Bidding Behavior in Austrian Treasury Bond Auctions

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To issue Treasury securities by auctions is a common method in many countries all over the world. The auction mechanisms used vary across countries. As our understanding of bidder behavior in Treasury auctions is still rather limited it is not surprising that the question which auction mechanism should be chosen is still unresolved.

In this study, we analyze the bidding behavior in Austrian Treasury bond auctions, using a dataset which contains all bids submitted by each bidder as well as the results of 137 Austrian Treasury auctions from February 1991 to May 2006. Bidders in bond auctions have various means to react to changing market conditions: They may change the degree of bid shading, the quantity of Treasury bonds demanded and the dispersion of their bids. This paper aims to investigate how bidders adjust their strategies to varying uncertainty in the bond market, to different numbers of participating bidders and to changes in the volume of bond issues.

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1 Introduction

Based on a dataset provided by the Österreichische Bundesfinanzierungsagentur (ÖBFA) and the Oesterreichische Kontrollbank (OeKB), this paper analyzes the bidding behavior in Austrian Treasury bond auctions. The dataset contains all bids submitted by each bidder as well as the results in 137 Austrian Treasury auctions over the period from February 1991 to May 2006.

Compared to other auctions, Treasury auctions leave much more room for strategic maneuvers to bidders as these are allowed to submit multiple bids for multiple quantities of bonds as price/quantity pairs. Starting with the highest bid, the OeKB ranks the submitted bids until the amount of bonds that is offered by the Treasury is met. Austrian Treasury auctions are discriminatory auctions, which means that winning bidders pay what they bid in contrast to uniform-price auctions, where all winning bidders pay the same price per unit of the auctioned good. For almost all auction formats, theory predicts that rational bidders place their bids below what they believe the good is worth, i.e. bidders shade their bids.[4]

In bond auctions, bidders have various means to react to changing market conditions: They may adjust

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[4] *In the context of bond auctions bid shading means that, given a certain price, bidders demand less than they would actually like to receive at the bid price. Hence, some authors prefer to call this phenomenon "demand reduction" instead of "bid shading" (Krishna, 2002).*

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the degree of bid shading, the total amount of bonds demanded and the dispersion of their bids. The aim of this paper is to investigate how bidders adjust their strategies to varying uncertainty in the bond market, to varying numbers of participating bidders and to changes in the volume of bond issues.

There is a considerable amount of primarily empirical papers that investigate bond auctions in various countries: Cammack (1991) and Sundaresan (1994) discuss the U.S.A., Umlauf (1993) Mexico, Hamao and Jegadeesh (1998) deal with Japan, Gordy (1999) analyzes Portugal, Hortaçsu (2002) Turkey, Nyborg et al. (2002) discuss Sweden, and Keloharju et al. (2005) Finland. Given the focus of this study and the similarities between the various auction mechanisms, this paper closely relates to Nyborg et al. (2002) and Hortaçsu (2002).

The paper is organized as follows. The Austrian Treasury auctions are described in section 2. The relevant auction theory is discussed in section 3 with an emphasis on testable implications. Section 4 presents the estimation results and section 5 concludes.

2 Treasury Auctions in Austria

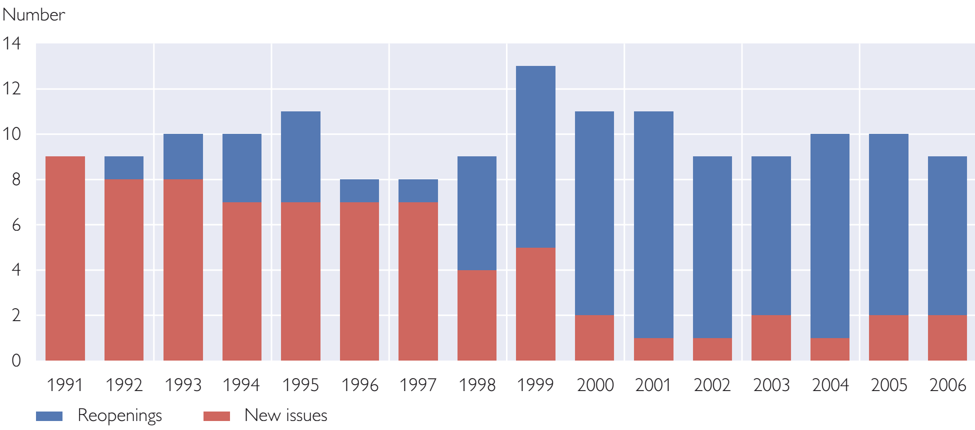
Since 1991 Austrian Treasury bonds have been sold through sealed, multiple-bid, discriminatory yield tenders or price auctions. Treasury auctions are organized by the OeKB on behalf of the ÖBFA. New bonds may be issued through yield tenders or through a syndicate of banks. In the recent past only the latter method was used. Whereas new issues prevailed in the 1990s, Treasury policy now focuses on reopening existing instruments to enhance the liquidity in these bonds. New securities are issued only occasionally (one or two issues per year) to close gaps in traded maturities (chart 1). In 2001 the ÖBFA changed the method used to issue reopenings from yield tenders to price auctions. Participation in these auctions is managed by the ÖBFA. Banks that meet certain requirements in terms of capital, number of employees, number of branches, and trading volume in euro-denominated government bonds are eligible to apply for participation. They have to be approved by ÖBFA. From 1991 to 1996 there were between 12 to 15 bidders per auction. Owing to regulatory changes, this number increased to 20 to 25 bidders in the years to follow (chart 2). Currently there are 25 approved bidders who not only may, but must submit competitive bids in every Treasury auction.[5]

In Austria, Treasury auctions are held approximately every six weeks (except for August). The preliminary schedule for each year is advertized one year in advance at the end of each year. One week before each auction, the ÖBFA announces the characteristics of the bond to be auctioned, i.e. maturity, annual coupon dates and size in the case of new issues and, for reopenings, the bond to be reopened and the nominal value to be issued. Competitive bids must be submitted electronically between 10:00 a.m. and 11:00 a.m. on the auction day (which usually is a Tuesday). The issuer has the right to recall the auction until noon. This option has been ex-

