Competition in Treasury Auctions*

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Abstract

We investigate the role of competition on the outcome of Austrian Treasury auctions. Austria's EU accession led to an increase in the number of banks participating in treasury auctions. We use structural estimates of bidders' private values to examine the effect of increased competition on auction performance. We find robust evidence that bidders' surplus dropped sharply after EU accession, but less than reduced form estimates would suggest. The difference can be explained by reduced form estimates not taking into account the increase in valuations upon EU accession.

JEL Classifications: D44, G12, G21, L10, L13

Keywords: treasury auctions, multi-unit auctions, independent private values, competition, bidder surplus, auction format

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1 Introduction

To issue treasury securities by auctions is a common method to raise money for government expenditures in many countries over the world. The auction mechanisms used vary across countries. In this study, we analyze the bidding behavior in Austrian Treasury bond auctions, using data containing all bids submitted by each bidder between February 1991 and May 2008.

The empirical literature on security auctions has focused on the question of the appropriate auction design (uniform versus discriminatory, see Fevrier et al. (2004), Hortaçsu and McAdams (2010), Kastl (2011)) and the informational environment (independent private versus affiliated/common values, see Hortaçsu and Kastl (2012)). While our modeling and estimation approach closely follows the aforementioned papers, this paper asks a different question.[1] We examine to what extent the increased competition resulting from EU accession affected auction performance.

Before Austria's EU accession, only Austrian banks were allowed to participate in Austrian Treasury auctions. EU accession in 1995 led to an increase in the number of banks participating in the bidding process. While on average 13 bidders participated in Austrian Treasury auctions before 1995, this number increased to almost 25 between 1997 and 2008. By employing the resampling techniques suggested in Hortaçsu and McAdams (2010) and Kastl (2011), we obtain estimates of bidders' valuations of the auctioned bonds for the periods before and after EU accession respectively. Based on these estimates, we examine the surplus obtained by bidders in the two different time periods. We focus on estimates of the surplus, because it provides a measure of how much additional interest the government has to pay due to private information and imperfect competition. We find that the Austrian government benefited from increased competition in the bidding process for its debt issues. The surplus left to bidding banks was reduced by about 3.5 basis points or eighty percent (corresponding to 1.1 million Euro per auction).

We also compare the structural estimates with results from difference-in-difference estimates that treat EU accession as a quasi-experiment using German bond yields as a control group. The difference-in-difference estimates find a much larger effect suggesting that EU accession lead to a 50 basis point reduction in yields. We provide an explanation for the discrepancy of results, by comparing our structural estimates of bidders' valuations relative to German yields before and after EU accession. This comparison establishes that a large fraction of the estimated reduced form effect is due to a change in valuations: Valuations increased relative to German yields by around 40

[1] For a survey on this literature with an emphasis on recent advances in empirical analysis of financial markets, see Kastl (2016).

basis points after EU accession. We discuss the reasons why Austrian bonds become more valuable after EU accession.

We then examine whether the decline in surplus could be accounted for by solely increasing bidder numbers without changing bidding behavior. We find that this effect can only account for half of the reduction in surplus, and conclude that more aggressive bidding due to the stronger competition also played a significant role. Finally, we use our estimates to perform counterfactuals along the lines of Hortaçsu and McAdams (2010) to illustrate the effect of changing the format to a hypothetical uniform auction. We show that this alternative format would have increased government revenue before EU accession. With increased competition, the choice of auction format plays a much smaller role, both in terms of revenue as well as allocative efficiency, but from a government's perspective the discriminatory auction would be slightly better.

How the number of competitors affects the level of competition and market outcomes more broadly is a long standing question. See for instance Weiss (1989)'s review of the effect of the number of firms on market price. The question is reflected in Selten (1973)'s finding that "four are few and six are many" referring to the number of firms that separates a small group of firms from a large one. This has been followed by a series of laboratory experiments (e.g. Huck et al. (2004)), but only little research was done on non-experimental data where the number of potential competitors has changed exogenously. Closely related to our work is the analysis of entry into local markets by Bresnahan and Reiss (1991), who find that competitive conduct changes quickly as the number of incumbents increases with increasing market size. We contribute to this literature by comparing the outcome of treasury auctions in two different episodes with different bidder numbers.

The remainder of the paper is organized as follows. Section 2 describes the institutional environment of Austrian treasury auctions. We describe the data, give summary statistics, and provide descriptive evidence of the increased competition on the outcomes of Austrian treasury auctions. We also show results from difference-in-difference regressions. Section 3 presents the bidding model and estimation technique as well as estimation results. Section 4 presents our analysis of the effect of competition on bidder surplus, the auction format and efficiency. Section 5 concludes.

