N}\left(1 + \frac{N}{2}\right)\right)$, then let s^* solve $P = c + \frac{\beta}{N}\left(1 + \frac{N}{2}s^*\right)$. Bidder $i \neq 2$ does not bid when $s_i \leq s^*$; when $s_i > s^*$, he bids

$$b(s_i) \quad = \quad c + \tfrac{\beta}{N}\left(\tfrac{N-2}{N-1}s_i + \tfrac{s_i}{N-1}\left(\tfrac{s^*}{s_i}\right)^{N-1} + (N-2)\tfrac{s_i}{2} + 1\right)$$

- If $P \leq c + \frac{\beta}{N}$, then bidders $i \neq 2$ each bid

$$b(s_i) \quad = \quad c + \tfrac{\beta}{N}\left(\tfrac{N-2}{N-1}s_i + (N-2)\tfrac{s_i}{2} + 1\right)$$

Second Round Beliefs and Strategies After Deviations By Bidders $i \geq 2$ And 1

Again, assume $i = 2$ is the identity of the bidder who deviated by failing to drop out immediately in the first round, and that bidder 1 deviated in the first round as well, either by dropping out at a price $P < P^*$, or by failing to drop out at P^*, in which case either he or bidder 2 dropped out at a price $P > P^*$. In this case, all other players $3, \ldots, N$ believe that $s_1 = s_2 = 1$. Bidding strategies are:

- Bidders 1 and 2 (regardless of their actual types) do not bid

- If $P \geq c + \frac{\beta}{N}\left(1 + \frac{N-3}{2} + 2\right)$, then nobody bids
- If $P \in \left(c + \frac{2\beta}{N}, c + \frac{\beta}{N}\left(1 + \frac{N-3}{2} + 2\right)\right)$, then let s^* solve

$$P = c + \frac{\beta}{N}\left(s^* + (N-3)\frac{s^*}{2} + 2\right)$$

Bidder $i \geq 3$ does not bid when $s_i \leq s^*$; when $s_i > s^*$, he bids

$$b(s_i) = c + \frac{\beta}{N}\left(\frac{N-3}{N-2}s_i + \frac{s_i}{N-2}\left(\frac{s^*}{s_i}\right)^{N-2} + (N-3)\frac{s_i}{2} + 2\right)$$

- If $P \leq c + \frac{2\beta}{N}$, then bidders $i \geq 3$ each bid

$$b(s_i) = c + \frac{\beta}{N}\left(\frac{N-3}{N-2}s_i + (N-3)\frac{s_i}{2} + 2\right)$$

Overview of Why This Is An Equilibrium

Any history not considered above could only be reached via simultaneous deviations by multiple bidders, and we therefore do not specify what happens at those histories. Proof that these strategies constitute an equilibrium, and modification of equilibrium strategies for the cases $N = 3$ and $N = 2$, are supplied in a separate online-only appendix. Here, we just supply some rough intuition.

The main deviation we need to prevent is some bidder $i \geq 2$ (WLOG bidder 2) choosing to bid in the first round, rather than conceding the premium to bidder 1. To prevent this, we "punish" such a move by bidder 2 by having bidder 1 keep bidding in the first round up until price P^*, and then give all bidders the belief that $s_2 = 1$; P^* is set just high enough that in the second round, bidder 2 is likely to get "stuck" with the security, which on average is overpriced enough to negate his gain from winning the premium.

Of course, this requires bidder 1 to participate in the punishment by bidding up to P^* in the first round. This is credible for two reasons. First, following his initial deviation, bidder 2's strategy calls for him to bid up to $P^{**} > P^*$ in the first round, so bidder 1 does not expect to win the first round; and second, should bidder 1 fail to punish appropriately, he too is punished, by the belief that $s_1 = 1$ in the subsequent second round. Thus, bidder 1 earns zero expected payoff if he deviates from his equilibrium "punishment" strategies, and no worse than 0 if he follows them.

On the equilibrium path, then, all bidders but 1 drop out immediately in the first round, so no information is revealed, and the second round proceeds like a normal, pure Dutch auction.