[5] *For a more detailed description of Austrian Treasury auctions see Oesterreichische Kontrollbank AG (2007).*

Chart 1

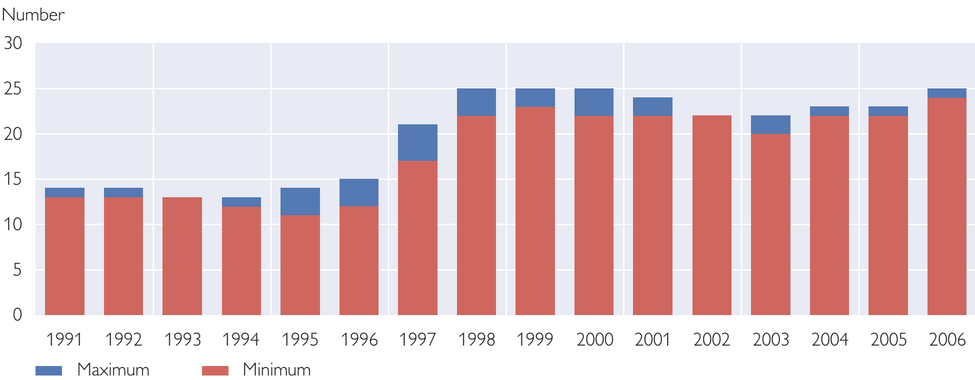
New Issues and Reopenings per Year



Source: OeKB.

Chart 2

Approved Bidders per Year



Source: OeKB.

ercised only once since 1998. The results of the auction are published immediately after the issuer approves the auction. This publicly available information is rather detailed and includes the aggregate quantity of bonds bid for, the highest bid, the lowest winning bid (stop-out price), the lowest bid, the quantity-weighted average bid and the quantity-weighted average winning bid. 15% of the competitive volume of bonds is offered for non-competitive bids, which may be submitted until 11:00 a.m. on the next day. 10% of the issued volume is retained by the Treasury to be sold on the secondary market. Settlement takes place three days after the auction and is matched with settlement in the secondary market. New issues are listed at Wiener Börse AG three days after the relevant auction.[6]

[6] *Austrian bonds are traded on the secondary market. There is no when-issued market, however.*

Tender example

Suppose the Treasury announces to reopen a bond by issuing another EUR 1,000 of face value. The features of the bond (coupon payments, time to maturity) are known. There are two bidders, A and B. As it is a reopening, the submitted bids consist of a quantity of bonds in terms of face value and a price per EUR 100 of face value at which the bidder is willing to buy this quantity. Bidder A submits the following bids: EUR 600 at a price of EUR 105, and EUR 500 at a price of EUR 80. B's bids are EUR 400 at a price of EUR 110, EUR 300 at EUR 105, and EUR 400 at EUR 100. The Treasury ranks the bids according to the price until supply equals demand. At a price of EUR 110 the aggregate demand equals EUR 400. At a price of EUR 105 the aggregate demand equals EUR 1,300 and exceeds the supply. The bids at the stop-out price of 105 are rationed proportionally. The amount bidded for at EUR 105 is EUR 900 of face value, but only EUR 600 of face value are available. Hence, bidder A wins EUR 400 (=600(2/3)) and B wins EUR 200 (=300*(2/3)) at a price of EUR 105, and EUR 400 at a price of EUR 110. In a discriminatory auction the bidders pay what they bid. A pays 400*105 = EUR 42,000 and B pays 400*110 + 200*105 = EUR 65,000. If we assumed a uniform auction, winning bidders would have to pay the stop-out price. So A would pay EUR 42,000 and B EUR 63,000. Note, however, that bidders take into account whether it is a discriminatory or a uniform auction when they submit their bids. So they will bid differently in uniform auctions than in discriminatory auctions.*

*Now suppose the Treasury issues a new bond via a yield tender. In this case bidders submit bids consisting of a quantity of bonds demanded in terms of face value and a coupon rate, i.e. par yield. Assume the bond matures in two years and pays one coupon per year. The actual coupon rate will equal the quantity-weighted average winning yield. The Treasury sells EUR 1,000 of face value. Suppose bidder A submits the following bids: EUR 600 at a yield of 5% and EUR 400 at a yield of 10%. Bidder B's bids are EUR 400 at a yield of 4%, EUR 300 at a yield of 5%, and EUR 400 at a yield of 6%. Clearly, the Treasury prefers a lower par yield. So the bids are ranked ascending. The stop-out price is 5%. A wins EUR 400 at a yield of 5%, B wins EUR 400 at a yield of 4% and EUR 200 at a yield of 5%. The coupon rate of the bond issue equals the weighted average winning yield of 4.6%. This translates into a price of EUR 101.13 per EUR 100 of face value at a yield of 4% and EUR 99.26 at a yield of 5%. A has to pay EUR 39,702.49 (=400*99.26) and B has to pay EUR 60,303.91 (=400*101.13+200*99.26).*