2 Austrian Treasury Auctions

Since 1991 Austrian Treasury bonds have been sold through sealed, multiple-bid, discriminatory yield tenders or price auctions. Treasury auctions are organized by the Oesterreichische Kontroll-

bank AG (OeKB). OeKB holds the auctions on behalf of the Austrian Treasury (Oesterreichische Bundesfinanzierungsagentur – OeBFA), the debt management office of the Republic of Austria. New bonds may be issued through yield tenders, price auctions or through a syndicate of banks. Whereas new issues prevailed in the 1990s, treasury policy now focuses on reopening existing instruments to enhance their liquidity. New securities are issued only occasionally (one or two issues per year) to close gaps in traded maturities. In the recent past these securities were issued through a syndicate of banks. In 2001, the OeBFA switched from using yield tenders to price auctions when reopening an existing instrument. Participation in these auctions is managed by the OeBFA. Banks meeting 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. Upon approval by the OeBFA, bidders not only may, but must submit competitive bids in every auction. Banks failing to submit bids faced consequences. For example, from 2001 onwards, banks not submitting bids were excluded from non-competitive allocation (see below).[2] The identity of currently approved banks is public information through the OeKB.

Treasury auctions are held approximately every six weeks. At the end of the calendar year, a preliminary schedule for the coming year is published. One week before each auction, the OeBFA announces the characteristics of the bond to be auctioned, i.e. maturity, planned issue size, and in the case of new issues, coupon size and date. Competitive bids must be submitted electronically between 10:00 a.m. and 11:00 a.m. on the auction day (usually a Tuesday). The issuer has the right to recall the auction until noon.

The bids must be submitted in denominations of currently one million Euro[3] or a multiple thereof containing the yield or the price at which the bidder is prepared to accept the nominal amount. Multiple bids are allowed. Bids may be modified and submitted up to the deadline as often as desired. The minimum total volume an approved bank is obligated to bid corresponds to the issue size announced by the issuer divided by the number of auction participants. The maximum volume a bank is allowed to bid amounts to 100% of the total issue size; in the case of an issue size of one billion Euro or above the upper limit for bids is 30% of the total issue size. Austrian Treasury auctions are discriminatory auctions, which means that winning bidders pay their bid on shares won. This is in contrast to the other prevalent format, uniform-price auctions in which all winning bidders pay the same price per unit. We will revisit the role of the auction

[2]Email conversation with Maria Kucera from the OeKB.

[3]This amount was adjusted over time. In the very beginning, bids had to be submitted in denominations of one million ATS.

format in Section 4.

The OeFBA makes an additional 15% of the competitive issue available for noncompetitive bids. 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 until 11:00 a.m. following the auction day. The quantity of bonds that bidders may demand depends on the weighted average of the competitive awards of the two preceding auctions. As illustrated in Elsinger and Zulehner (2007), noncompetitive bids play a small role with less than 2% of total issue size being allocated through noncompetitive bids. We will therefore abstract from the option of submitting noncompetitive bids in the structural model.[4]

2.1 Data

Our dataset was provided by the OeBFA and the OeKB, and contains all bids submitted by each bidder as well as the results in 153 Austrian Treasury auctions over the period from February 1991 to May 2008. For each auction, we know the bid schedule of each bidder and the winning allocation for each bidder. We also have information on volume and maturity of the bond. Since the OeBFA moved from yield tenders to price auctions in 2001, we converted bids observed after 2001 into annual yields using information on coupon size, coupon dates, and maturity.[5] We will estimate the marginal valuations in terms of yields, but for illustrative purposes, will use reverse axis scales.

We complement the auction data with secondary market yields obtained from Bloomberg. Due to the limited liquidity in the secondary market for Austrian bonds in the early period, information on secondary market yields was only available from the 15th auction (October 1992) onwards. To compare the results from the structural analysis with difference-in-difference estimates, we obtained German government bond yields from Bloomberg. We identified German bonds as close as possible to the Austrian bonds in terms of time to maturity. To capture the macroeconomic conditions, we also include the consumer price index and GDP growth for Austria and Germany from the OECD.