References

1. Avery, Christopher, "Strategic Jump Bidding in English Auctions," *Review of Economic Studies* 65 (1998), 185-210.
2. Āzacis, Helmuts, and Roberto Burguet, "Incumbency and Entry in License Auctions: The Anglo-Dutch Auction Meets Another Simple Alternative," *International Journal of Industrial Organization* 26 (2008), 730-745.
3. Baasch, Ernst, "Die Hamburgische Waren-Auktionen vor der Einführung der Reichs-Gewerbe-Ordnung," in: Ernst Baarsch, *Forschungen zur Hamburgischen Handelsgeschichte, Band 3* (Hamburg: Herold'sche Buchhandlung, 1902), 62-122.
4. Bikchandani, Sushil, Philip Haile, and John Riley, "Symmetric Separating Equilibria in English Auctions," *Games and Economic Behavior* 38 (2002), 19-27.
5. Blondé, Bruno, and Dries Lyna, "De culturele constructies voorbij? Prijsevoluties op de veilingmarkten voor schilderijen in de Oostenrijkse Nederlanden (1739-1794)", in: *Tijdschrift voor Sociale en Economische Geschiedenis* 9:1 (2012), 57-86.
6. Bochove, Christiaan van, "Configuring Financial Markets in Preindustrial Europe," *Journal of Economic History* 73 (2013), 247-278.
7. Bochove, Christiaan van, "External debt and commitment mechanisms: Danish borrowing in Holland, 1763-1825", *The Economic History Review* 67:3 (2014), 652-677.
8. Boerner, Lars, and John William Hatfield, "The Design of Debt Clearing Markets: Clearinghouse Mechanisms in Pre-Industrial Europe", SSRN Working Paper, 2014.
9. Boerner, Lars and Daniel Quint, "Medieval Matching Markets," working paper, 2016.
10. Burhop, Carsten, and Sergey Gelman, "Liquidity Measures, Liquidity Drivers and Expected Returns on an Early Call Auction Market," MPI Bonn Working Paper, 2011.
11. Carlos, Ann, and Larry Neal, "Amsterdam and London as Financial Centers in the 18th Century," *Financial History Review* 18 (2011), 21-46.
12. Cassady, Ralph Jr., *Auctions and Auctioneering* (University of California Press, 1967).
13. Chadhuri, K.N., *The English East India Company: The Study of an Early Joint-Stock Company, 1600-1640* (London: Cass, 1965).
14. Cruz, Laura, *The Paradox of Prosperity: The Leiden Booksellers' Guild and the Distribution of Books in Early Modern Europe* (New Castle: Oak Knoll Press, 2009).
15. De Marchi, Neil, "The role of Dutch auctions and lotteries in shaping the art market(s) of 17th century Holland," *Journal of Economic Behavior and Organization* 28 (1995), 203-221.
16. Dickson, P.G.M., *The Financial Revolution in England: A Study in the Development of Public Credit* (London: MacMillan, 1967).
17. Drelichman, Mauricio, and Hans-Joachim Voth, *Lending to the Borrower from Hell: Debt, Taxes, and Default in the Age of Philip II* (Princeton: Princeton University Press, 2014).
18. Duffie, Darrell, Nicolae Gârleanu, and Lasse Heje Pedersen, "Over-the-Counter Markets," *Econometrica* 73 (2005), 1815-1847.
19. Ebeling, Dietrich, *Der Holländerholzhandel in den Rheinlanden: Zu den Handelsbeziehungen*

zwischen den Niederlanden und dem westlichen Deutschland im 17. und 18. Jahrhundert (Stuttgart: Steiner, 1992).

20. Engelbrecht-Wiggans, Richard, Paul Milgrom, and Robert Weber, "Competitive Bidding and Proprietary Information," *Journal of Mathematical Economics* 11 (1983), 161-169.
21. Engelbrecht-Wiggans, Richard, and Tomas Nonnenmacher, "A Theoretical Basis for 19th-Century Changes to the Port of New York Imported Goods Auction," *Explorations in Economic History* 36 (1999), 232-245.
22. Faber, S., "Over Amsterdamse schapen", in: H. Bianchi (ed.), *Uit het recht: Rechtsgeleerde opstellen aangeboden aan mr. P.J. Verdam* (Deventer: Kluwer, 1971), 125-136.
23. Gelderblom, Oscar, and Joost Jonker, "Completing a financial revolution: the finance of the Dutch East India trade and the rise of the Amsterdam capital market, 1595-1612," *Journal of Economic History* 64 (2004), 641-672.
24. Gelderblom, Oscar, and Joost Jonker, "Public Finance and Economic Growth: The Case of Holland in the 17th Century," *Journal of Economic History* 71 (2011), 1-39.
25. Glamann, Kristof, *Dutch-Asiatic Trade 1620-1740* (Copenhagen/ The Hague: Danish Science Press / Martinus Nijhoff, 1958).
26. Goeree, Jacob, and Theo Offerman, "The Amsterdam Auction," *Econometrica* 72 (2004), 281-294.
27. Goldgar, Anne, *Tulipmania: Money, Honor, and Knowledge in the Dutch Golden Age* (University of Chicago Press, 2007).
28. Greif, Avner, "Contract Enforceability and Economic Institutions in Early Trade: The Maghribi Traders' Coalition", *American Economic Review* 83 (1993), 525-548.
29. Greif, Avner, "Cultural Beliefs and the Organization of Society: A Historical and Theoretical Reflection on Collectivist and Individualist Societies," *Journal of Political Economy* 102 (1994), 912-950.
30. Greif, Avner, *Institutions and the Path to the Modern Economy: Lessons from Medieval Trade* (Cambridge University Press, 2006).
31. Greif, Avner, Paul Milgrom, and Barry R. Weingast, "Coordination, Commitment, and Enforcement: The Case of the Merchant Guild," *Journal of Political Economy* 102 (1994), 745-776.
32. Hendricks, Kenneth, Robert Porter, and Charles Wilson, "Auctions for Oil and Gas Leases with an Informed Bidder and a Random Reservation Price," *Econometrica* 62 (1994), 1415-1444.
33. Hoes, H.J., "Voorgeschiedenis en ontstaan van het Financieele dagblad, 1796-1973," *Economisch en sociaal-historisch jaarboek* 49 (1986), 1-43.
34. Hautcoeur, Pierre-Cyrille, and Angelo Riva, "The Paris Financial Market in the 19th Century: Complementarities and Competition in Microstructures" (2011), forthcoming in *Economic History Review*.
35. Hu, Audrey, Theo Offerman, and Liang Zou, "Premium Auctions and Risk Preferences,"

Working Paper, 2010.