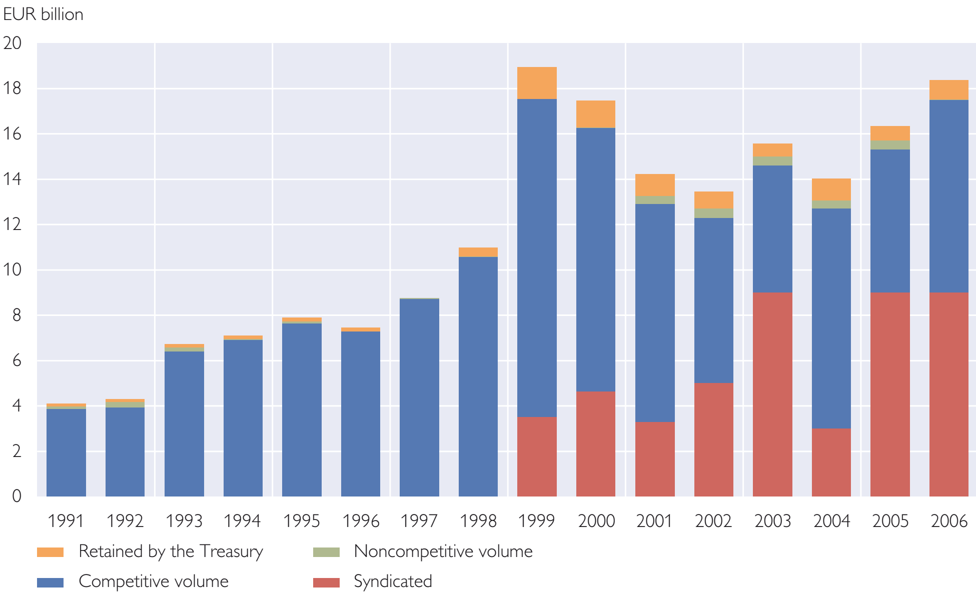
Competitive bids consist of an integer multiple of EUR 100,000 of face value and – depending on whether the method used is a yield tender or a price auction – the yield or price at which the bidder is willing to buy the quantity of bonds in question. Bidders may submit multiple bids and usually do so. The average number of bids per bidder in Austrian Treasury auctions is 5 (median: 4) and the maximum number is as high as 27. The minimum demand for each participating bank is equal to the total face value issued divided by the number of participants. This lower limit can always be met by submitting sufficiently low-price (high-yield) bids. If the total amount issued is above EUR 1 billion, bidders are not allowed to bid for more than 30% of the total amount issued. This limit seems to be binding as at least one bidder demands 30% of the issue in almost every auction in which the total amount issued is above EUR 1 billion.[7] In smaller auctions (below EUR 1 billion) the maximum demanded and, more importantly, the maximum awarded fraction of the issued bonds is in general above 30%. The submitted bids are ranked according to yield (ascending) or price (descending) until supply equals demand at the stop-out price. For each winning bid the bidder pays what he bid. Proportional rationing at the highest winning yield or the lowest winning price is possible.

Noncompetitive bids are quantity bids at a price that is equal to the quantity-weighted average of the winning competitive bids. The participating banks have the right, but not the obligation, to submit noncompetitive bids at every auction. The quantity of bonds that bidders might demand depends on the weighted average of the competitive awards of the two preceding auctions.

Chart 3 shows the volumes in terms of face value issued per year. Even though there are only a few new issues per year, they account for a significant fraction (approximately 50% in 2006) of the overall issued amount of bonds. The issued face values of the individual auctions and the ratio of quantity demanded to quantity supplied are displayed in chart 4. The issued amounts per auction proved quite stable up to 1997 and became rather volatile thereafter. The ratio of quantity demanded to quantity supplied decreases with the size of the auction. It hit its minimum of 1.22 in 2000 when the amount issued reached a historical maximum of EUR 2.5 billion. The maximum value was 6.5 when the amount issued was as low as

Chart 3

Austrian Treasury Bond Issues per Year

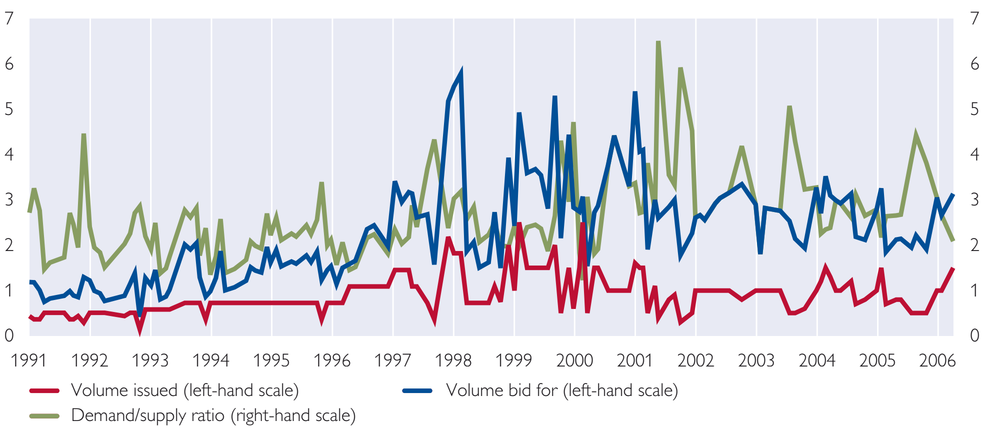


Source: OeKB.

[7] *Bidding for 30% of the issued amount does not necessarily imply that the bidder has such a high demand at a reasonable price as the entire demand could be at very low prices. In the present dataset we find that the total demanded quantity is not related to the "seriousness" of the bids. There is no connection between the demanded quantity and the ratio of awarded quantity to demanded quantity.*

Chart 4

Issued Volume per Auction



Source: OeKB.

EUR 0.4 billion. The average demand/supply ratio is 2.63, with a standard deviation of 0.89.

The total number of bids in our sample is 12,850, averaging 93.8 bids per auction. The average spread between the highest and the lowest bids for yield tenders (price auctions) is 23 basis points (58 cent per EUR 100 of face value) and the average spread between the highest bid and the stop-out price is 4.5 basis points (9.2 cent). The ratio between these two spreads lies between 10% and 40%, with a mean value of 20%. The fact that the stop-out price is much closer to the highest bid than to the lowest suggests that some bids are rather low to meet the above-mentioned minimum quantity requirement.

The approved bidders are heterogeneous in terms of total assets. We therefore expect and find that there is a lot of variation in the demanded quantities (similarly to Hortaçsu, 2002). The award concentration in Austrian Treasury bond auctions is high. The four bidders with the highest allotments in an auction purchase, on average, 65% of the issue (minimum 40%, maximum 100%). The ten highest bids are on average awarded 22% of the total volume of bonds.

3 Theoretical Considerations and Empirical Specification of Bidder Behavior

Bidders in Treasury auctions submit price/quantity pairs. Other strategic instruments that are available to bidders are the number of submitted bids and the dispersion of their bids. How bidders use these instruments will depend on the value of the respective bond and on whether there is a resale market for this bond, on the number of bidders that participate in the auction and on the size of the auction. In this section, we outline the implications of auction theory on bidders' behavior and describe the related empirical models. We analyze bidders' behavior in the Austrian Treasury market by separately investigating bid shading, i.e. the difference between the value of the bond and the submitted bid in the auction, the quantities of bonds demanded by bidders and the intra-bidder dispersion of bids. For the definition of the variables and the regression equations used in our analysis, we follow the approaches suggested by Nyborg et al. (2002) and Hortaçsu (2002).

If we consider auctions as strategic games, the players' bidding behavior is our main concern as it will determine the price that will be attained in the auction and thus the seller's expected revenue. There are various possibilities of viewing Treasury auctions as games. First, we may see them as appropriately summarized by a single-unit auction. In this case we ignore the fact that bidders submit entire demand schedules consisting of multiple price/quantity pairs instead of single bids. Despite this simplification, considerations based on theoretical auction literature will provide us with certain insights. The other possibilities are to view Treasury auctions as multi-unit auctions or as share auctions. The main difference between these two types is that the latter assumes that the units for sale are perfectly divisible.

The auction literature further distinguishes between independent private and common value auctions. The value of the unit for sale is thought to be of a private nature to the bidder if he knows the exact value the unit offered for sale has to him. If this is not the case or if there is the possibility of resale, a unit for sale is thought to have a common value.[8] As there is a secondary market for bonds, Treasury auctions are usually considered as common value auctions. One exception is Hortaçsu (2002, 2006), who argues that the main aim of banks which participate in Turkish Treasury auctions is to fulfill their reserve requirements.

The final determinants in an auction are the allocation of the units for sale and the payment mechanism. The allocation is always such that the highest bidder(s) obtain(s) the unit(s) for sale, whereas the payment mechanism differs depending on the type of auction. In sealed single-unit auctions, we distinguish between first-price and second-price auctions.[9] The corresponding types in multi-unit or share auctions are discriminatory or uniform auctions.[10] First-price and discriminatory auctions are characterized by a pay-as-bid principle. In first-price auctions, the winning bidder pays the amount he submitted as a bid and in discriminatory auctions the highest bidders pay the price they submitted as bids. In second-price auctions, the highest bidders only pay the bid of the second highest bidder, and in uniform-price auctions the highest bidders pay the highest losing bid. As a consequence, bidders adapt their strategic bidding behavior to the different payment mechanisms.

3.1 Theoretical Considerations for Treasury Auctions

We first lay out the strategic behavior of bidders in a single-unit first-price auction with independent private values. We then proceed to a single-unit first-price auction with a common value and finally, we discuss discriminatory multi-unit and share auctions.

Assume a single indivisible good is for sale to one of I risk-neutral bid-

[8] *For mixtures of these two extremes see Milgrom and Weber (1982).*

[9] *Other single-unit auctions are the ascending (or English) auction and the descending (or Dutch) auction. See e.g. Krishna (2002).*

[10] *Other types are the Vickrey auction and the Ausubel auction. See for example, Krishna (2002).*

ders. Each of the bidders knows the private value he assigns to the relevant good, but he does not know anything about the values assigned by the other bidders. Let v_i be bidder i's valuation of the good. These valuations v_i are modeled as independent draws from a continuous probability distribution. Bidders are assumed to behave competitively and not to collude. These assumptions allow us to treat auctions as a noncooperative game. A strategy for bidder i is a function mapping his valuation v_i into a bid $b_i \geq 0$. Bidder i wins the auction if his bid exceeds the bids of all other bidders. The price he has to pay is his bid. The decision problem bidder i faces is to choose, conditional on his valuation, a bid b_i that maximizes the expected value minus the price. It can be shown that the equilibrium strategy is a function of the bidder's own valuation, the number of participating bidders and the distribution of valuations, F.[11] The optimal bidding behavior is to shade one's own bid as a function of the number of participating bidders I. It can be shown that bid shading, i.e. the difference between the value bidder i assigns to the good and his bid, $\delta_i = v_i - b_i$, decreases with the number of bidders.

Let us now consider the common value model. The object to be sold has an unknown common value of v. Each of the I risk-neutral bidders receives a signal s_i with a mean of v and a standard deviation of η_s. These signals are modeled as independent draws from a continuous probability distribution. Based on these signals, bidders have different estimates of the good's post-auction price. The winning bidder realizes that he is the bidder who made the highest estimate of the object's value. Winning the auction implies that he most likely overvaluated the object's price. This phenomenon is called the winner's curse. Rational bidders optimally shade their bids to account not only for competition in the auction itself, but also for the winner's curse, where the variance η_s of the received signal determines the degree of bid shading. We expect that higher uncertainty, i.e. a larger η_s, leads to higher bid shading. If we now define bid shading as the difference of the common value v and bidder i's bid, i.e. $\delta_i = v - b_i$, it is, via the submitted bid, a function of uncertainty η_s and the number of bidders I.

If there is more than one unit for sale and bidders additionally demand more than one unit, Ausubel (2004) demonstrates that in a common value model the winner's curse might be even more pronounced than in a single-unit auction.[12] The more units a bidder wins, the worse he is off. Ausubel refers to this phenomenon as the "champion's plague." Rational bidders adjust for champion's plague by reducing their demand for any given price. Thus, we expect higher uncertainty to be followed by more bid shading (δ_i), by higher intra-bidder dispersion (σ_i) and lower quantity demanded (y_i). Nyborg et al. (2002) further argue that when bidders are capacity-constrained, bid shading might also be a function of the auction size Q, i.e. the number of units for sale. They provide similar argu-

[11] See e.g. Milgrom and Weber (1982) or Krishna (2002).