36. Jonckheere, Koenraad, *The Auction of King William's Paintings (1713): Elite International Art Trade at the End of the Dutch Golden Age* (Amsterdam: John Benjamins Publishing Company, 2008).
37. Jonker, Joost, *Merchants, Bankers, Middlemen: The Amsterdam Money Market during the First Half of the 19th Century* (Amsterdam, 1996).
38. Jonker, Joost, and Keetie Sluyterman, *At home on the world markets: Dutch international trading companies from the 16th century until the present* (The Hague: Sdu Uitgevers, 2000).
39. Kirkegaard, René, "A Mechanism Design Approach to Ranking Asymmetric Auctions," *Econometrica* 80 (2012), 2349-2364.
40. Klemperer, Paul, "Auctions with Almost Common Values,", *European Economic Review* 42 (1998), 757-769.
41. Klemperer, Paul, "What Really Matters in Auction Design," *Journal of Economic Perspectives* 16 (2002), 169-189.
42. Klemperer, Paul, *Auctions: Theory and Practice* (Princeton University Press, 2004).
43. Koudijs, Peter, " 'Those who Know Most': Insider Trading in 18th c. Amsterdam," forthcoming, *Journal of Political Economy.*
44. Krishna, Vijay, *Auction Theory* (San Diego: Academic Press, 2002).
45. Kröhne, Marie, *Die Grosshandelsversteigerungen* (Tübingen: H. Laupp, 1909).
46. Lankhorst, Otto S.,"Dutch Book Auctions in the 17th and 18th Centuries", in: Robin Myers, Michael Harris and Giles Mandelbrote (eds.), *Under the Hammer: Book Auctions Since the 17th Century* (New Castle / London: Oak Knoll Press & The British Library, 2001), 65-87.
47. Le Moine de l'Espine, Jacques, *De Koophandel Van Amsterdam* (Rotterdam, 1694-1801).
48. Levin, Dan, and Lixin Ye, "Hybrid Auctions Revisited," *Economics Letters* 99 (2008), 591-594.
49. Liesker, R., and W. Fritschy, *Gewestelijke financiën ten tijde van de Republiek der Verenigde Nederlanden IV: Holland (1572-1795)* (The Hague, 2004).
50. Liu, Yong, *The Dutch East India Company's Tea Trade with China, 1757-1781* (Leiden and Boston: Brill, 2007).
51. LoPucki, Lynn, and Joseph Doherty, "Bankruptcy Fire Sales," *Michigan Law Review* 106 (2007), 1-60.
52. Mak van Waay, J., *Veilingen en kunstveilingen: Schets van het veilingwezen in Nederland* (Amersfoort: Melchior, 1936).
53. Malinowski, Mikołaj, "Weekly prices in Amsterdam in the 18th century (grains, colonial goods, bills, agio)," available at http://www.iisg.nl/hpw.
54. Maskin, Eric, and John Riley, "Asymmetric Auctions," *Review of Economic Studies* 67 (2000), 413-438.
55. McLean, Richard, and Andrew Postelwaite, "Informational Size and Efficient Auctions," *Review of Economic Studies* 71 (2004), 809-827.

56. Meerkerk, Edwin van, "Maandelykse Nederlandsche Mercurius (1756-1807)," in: *Magazine! 150 jaar Nederlandse publiekstijdschriften*, Marieke van Delft, Nel van Dijk and Reinder Storm, eds. (Zwolle: Waanders, 2006), 14-15.
57. Michie, Ranald C., *The London Stock Exchange: A History* (Oxford University Press, 2001).
58. Middelhoven, P. J., "De Amsterdamse veilingen van Noord-Europees naaldhout 1717-1808. Een bijdrage tot de Nederlandse prijsgeschiedenis," *Economisch – en sociaal-historisch jaarboek* 41 (1978), 86-114.
59. Milgrom, Paul, *Putting Auction Theory to Work* (Cambridge University Press, 2004).
60. Milgrom, Paul, "Critical Issues in Auction Market Design," *Economic Inquiry* 48 (2011), 311-320.
61. Milgrom, Paul, and Robert Weber, "A Theory of Auctions and Competitive Bidding," *Econometrica* 50 (1982), 1089-1122.
62. Milgrom, Paul, and Robert Weber, "The Value of Information in a Sealed-Bid Auction," *Journal of Mathematical Economics* 10 (1982b), 105-114.
63. Montias, John Michael, *Art at Auction in 17th Century Amsterdam* (Amsterdam University Press, 2002).
64. Neal, Larry, *The Rise of Financial Capitalism: International Capital Markets in the Age of Reason* (Cambridge University Press, 1990).
65. Neyman, J., and Elizabeth L. Scott, "Consistent Estimates Based on Partially Consistent Observations," *Econometrica* 16 (1948), 1-32.
66. Noordkerk, Hermannus, *Handvesten, ofte Privilegien ende Octroyen, Mitsgaders Willekeuren, Costuimen, Ordonnantien en Handelingen der Stad Amstelredam* (Amsterdam, 1748).
67. North, Douglass, and Barry Weingast, "Constitutions and Commitment: The Evolution of Institutions Governing Public Choice in 17th-Century England," *Journal of Economic History* 49 (1989), 803-832.
68. O'Hara, Maureen, *Market Microstructure Theory* (Wiley, 1995).
69. O'Hara, Maureen, "Presidential Address: Liquidity and Price Discovery," *Journal of Finance* 58 (2003), 1335-1354.
70. O'Hara, Maureen, "Optimal Microstructures," *European Financial Management* 13 (2007), 825-832.
71. Petram, Lodewijk, "The World's First Stock Exchange: How the Amsterdam Market for Dutch East India Company Shares Became a Modern Securities Market, 1602-1700," Dissertation, University of Amsterdam, 2011.
72. Philips, Rosa, "Entwicklung der Welthandelsauktionen in Holland," Dissertation, University of Cologne, 1924.
73. Postma, Johannes Menne, *The Dutch in the Atlantic Slave Trade 1600-1815* (Cambridge, 1990).
74. Postma, Johannes, and Victor Enthoven (eds.), *Riches from Atlantic Commerce: Dutch Transatlantic Trade and Shipping, 1585-1817* (Leiden, 2003).

75. Prooije, L.A. van, “De invoer van Rijns hout per vlot 1650-1795,” *Economisch – en sociaal-historisch jaarboek* 53 (1990), 30-79.
76. Ricard, Jean Pierre, *Le négoce d'Amsterdam: contenant tout ce que doivent savoir le marchands* (Amsterdam, 1722).
77. Roth, Alvin E., “The Economist as Engineer: Game Theory, Experimentation, and Computation as Tools for Design Economics,” *Econometrica* 70 (2002), 1341-1378.
78. Roth, Alvin E., “What have we learned from market design,” *Economic Journal* 118 (2008), 285-310.
79. Sautijn Kluit, W.P., *De Amsterdamsche Beurs in 1763 and 1773: Eene bijdrage tot de geschiedenis van den handel* (Amsterdam, 1865).
80. Scheltema, Pieter, *De Beurs Van Amsterdam* (Amsterdam: G. Portieljie, 1846).
81. Schillemans, C. A., “De houtveilingen van Zaandam in de jaren 1655-1811,” *Economisch – historisch jaarboek* 23 (1947), 171-315.
82. Scott, William R., *The Constitution and Finance of English, Scottish and Irish Joint-Stock Companies to 1720, volume 1* (Cambridge University Press, 1912).
83. Shubik, Martin, *The Theory of Money and Financial Institutions Volume 1* (Cambridge: MIT Press, 1999).
84. Sobel, Robert, *The Big Board: A History of the New York Stock Market* (Washington, DC: Beard Books, 2000) (first published 1965).
85. Steen, Nicole van der, “De Europische Mercurius en de Maandelijkse Nederlandsche Mercurius: de evolutie van een periodieke kroniek tot 'de' Mercurius,” *Ex tempore* 15 (1996), 211-235.
86. The Soundtoll Registers online (available at http://www.sountoll.nl; downloaded on 7 October, 2011).
87. Thielmann, Georg, *Die römische Privatauktion* (Berlin: Duncker & Humblot, 1961).
88. Vitiello, Domenic, and George E. Thomas, *The Philadelphia Stock Exchange and the City It Made* (Philadelphia: University of Pennsylvania Press, 2010).
89. Voort, Johannes Petrus van de, “De Westindische plantages van 1720 tot 1795: Financiën en handel,” Dissertation, Katholieke Universiteit Nijmegen, 1973.
90. Vries, Jan de, and Ad van der Woude, *The First Modern Economy: Success, Failure, and Perseverance of the Dutch Economy, 1500-1815* (Cambridge University Press, 1997).
91. Wegener Sleeswijk, Anne, *Franse wijn in de Republiek in de 18e eeuw: Economisch handelen, institutionele dynamiek en de herstructurering van de markt* (unpublished dissertation, University of Amsterdam, 2006).
92. Wegener Sleeswijk, Anne, “Hearing, Seeing, Tasting and Bidding: Information at the Dutch Auction of Commodities in the 18th century,” in: *Information Flows: New Approaches in the Historical Study ofBusiness Information*, Leos Müller and Jari Ojala, eds. (Helsinki: Finnish Literature Society, 2007), 169-192.
93. Welling, George M., *The Prize of Neutrality: Trade relations between Amsterdam and North*

America 1771-1817. A study in computational history, Historisch Seminarium van de Universiteit van Amsterdam, 1998. (Data available at http://www.let.rug.nl/˜welling/appendix.html; downloaded on 7 October, 2011)