[12] There is a difference between multi-unit auctions at which bidders demand one unit and multi-unit auctions at which bidders demand more than one unit. Milgrom and Weber (2000) describe the optimal bidding behavior for the first type of auctions.

mentation for intra-bidder dispersion and the quantity demanded by bidders.

Another model of a multi-unit auction is the share auction model described by Wilson (1979). In this model, there are Q units of a perfectly divisible good for sale. Risk-neutral bidders are assumed to submit downward sloping demand schedules, i.e. bid functions, and the market clearing price will be at the point where bidder i's demand curve intersects his "residual supply curve," i.e. total supply minus the demand of all other bidders as a function of the price. Wilson (1979) assumes the common value model and shows that under specific distributional assumptions a seller might experience a reduction in revenue compared to a single-unit auction. Back and Zender (1993) demonstrate that, when bidders' marginal value v for the auctioned good is constant across bidders and when this value is perfectly known, all bidders pay the same price and make no profits. Wang and Zender (1998) additionally incorporate risk aversion and uncertainty about total supply and the value of the auctioned good into the bidding environment. Bidders, however, are still assumed to have no private information on the value of the auctioned good. Hortaçsu (2002) derives the predictions of the above model for bid shading, $\delta_i = v - b_i$. Bid shading increases as the uncertainty in the value of the good, η_v, increases and decreases with the number of bidders I. Hortaçsu (2002) further describes the predictions for a model where bidders have access to private information on the value of the auctioned good. He shows that bid shading, $\delta_i = v_i - b_i$, increases with the precision of bidders' valuations η_v and that, under certain conditions, it also increases with the number of bidders, I. He further shows that the slope of the bid function is independent of the uncertainty η_v and decreases with the number of bidders I.

3.2 Empirical Implementation of the Models

Theoretical argumentation suggests that bid shading is a function of uncertainty, auction size and/or the number of bidders. The same is true for intra-bidder dispersion, the quantities demanded by bidders and bidders' profits. To test the theoretical predictions, we set up regression equations like Nyborg et al. (2002) or Hortaçsu (2002) and estimate various specifications with data from Austrian Treasury auctions. For the estimations we have to construct variables that measure bid shading, the intra-bidder dispersion of bids and uncertainty. We use different measures, thereby following Nyborg et al. (2002) and Hortaçsu (2002). The descriptive statistics of these measures are given in table 1.

Nyborg et al. (2002) measure bid shading using a bidder-specific discount and an average discount. The first measure is equal to

(1) $\delta^{NRS}_{il} = p_l - p_{il}$

where p_l is the post-auction price and p_{il} is the quantity-weighted average bid of bidder i in auction l, with $i=1,\ldots, I_l$, and $l=1,\ldots, L$. The second measure is the mean of (1) and is equal to

(2) $\delta^{NRS}_{l} = E_i\,[\delta^{NRS}_{il}]_l$

where E_i denotes the mean with respect to $i=1,\ldots, I_l$. Nyborg et al. (2002) measure uncertainty, i.e. η^{NRS}_{l}, as the auction day volatility of bond returns using an ARCH(2) process. Their basic regression equation uses bid shading δ^{NRS}_{il} as the dependent variable, and uncertainty η^{NRS}_{l} and the

Table 1

Descriptive Statistics

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
NRS measure for bid shading $\delta^{NRS} \times 10^{-2}$	995	−0.04	0.43	−1.56	1.15
Hortaçsu measure for bid shading δ^{H}	754	−0.14	0.42	−1.80	0.83
NRS measure for uncertainty $\eta^{NRS} \times 10^{-6}$	1,848	0.98	0.79	0.18	4.08
Hortaçsu measure for uncertainty η^{H}	1,848	0.01	0.05	0.04	0.22
Auction size	1,848	0.93	0.33	0.30	1.60
Number of bidders	1,848	22.61	1.01	20.00	25.00
Dispersion of bids	922	0.05	0.05	0.00	0.65
Quantity demanded by bidders	995	0.12	0.01	0.02	0.70
Profits	519	−0.18	0.43	−1.62	0.64
Slope	754	−2.33	3.01	−23.79	−0.08

Source: Authors' calculations based on OeKB data.

Note: Table 1 presents the descriptive statistics of the variables used in the regression equations. The NRS (= Nyborg et al., 2002) measure for bid shading δ^{NRS} is the discount defined in equation (1). The Hortaçsu (2002) measure for bid shading δ^{H} is defined in equation (8). The NRS measure for uncertainty η^{NRS} is defined as the auction day volatility of bond returns using an ARCH(2) process. The Hortaçsu measure for uncertainty η^{H} is defined by the standard deviation of inventory requirements and by the dispersion of the intercepts of bidders' linearized demand schedules, i.e. $\eta^{H}_{l} = SD_i\,[\alpha_{il}]_l$, where SD_i is the standard deviation with respect to $i = 1,\ldots, I_l$.

auction size Q_l as the independent variables:

$$(3)\ \delta^{NRS}_{il} = \gamma_0 + \gamma_1 \eta^{NRS}_{l} + \gamma_2 Q_l + \omega_{il}$$

where ω_{il} is an error term. We expect a positive sign for γ_1. A higher uncertainty should translate into higher bid shading. Nyborg et al. (2002) use auction size to control for the impact of the behavior of capacity-constrained bidders. The relative amount these bidders can demand is obviously smaller in larger auctions. A larger auction size might induce these bidders to bid more cautiously and thus to shade their bids more. If there are no capacity constraints, we expect no effect of the auction size on bid shading because both the price bidders submit in the auction as well as the post-auction price should decrease. We extend this specification to account for the effect of competition as follows

$$(4)\ \delta^{NRS}_{il} = \gamma_0 + \gamma_1 \eta^{NRS}_{l} + \gamma_2 Q_l + \gamma_3 I_l + \omega_{il}$$

where I_l is the number of bidders and ω_{il} is an error term. In a private value setting, we would expect γ_3 to be negative. The larger the number of bidders, the lower the degree of bid shading. In a common value setting, the effect of increased competition is ambiguous Hortaçsu (2002).