94. Wooldridge, Jeffrey M., *Econometric Analysis of Cross Section and Panel Data* (Cambridge: MIT Press, 2002).

Primary Sources

1. "ACA, Remonstrantse Gemeente": Amsterdam City Archive, Archief van de Remonstrantse Gemeente (entry number 612).
2. "ACA, Schout en Schepenen": Amsterdam City Archive, Archieven van de Schout en Schepenen, van de Schepenen en van de Subalterne Rechtbanken (entry number 5061).
3. "ACA, Willige verkopingen": Amsterdam City Archive, Archief van de Burgemeesters: willige verkopingen (veilingen van huizen, erven en obligaties) (entry number 5068).
4. "ACA, Koopmanschappen": Amsterdam City Archive, Archief van de Burgemeesters: verkopingen van koopmanschappen door makelaars (entry number 5069).
5. "ACA, Houtwaren": Amsterdam City Archive, Archief van de Burgemeesters: verkopingen van houtwaren door makelaars (entry number 5070).
6. "ACA, Scheepsverkopingen": Amsterdam City Archive, Archief van de Burgemeesters: scheepsverkopingen door makelaars (entry number 5071).
7. "ACA, Desolate Boedelkamer": Amsterdam City Archive, Archief van de Commissarissen van de Desolate Boedelkamer (entry number 5072).
8. *Amsterdamsch Effectenblad.*
9. *De maandelykse Nederlandsche Mercurius* (partially available online at http://books.google.com).
10. *Nieuw Algemeen Effectenblad.*
11. *Prijscourant.*
12. *Prijs-courant der Effecten.*
13. "UCA, Notarissen": Utrecht City Archive, Notarissen geresideerd hebbende te Utrecht-stad, 1560-1905 (entry number 34-4).
14. "UCA, Vlaer & Kol": Utrecht City Archive, Archief van de familie Kol, 1516, 1719-1964 (entry number 715-1).
15. Website of the Real Estate Agents Association Amsterdam documenting rules of the First Amsterdam Real Estate Auction: http://www.mva-makelaars.nl/veilingx/english.shtml (website accessed 30 January 2012). More elaborate regulations (in Dutch) are available at http://www.mva-makelaars.nl/veilingx/downloads/algemene_voorwaarden_veiling.pdf.

Table 1: Second Round Bidding by Issuer Type and Time

Type of Security	*Number of Observations*	*First Year Present*	*Last Year Present*	*% Won in 2nd Round*
all securities	16,854	1766	1783	23%
Holland securities	5,316	1766	1783	14%
other Dutch securities	1,669	1766	1783	20%
foreign government securities	1,860	1766	1783	14%
plantation securities	6,959	1766	1783	30%
private company securities	1,050	1766	1783	34%
securities in foreign currency	394	1766	1783	25%
pre-crisis	3,617	1766	1772	9%
pre-crisis, Holland	1,704	1766	1772	10%
pre-crisis, other Dutch	611	1766	1772	11%
pre-crisis, foreign government	413	1766	1772	3%
pre-crisis, plantation	718	1766	1772	5%
pre-crisis, private company	171	1766	1772	19%
Anglo-Dutch war, plantation	652	1781	1783	39%
Anglo-Dutch war, others	2,343	1781	1783	17%
season (winter)	4,187	1766	1783	24%
own security	3,488	1766	1783	23%

Table 2: Most Frequent Auction Winners

Name of Bidder	*Securities Won*	*First Year*	*Last Year*	*% Won in 2nd Round*
W. Zeelt	604	1769	1783	17%
W.H. Stoopendaal	580	1766	1783	36%
G. Jarman	519	1766	1783	26%
A. van Ketwich	401	1766	1783	15%
D. Leuveling	379	1770	1783	30%
J.P. Heimbach	364	1766	1782	14%
E. Croese	288	1767	1783	37%
H. van Blomberg	280	1772	1783	69%
A. van Vloten	277	1768	1783	25%
Tideman and Scholten	249	1771	1777	22%
top 10 total	3,941	1766	1783	28%
top 20 total	5,869	1766	1783	27%
top 50 total	9,266	1766	1783	24%
top 83 total	11,323	1766	1783	23%
total	16,854	1766	1783	23%

Table 3: Second-Round Bidding and Learning/Price Discovery

	Holland	*Other Dutch*	*Foreign*	*Private Company*	*Plant-ation*	*All*
Number of observations...						
Sale #1 from a given issuer*	321	402	412	326	645	1,706
Sale #2	288	277	316	190	538	1,609
Sales #3-5	750	417	555	278	1,218	3,218
Sales #6-10	935	274	362	157	1,291	3,019
Sales #11-20	1,190	174	171	74	1,380	2,989
Sales #21+	1,832	125	44	25	1,887	3,913
Fraction won in second round						
Sale #1	23%	29%	21%	45%	46%	**34%**
Sale #2	19%	23%	12%	37%	35%	**26%**
Sales #3-5	17%	22%	14%	32%	31%	**22%**
Sales #6-10	15%	18%	09%	20%	31%	**20%**
Sales #11-20	13%	11%	16%	18%	30%	**20%**
Sales #21+	10%	0%	9%	12%	23%	**16%**

* Different issuers from the same plantation are treated as identical.