To assess the impact of uncertainty on the intra-bidder dispersion of bids, the quantity demanded by bidders and on the profits and measures for award concentration, Nyborg et al. (2002) define further dependent variables and estimate models analogous to (3). We do the same but use equation (4) instead. The intra-bidder dispersion of bids is defined as the quantity-weighted standard deviation of bidder i's bids in auction l:

$$(5)\ \sigma_{il} = SD_j\,[p_{ijl}\, q_{ijl} / q_{il}\,]_{il}$$

where p_{ijl} and q_{ijl} are the j^{th} bid of bidder i in auction l, $j = 1,\ldots,J_{il}$, and J_{il} is the number of bids bidder i submits in auction l. q_{il} is equal to the total demand. SD_j denotes the standard deviation with respect to $j = 1,\ldots,J_{il}$. Bidders react to an increase in uncertainty with more dispersed bids. Auction size is expected to have a positive impact on intra-bidder dispersion, and the number of bidders is expected to have a negative impact. The quantity demanded by bidder i in auction l as a fraction of auction size is equal to

(6) $y_{il} = q_{il} / Q_l$

where Q_l is the size of auction l. Bidders demand lower quantities when there is an increase in uncertainty (Nyborg, 2002). Auction size is expected to have a positive impact on the quantity demanded by bidders, and the number of bidders is expected to have a negative impact. A measure of revenue is the profit per unit sold, which we define as the post-auction price minus the quantity-weighted winning bid:

(7) $\Pi_{il} = p_l - E_j \,[\, p_{wijl}\, q_{wijl} / q_{wil}]$

where the subscript w denotes winning prices and winning quantities, and where q_{wil} is equal to the total awarded demand of bidder i in auction l. Finally, we define bid-specific and bidder-specific award concentration as the fraction of awards captured by the five highest individual bids and by the five largest firms and denote them with BAC_l and FAC_l. We use each of these variables as a dependent variable in equation (4).

Hortaçsu (2002) tests theoretical predictions with different measures for bid shading and uncertainty. His definition of bid shading is based on the consideration that bidders' demand schedules can be described by a linear function. He defines bid shading as follows

(8) $\delta^H{}_l = p_l - E_i\,[\alpha_{il}]_l$

where $E_i\,[\alpha_{il}]_l$ is the mean of the intercepts α_{il} of the bidder-specific demand schedules in auction l. To obtain the intercepts α_{il}, we regress for each bidder i and each auction l the bid-specific price p_{ijl} on the bidder-specific aggregated quantity a_{ijl}:

(9) $p_{ijl} = \alpha_{il} + \beta_{il}\, a_{ijl} + \varepsilon_{ijl}$

where α_{il} and β_{il} are the bidder-specific coefficients to be estimated, ε_{ijl} is an error term and j denotes the bids bidder i submits in auction l with ($j = 1,..., J_{il}$). Hortaçsu (2002) measures uncertainty by the standard deviation of the bidders' reserve requirements and by the dispersion of the intercepts of bidders' linearized demand schedules, i.e. $\eta^H{}_l = SD_i\,[\alpha_{il}]_l$, where SD_i is the standard deviation with respect to $i = 1,..., I_l$. We assume that banks' reserve requirements are constant over time. Therefore, we use only the volatility of the intercepts as an uncertainty measure. To test the predictions of Wang and Zender (1998), Hortaçsu (2002) uses bid shading $\delta^H{}_{il}$ as the dependent variable and uncertainty $\eta^H{}_l$ and the number of bidders I_l as the independent variables:

(10) $\delta^H{}_{il} = \gamma_0 + \gamma_1\, \eta^H{}_l + \gamma_2\, I_l + \upsilon_{il}$

where ω_{il} is an error term. Wang and Zender (1998) expect bid shading to increase with uncertainty, i.e. ($\gamma_1 > 0$), and decrease with the number of bidders, i.e. ($\gamma_2 < 0$). We extend this specification to account for the effect of the auction size and also to make it comparable to (4) as follows:

(11) $\delta^H{}_{il} = \gamma_0 + \gamma_1\, \eta^H{}_l + \gamma_2\, I_l + \gamma_3\, Q_l + \upsilon_{il}$

where υ_{il} is an error term.

Hortaçsu (2002) further argues that the slopes of the bidder-specific demand schedules are a log-linear function of uncertainty and the number of bidders. To test these predictions, he uses the logarithm of the absolute value of the bidder-specific slopes as the dependent variable and a measure for uncertainty and the number of bidders as the independent variables:

(12) $log[|\beta_{il}|] = \gamma_0 + \gamma_1\, \eta^H{}_l + \gamma_2\, I_l + \mu_{il}$

where μ_{il} is an error term. According to the predictions of Hortaçsu (2002), we expect γ_1 to be insignificant and γ_2 to be positive.

4 Estimation Results

This section presents the results obtained from the above estimations.

Tabelle 2

Estimation Results with Bidder-Specific Bid Shading as Dependent Variable

	(1)	(2)	(3)	(4)
Constant	0.0014	−0.0190	−0.1738	−0.3509
	(3.03)**	(5.94)***	(0.84)	(1.69)
NRS measure for uncertainty	0.2638	0.4012		
	(3.85)***	(5.70)***		
Hortaçsu measure for uncertainty			0.7133	0.3061
			(3.36)***	(1.34)
Auction size	−0.0026	−0.0032		−0.1362
	(6.33)***	(7.82)***		(4.45)***
Number of bidders		0.0009	0.0023	0.0175
		(6.44)***	(0.25)	(1.80)
Bidder-specific fixed effects	yes	yes	yes	yes
	(2.30)***	(2.24)***	(2.28)***	(2.67)***
Number of observations	995	995	707	707
R-squared	0.0640	0.1027	0.0171	0.0453

Source: Authors' calculations based on OeKB data.