Table 4: Variable Names and Definitions

Variable	**Definition**
	issuer/ security characteristics
Holland securities	equals 1 if the security was issued by the province of Holland
other Dutch securities	equals 1 if the security was issued by any other Dutch state, province, or city government, or the Navy Boardsto d
foreign government securities	equals 1 if the security was issued by a foreign (non-Dutch) government
plantation securities	equals 1 if the security was issued by a plantation-owner
private company securities	equals 1 if the security was issued by a private company
securities in foreign currency	equals 1 if the security was *not* issued in Dutch guilders
	historical events
pre-crisis	equals 1 if the auction took place between 1766-1772
pre-crisis Holland securities	pre-crisis times Holland securities
pre-crisis other Dutch securities	pre-crisis times other Dutch securities
pre-crisis foreign government securities	pre-crisis times foreign government securities
pre-crisis plantation securities	pre-crisis times plantation securities
pre-crisis private company securities	pre-crisis times private company securities
Anglo-Dutch war plantation	equals 1 if the auction took place between 1780-1783 and the security is a plantation security
Anglo-Dutch war others	equals 1 if the auction took place between 1780-1783 and the security is not a plantation security
time trend	linear time trend, measured in months
winter	equals 1 if the auction took place in January, February, or March

	learning
same Holland securities before	takes value 1 for the second consecutive Holland security being sold, 2 for the third consecutive Holland security being sold, and so on; takes value 0 for other issuers
same other Dutch securities before	takes value 1 for the second consecutive security being sold from the same non-Holland Dutch issuer, takes value 2 for the third, and so on; takes value 0 for other issuers
same foreign government securities before	takes value 1 for the second consecutive security being sold from the same foreign government issuer, 2 for the third, and so on
same plantation securities before	takes value 1 for the second consecutive security being sold from the same plantation, 2 for the third, and so on. (Different issuers from the same plantation are treated as identical.)
same private company securities before	takes value 1 for the second consecutive security being sold issued by the same private company, 2 for the third, and so on
	auction room effects
days between auction	number of days between this auction and the previous auction
goods sold	number of securities sold during this auction day
top83	number of the top 83 winners (those who won at least 50 securities in our data) who won at least one security on this auction day
over30	number of the top 83 winners who won at least one security on the auction day and, over our data, won at least 30% of their securities with a second-round bid
under10	number of the top 83 winners who won at least one security on the auction day in question and, over our data, won less than 10% of their securities with a second-round bid
second stage winning bidders	over30 divided by top83
first stage winning bidders	under10 divided by top83
	other auction effects
own auction	equals 1 if winner is also one of the lot's selling brokers
	exchange markets
grain price	price of Polish grain on the Amsterdam exchange the day of the auction
sugar price	price of sugar from St. Domingo on the Amsterdam exchange the day of the auction
agio price	price of bank guilders the day of the auction, expressed in current guilders
Hamburg price	exchange rate on Hamburg the day of the auction (Stuivers/Thaler)

Table 5: Summary Statistics for Explanatory Variables

Variable	*Mean*	*Std Dev*	*Min*	*Max*
other Dutch securities	0.099	0.299	0	1
foreign government securities	0.110	0.313	0	1
plantation securities	0.413	0.492	0	1
private company securities	0.062	0.242	0	1
securities in foreign currency	0.023	0.151	0	1
pre-crisis	0.215	0.411	0	1
pre-crisis Holland securities	0.101	0.301	0	1
pre-crisis other Dutch securities	0.036	0.187	0	1
pre-crisis foreign government securities	0.025	0.155	0	1
pre-crisis plantation securities	0.043	0.202	0	1
pre-crisis private company securities	0.010	0.100	0	1
Anglo-Dutch War, plantation	0.039	0.193	0	1
Anglo-Dutch War, other	0.139	0.346	0	1
time trend	122.33	54.50	1	216
winter	0.248	0.432	0	1
own auction	0.218	0.413	0	1
same Holland securities before*	18.83	20.83	0	146
same other Dutch securities before*	7.11	14.88	0	104
same foreign government before*	4.20	5.77	0	48
same plantation securities before*	18.01	26.25	0	194
same private company securities before*	3.41	4.99	0	30
days between auction	14.91	11.85	1	63
goods sold	72.50	56.35	1	289
over30/top83	0.23	0.14	0	1
under10/top83	0.14	0.13	0	1
grain price	201.36	24.94	145.6	268.8
sugar price	0.28	0.09	0.11	0.46
agio price	4.68	0.32	1.50	5.13
Hamburg price	33.47	0.72	30.69	36

* average and standard deviation are among securities of that issuer type; variables takes value 0 on other issuer types

Table 6: Determinants of Second Round Bidding: Probit Regressions (part 1)

Dependent variable:	*second stage winning (1) vs. first stage winning (0)*						
second stage winning	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			issuer/ security characteristics				
other Dutch securities	0.08*** (0.01)	0.08*** (0.01)	0.09*** (0.01)	0.11*** (0.02)	0.11*** (0.02)	0.11*** (0.02)	0.11*** (0.02)
foreign government securities	-0.00 (0.01)	-0.01 (0.01)	-0.03** (0.01)	-0.00 (0.01)	-0.00 (0.01)	-0.01 (0.01)	-0.01 (0.01)
plantation securities	0.17*** (0.01)	0.17*** (0.01)	0.13*** (0.01)	0.17*** (0.01)	0.15*** (0.01)	0.16*** (0.01)	0.15*** (0.01)
private company securities	0.23*** (0.02)	0.22*** (0.02)	0.19*** (0.02)	0.21*** (0.02)	0.21*** (0.02)	0.21*** (0.02)	0.22*** (0.02)
securities in foreign currency		0.09*** (0.03)	0.07*** (0.03)	0.07*** (0.03)	0.07*** (0.03)	0.06** (0.03)	0.06** (0.03)
			historical events				
pre-crisis			-0.15*** (0.01)	-	-	-	-
pre-crisis Holland securities				-0.08*** (0.01)	-0.09*** (0.01)	-0.02 (0.02)	-0.09*** (0.01)
pre-crisis other Dutch securities				-0.12*** (0.01)	-0.13*** (0.01)	-0.08*** (0.02)	-0.13*** (0.01)
pre-crisis foreign government securities				-0.17*** (0.01)	-0.18*** (0.01)	-0.15*** (0.02)	-0.18*** (0.01)
pre-crisis plantation securities				-0.20*** (0.01)	-0.20*** (0.01)	-0.18*** (0.01)	-0.20*** (0.01)
pre-crisis private company securities				-0.12*** (0.02)	-0.13*** (0.02)	-0.08*** (0.03)	-0.13*** (0.02)
Anglo-Dutch war plantation					0.06*** (0.02)	-0.01 (0.02)	0.06*** (0.02)
Anglo-Dutch war others					-0.04*** (0.01)	-0.08*** (0.01)	-0.04*** (0.01)
time trend						0.00* (0.00)	-
winter							0.06*** (0.01)
log pseudo likelihood	-8698.91	-8692.88	-8496.53	-8437.83	-8425.28	-8398.35	-8399.29
number of observations	16,854	16,854	16,854	16,854	16,854	16,854	16,854
LR Chi2	627.93	640.02	1032.70	1150.12	1175.22	1229.07	1227.19
prob>Chi2	0	0	0	0	0	0	0
Pseudo R2	0.035	0.036	0.057	0.064	0.065	0.068	0.070

* / ** / *** indicate statistical significance at the 10% / 5% / 1% level, respectively

Table 7: Determinants of Second Round Bidding: Probit Regressions (part 2)

Dependent variable:	*second stage winning (1) vs first stage winning (0)*					
second stage winning	(8)	(9)	(10)	(11)	(12)	(13)
			issuer/ security characteristics			
other Dutch securities	0.10*** (0.03)	0.10*** (0.03)	0.11*** (0.03)	0.11*** (0.03)	0.11*** (0.03)	0.11*** (0.03)
foreign government securities	-0.04** (0.02)	-0.04** (0.02)	-0.04** (0.02)	-0.04* (0.02)	-0.05** (0.02)	-0.05** (0.02)
plantation securities	0.14*** (0.02)	0.14*** (0.02)	0.14*** (0.02)	0.14*** (0.02)	0.13*** (0.02)	0.13*** (0.02)
private company securities	0.23*** (0.03)	0.23*** (0.03)	0.24*** (0.03)	0.24*** (0.03)	0.23*** (0.03)	0.23*** (0.03)
securities in foreign currency	0.05** (0.03)	0.06** (0.03)	0.05** (0.02)	0.04 (0.02)	0.02 (0.02)	0.02 (0.02)
			historical events			
pre-crisis	-	-	-	-	-	-
pre-crisis Holland securities	-0.09*** (0.01)	-0.10*** (0.01)	-0.10*** (0.01)	-0.09*** (0.01)	-0.09*** (0.01)	-0.06*** (0.02)
pre-crisis other Dutch securities	-0.12*** (0.01)	-0.13*** (0.01)	-0.13*** (0.01)	-0.13*** (0.01)	-0.13*** (0.01)	-0.10*** (0.02)
pre-crisis foreign government securities	-0.17*** (0.01)	-0.18*** (0.01)	-0.18*** (0.01)	-0.17*** (0.01)	-0.17*** (0.01)	-0.15*** (0.02)
pre-crisis plantation securities	-0.20*** (0.01)	-0.20*** (0.01)	-0.20*** (0.01)	-0.19*** (0.01)	-0.19*** (0.01)	-0.18*** (0.01)
pre-crisis private company securities	-0.14*** (0.02)	-0.15*** (0.01)	-0.15*** (0.03)	-0.14*** (0.02)	-0.15*** (0.02)	-0.13*** (0.02)
Anglo-Dutch war plantation	0.02 (0.02)	0.02 (0.02)	0.02 (0.02)	-0.00 (0.02)	0.00 (0.02)	-0.04*** (0.02)
Anglo-Dutch war others	-0.04*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)	-0.06*** (0.01)	-0.06*** (0.01)	-0.09*** (0.01)
time trend	-	-	-	-	-	-
winter	0.06*** (0.01)	0.06*** (0.01)	0.05*** (0.01)	0.07*** (0.01)	0.06*** (0.01)	0.06*** (0.01)
			learning			
same Holland securities before	-0.04*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)	-0.03*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)
same other Dutch securities before	-0.07*** (0.01)	-0.08*** (0.01)	-0.06*** (0.02)	-0.08*** (0.01)	-0.08*** (0.01)	-0.08*** (0.01)
same foreign government securities before	-0.03** (0.01)	-0.03** (0.01)	-0.03** (0.01)	-0.03** (0.01)	-0.02* (0.01)	-0.02 (0.01)