Note: Table 2 presents the estimation results obtained with bidder-specific bid shading as the dependent variable. Column 1 presents the basic specification of NRS (= Nyborg et al., 2002) with uncertainty and auction size as the independent variables; column 2 extends the specification presented in column 1 by the number of bidders. Column 3 presents the basic specification of Hortaçsu (2002) with uncertainty and the number of bidders as the independent variables; column 4 extends the specification presented in column 3 by auction size. All specifications are estimated with bidder-specific fixed effects. Absolute values of t-statistics are shown in parentheses below the parameter estimates. For the bidder-specific fixed effects, the values of the F-statistics are shown.

We estimate equations (3), (4), (10) and (11) with ordinary least squares and, when appropriate, with bidder-specific fixed effects. We run additional regressions with intra-bidder dispersion, the quantities demanded by bidders and the profits and measures for award concentration as the dependent variable, respectively. Finally, we test the predictions for the slopes of the bidder-specific demand schedules. As reliable secondary market prices for the first part of our sample are lacking, we use a subsample of price auctions (44 auctions from February 2001 to May 2006) for our estimations.

Table 2 and table 3 present the estimation results for bid shading. Table 2 includes the estimation results when we use bidder-specific bid shading as the dependent variable. Each of the regressions in this table is estimated with bidder-specific fixed effects.[13] We find that most of the coefficients have the expected sign and are significant. We also find that the bidder-specific fixed effects are significant. The explanatory power of the regressions is low. R-squared lies between 1.7 and 10.3% and is roughly in line with Nyborg et al. (2002).

As expected, uncertainty has a positive effect on bid shading. A 1% increase in price volatility results in an increase in the above defined discount measure by 0.26% of the face value (column 1). Auction size is included to control for capacity-constrained bidders. We obtain a negative estimated coefficient for auction size, which means that bidders shade their bids to a lesser extent when a larger quantity is offered. The economic effect of the auction size is small, however. A EUR 1 billion increase in auction size reduces the discount by 0.0026%. This result indi-

[13] *We do not report the results obtained from estimations without bidder-specific fixed effects as there are no differences to the results obtained when using specifications including bidder-specific fixed effects.*

Table 3

Estimation Results with Average Bid Shading as Dependent Variable

	(1)	(2)	(3)	(4)
Constant	0.0014	−0.0204	−0.2531	−0.4680
	(0.62)	(1.32)	(0.31)	(0.56)
NRS measure for uncertainty	0.2334	0.3822		
	(0.71)	(1.12)		
Hortaçsu measure for uncertainty			0.5290	0.0995
			(0.65)	(0.11)
Auction size	−0.0025	−0.0032		−0.1439
	(1.28)	(1.61)		(1.15)
Number of bidders		0.0010	0.0067	0.0238
		(1.43)	(0.18)	(0.61)
Number of observations	44	44	41	41
R-squared	0.0585	0.1040	0.0127	0.0469

Source: Authors' calculations based on OeKB data.

Note: Table 3 presents the estimation results obtained with average bid shading as the dependent variable. Column 1 presents the basic specification of NRS (= Nyborg et al., 2002) with uncertainty and auction size as the independent variables; column 2 extends the specification presented in column 1 by the number of bidders. Column 3 presents the basic specification of Hortaçsu (2002) with uncertainty and the number of bidders as the independent variables; column 4 extends the specification presented in column 3 by auction size. Absolute values of t-statistics are shown in parentheses below the parameter estimates.

cates that the aggregate demand function is highly elastic.

When we add the number of bidders to the regression equation, the estimated coefficients of uncertainty and of auction size change only slightly and remain significant (table 2, column 2). The estimated coefficient of the number of bidders, however, does not have the expected sign. It is positive, i.e. the more bidders participate in an auction, the higher the bid shading will be. As previously argued, theoretical considerations predict the contrary.

The results obtained when using the definitions by Hortaçsu (2002) are poorer than those obtained when using the definitions by Nyborg et al. (2002). The estimated coefficients – presented in columns 3 and 4 (table 2) – show larger standard errors and a lower explained variance. Nevertheless, the estimated coefficients of uncertainty, auction size and the number of bidders are in line with the specifications presented in columns 1 and 2 (table 2). We observe positive coefficients for uncertainty and the number of bidders and negative coefficients for auction size. Hortaçsu (2002) obtains similar results but also suggests adding a term for the interaction of the number of bidders and shortfall, i.e. the ratio of total supply to total demand, to the regression equation. If bidders have to meet reserve requirements, participation in an auction might depend on the shortfall. We test such a specification for our dataset and find no evidence for this claim.

Table 3 includes the estimation results obtained when we use average bid shading as the dependent variable. We estimate the same specifications as presented in table 2 and find the same results as before but as the number of observations is low, the significance of the estimated coefficients is poor. We also find that the explanatory power of our regressions is again rather low. We obtain R-squareds between 1.3% and 10.4%. As there are no qualitative differences between the estimated coefficients of the chosen specification and the specification in which we use bidder-specific bid

Table 4

Further Estimation Results

Dependent variable	(1) Dispersion	(2) Quantities	(3) Profits	(4) Award concentration	(5) Slopes
Constant	−0.0691	0.0588	−2.1936	0.1643	0.3255
	(1.94)	(1.01)	(4.84)***	(0.77)	(0.50)
Nyborg measure for uncertainty	2.4357	−1.0037	41.3303	13.9587	
	(3.11)**	(0.78)	(4.17)***	(2.95)**	
Hortaçsu measure for uncertainty					5.2474
					(8.37)***
Auction size	−0.0070	0.0670	−0.2361	−0.0990	
	(1.55)	(9.03)***	(3.82)***	(3.55)***	
Number of bidders	0.0051	0.0001	0.0950	0.0017	−0.0262
	(3.23)**	(0.04)		(0.18)***	(0.92)
Bidder-specific fixed effects	yes	yes	yes	no	yes
	(5.39)***	(22.57)***	(0.98)		(25.88)***
Number of observations	922	995	519	44	754
R-squared	0.0187	0.0883	0.0765	0.3613	0.0886

Source: Authors' calculations based on OeKB data.