same plantation securities before	-0.04*** (0.00)	-0.04*** (0.00)	-0.04*** (0.01)	-0.04*** (0.00)	-0.04*** (0.00)	-0.03*** (0.00)
same private company securities before	-0.10*** (0.00)	-0.09*** (0.01)	-0.09*** (0.01)	-0.09*** (0.01)	-0.09*** (0.01)	-0.09*** (0.01)
auction room effects						
days between auction		0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)
goods sold			-0.00 (0.00)	-0.00 (0.02)	0.01** (0.01)	0.01 (0.01)
first stage winning bidders				-0.14*** (0.02)	-0.14*** (0.02)	-0.13*** (0.02)
second stage winning bidders				0.08*** (0.02)	0.09*** (0.02)	0.08*** (0.02)
other auction effects						
own auction					-0.01 (0.01)	-0.01 (0.01)
exchange market						
grain price						0.00*** (0.00)
agio price						-0.02 (0.01)
sugar price						0.40*** (0.07)
Hamburg price						-0.01* (0.01)
log pseudo likelihood	-8263.88	-8254.49	-8253.86	-8024.97	-7703.35	-7523.44
number of observations	16,854	16,854	16,854	16,554	15,917	15,581
Wald Chi2	1498.01	1516.80	1518.06	1644.86	1557.81	1588.02
prob>Chi2	0	0	0	0	0	0
Pseudo R2	0.083	0.084	0.084	0.093	0.092	0.091

* / ** / *** indicate statistical significance at the 10% / 5% / 1% level, respectively

Table 8: Determinants of Second Round Bidding: Robustness Checks

Dependent variable:	*second stage winning (1) vs first stage winning (0)*			
second stage winning	(1)	(2)	(3)	(4)
Estimator	Probit	Probit, robust standard errors	Probit, s.e. clustered by auction winner	Probit, s.e. clustered by auction day
issuer/ security characteristics				
other Dutch securities	0.11*** (0.03)	0.11*** (0.03)	0.11*** (0.04)	0.11*** (0.04)
foreign government securities	-0.05** (0.02)	-0.05** (0.02)	-0.05** (0.02)	-0.05 (0.03)
plantation securities	0.13*** (0.02)	0.13*** (0.02)	0.13*** (0.03)	0.13*** (0.04)
private company securities	0.23*** (0.03)	0.23*** (0.03)	0.23*** (0.05)	0.23*** (0.05)
securities in foreign currency	0.02 (0.02)	0.02 (0.02)	0.02 (0.04)	0.02 (0.05)
historical events				
pre-crisis Holland securities	-0.06*** (0.02)	-0.06*** (0.02)	-0.06 (0.04)	-0.06 (0.08)
pre-crisis other Dutch securities	-0.10*** (0.02)	-0.10*** (0.02)	-0.10*** (0.03)	-0.10*** (0.05)
pre-crisis foreign government securities	-0.15*** (0.02)	-0.15*** (0.02)	-0.15*** (0.02)	-0.15*** (0.03)
pre-crisis plantation securities	-0.18*** (0.01)	-0.18*** (0.01)	-0.18*** (0.01)	-0.18*** (0.02)
pre-crisis private company securities	-0.13*** (0.02)	-0.13*** (0.02)	-0.13*** (0.02)	-0.13*** (0.04)
Anglo-Dutch war plantation	-0.04*** (0.02)	-0.04*** (0.02)	-0.04*** (0.01)	-0.04 (0.04)
Anglo-Dutch war others	-0.09*** (0.01)	-0.09*** (0.01)	-0.08*** (0.02)	-0.09*** (0.03)
winter	0.06*** (0.01)	0.06*** (0.01)	0.06*** (0.01)	0.06** (0.03)
learning				
same Holland securities before	-0.04*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)
same other Dutch securities before	-0.08*** (0.01)	-0.08*** (0.01)	-0.06*** (0.02)	-0.08*** (0.02)

same foreign government securities before	-0.02 (0.01)	-0.02 (0.01)	-0.02 (0.02)	-0.02 (0.03)
same plantation securities before	-0.03*** (0.00)	-0.03*** (0.00)	-0.03*** (0.01)	-0.03*** (0.01)
same private company securities before	-0.09*** (0.01)	-0.09*** (0.01)	-0.09*** (0.02)	-0.09*** (0.02)
auction room effects				
days between auction	0.02*** (0.01)	0.02*** (0.01)	0.02* (0.01)	0.02 (0.02)
goods sold	0.01 (0.01)	0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)
first stage winning bidders	-0.13*** (0.02)	-0.13*** (0.02)	-0.13*** (0.03)	-0.13*** (0.05)
second stage winning bidders	0.08*** (0.02)	0.08*** (0.02)	0.08** (0.04)	0.08* (0.04)
other auction effects				
own auction	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.02)	-0.01 (0.02)
exchange market				
grain price	0.00*** (0.00)	0.00*** (0.00)	0.00** (0.00)	0.00 (0.00)
agio price	-0.02 (0.01)	-0.02 (0.01)	-0.02 (0.02)	-0.02 (0.02)
sugar price	0.40*** (0.07)	0.40*** (0.07)	0.40*** (0.12)	0.40* (0.22)
Hamburg price	-0.01* (0.01)	-0.01* (0.01)	-0.01 (0.01)	-0.01 (0.02)
log pseudo likelihood	-7523.44	-7523.44	-7523.44	-7523.44
number of observations	15,581	15,581	15,581	15,581
LR Chi2	1588.02	1422.56	531.62	344.34
prob>Chi2	0	0	0	0
Pseudo R2	0.096	0.096	0.096	0.096

* / ** / *** indicate statistical significance at the 10% / 5% / 1% level, respectively