Note: Table 4 presents the estimation results obtained when using intra-bidder dispersion, the quantity demanded by bidders, profits and the logarithm of the absolute value of the slopes of the bidder-specific demand schedules as the dependent variables. Columns 1 to 3 present the extended specification introduced in NRS (= Nyborg et al., 2002) with uncertainty, auction size and the number of bidders as the dependent variables. Column 4 presents the specification of Hortaçsu (2002) with uncertainty and the number of bidders as the independent variables. Absolute values of t-statistics are shown in parentheses below the parameter estimates. For the bidder-specific fixed effects, the values of the F-statistics are shown.

shading as the dependent variable, we do not comment on these results any further.

Table 4 presents further estimation results using intra-bidder dispersion, the quantity demanded, profits, a measure for award concentration and the logarithm of the absolute value of the slopes of bidder-specific demand schedules as the dependent variable. As before, the explanatory power of these results lies within the range of 2% to 9%. Only the explanatory power of the regression for award concentration is rather high with an R-squared of 34%.

According to the theoretical predictions discussed in section 3, an increase in uncertainty goes along with an increase in the dispersion of bids (table 4, column 1). A larger auction size entails a lower dispersion, and a larger number of bidders leads to a broader dispersion. Although insignificant, an increase in uncertainty implies an increase in the quantity demanded by bidders (table 4, column 2). Auction size and the number of bidders have a positive effect on the quantities demanded. The results we report in column 2 are obtained using absolute quantities demanded by bidders as the dependent variable. When we use the relative quantity demanded by bidders, we observe similar results – with the only difference that the coefficient of auction size is then negative. Hence, absolute demand increases less strongly than auction size, which means that relative demand decreases. Profits are positively influenced by uncertainty and the number of bidders and negatively influenced by auction size (table 4, column 3). These results reflect the results we obtain for bid shading (column 1 in table 2). Award concentration increases with uncertainty (table 4, column 4). This might indicate that bidders' strategic reactions to uncertainty vary. When uncertainty is high, some bidders may bid more cautiously than other bidders. The bidders who do not react in such a pronounced manner are most likely larger banks. A second observation is that award concentration decreases with auction size. The number of bidders has no significant effect on award concentration. The results for the slopes of the bidder-specific demand schedules are displayed in column 5 (table 4). We obtain a positive and significant effect of uncertainty and no effect of the number of bidders in contrast to the predictions of Hortaçsu (2002) but in line with his estimation results.

5 Summary and Concluding Remarks

In this study, we analyze the bidding behavior in Austrian Treasury bond auctions, which are discriminatory auctions that are characterized by a pay-as-bid principle. The winning bidders pay the amount they submitted as bids. Auction theory predicts that rational bidders shade their bids and that the amount of bid shading varies with the uncertainty that exists in the bond market, the number of participating bidders and the volume of bond issues. Beyond bid shading, bidders in bond auctions have additional means to react to market conditions, such as adjusting the total quantity demanded and the dispersion of their bids. We investigate how bidders in Austrian Treasury auctions adjust their strategies to the varying uncertainty in the bond market, to the different number of participating bidders and to changes in the volume of bond issues. Our dataset contains all bids submitted by each bidder as well as the awards won in 137 Austrian Treasury auctions from February 1991 to May 2006. For technical reasons, we have to restrict the sample to the 44 price auctions from February 2001 to May 2006 in our estimations.

The estimation results are in line with those presented in Nyborg et al. (2002) and Hortaçsu (2002). We find that the main driving force behind bid shading, intra-bidder dispersion, profits, and award concentration is uncertainty in the bond market. Only the quantity demanded does not react to bond market uncertainties. The fact that award concentration increases with uncertainty, in particular, indicates that asymmetries across bidders play an important role analyzing the strategic behavior of bidders. A future research task would therefore be to consider asymmetric auction models. Other variables that we investigated in the present study are auction size and the number of bidders. The effects of these two variables are very often significant, but do not always carry the expected sign. Auction size has a negative effect on bid shading, on intra-bidder dispersion, on the relative quantity demanded by bidders and on profits and award concentration and a positive effect on the absolute quantity demanded by bidders. Unexpectedly, the number of bidders has a positive effect on all strategic variables available for bidders.

For our regressions, we use different measures for bid shading and uncertainty. The results obtained when using the definitions by Hortaçsu (2002) are similar but qualitatively poorer than those obtained when using the definitions by Nyborg et al. (2002). A possible reason for this phenomenon might be that some of the assumptions put forward in Hortaçsu (2002) may not be applicable to Austrian Treasury auctions. We are therefore inclined to interpret the better results we obtain for the chosen specifications – in line with Nyborg et al. (2002) – as evidence for winner's curse and champion's plague, respectively.

The explanatory power of the proposed regressions is low, but this is again in line with Nyborg et al. (2002) and Hortaçsu (2002). Overall, our results indicate that the common value aspect seems to be prevalent in Austrian Treasury auctions and that asymmetries across bidders should not be neglected when analyzing Treasury auctions. To further decompose bid shading into an effect caused by uncertainties in the bond market and an effect that depends on the respective auction mechanism, a structural bidding model would have to be estimated, which remains a task for future research.

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