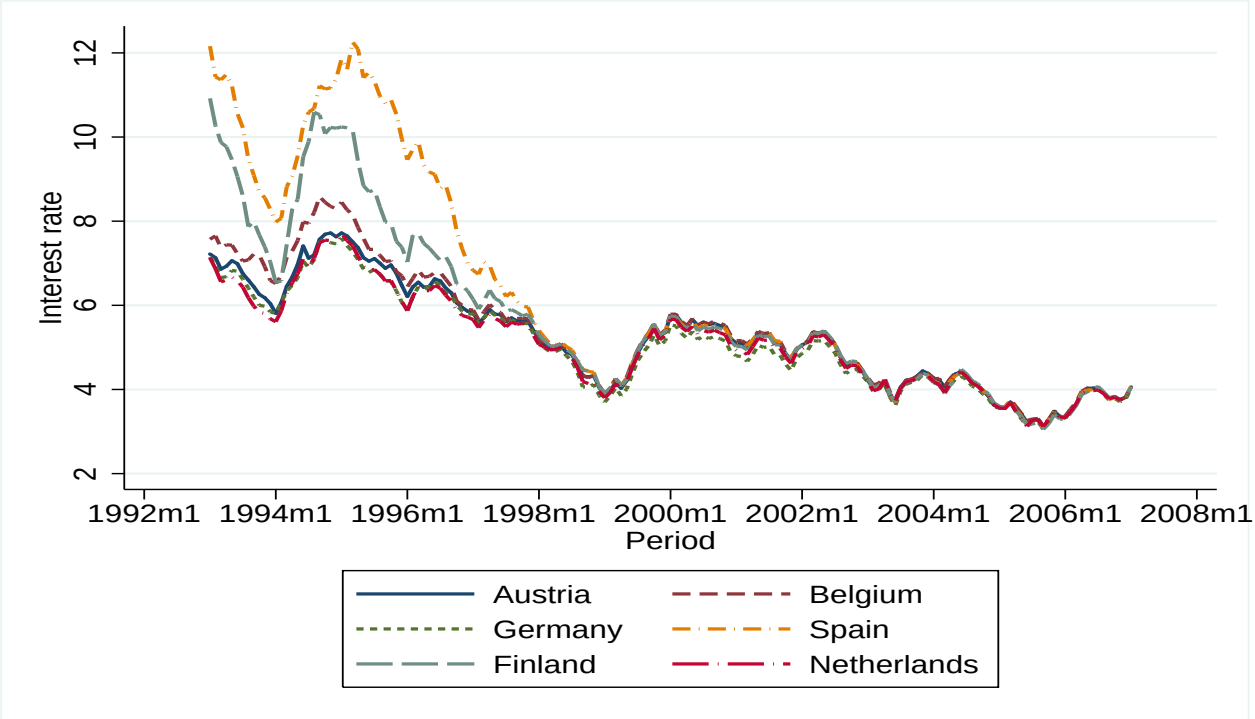
Our choice of German government bonds is based on the following consideration. As Figure 1 reveals the 10-year government bond interest rates move together for selected EU countries. This is of course particularly true for the period from the introduction of the Euro until August 2007 when the first signs of the financial markets crisis appeared. Before the introduction of the Euro

[4]Noncompetitive bids are common in Treasury auctions in several countries, although the exact rules regarding allocation and timing of submission of bids vary. While they do play a minor role in the eventual allocation, the option of purchasing at the average price may affect the bidding behavior and hence bias our results of valuations.

[5]The reverse is not possible, because with yield tenders only the issue size and maturity were announced. The coupon rate was determined after each such auction by rounding to the nearest one eight of the stop-out yield.

we observe a convergence process showing that Austrian government bond yields exhibit a pattern similar to that of yields for countries such as Germany, France or the Netherlands. German bonds are the most liquid instrument in Euro and therefore it is feasible to find a close match for every Austrian bond. This was not possible for other countries more similar to Austria in size like the Netherlands.

Figure 1: Development of Government Bond Yields in Europe, 1993-2006



Note: This figure shows the 10-year government bond interest rates for selected EU countries from 1992 until 2008. Source ECB.

In Table 1 we report summary statistics. In column (1), we report the mean values and standard deviations of our variables for all auctions. In column (2), we exclude auctions from the period 1995 to 1997. These years characterize the transition following Austria's EU accession in 1995 during which the number of bidders steadily increased. We also exclude the first fourteen auctions, because we could not identify information on secondary market yields. In Columns (3) and (4), we report the summary statistics for auctions before 1995 and for auctions after 1997. It can already be seen, that there was a substantial increase in the number of bidders, and that the average yield in Austria dropped by 25 basis points more than in Germany (a drop from 6.87 to 4.43 relative to a drop from 6.52 to 4.33).

Table 1: Summary statistics

Variable	(1) full	(2) full w/o 95-97	(3) pre	(4) post
Number of bidders	20.20	22.21	12.79	24.77
	(5.64)	(5.02)	(0.41)	(1.03)
Number of winning bidders	13.36	13.56	11.42	14.15
	(3.81)	(4.11)	(1.21)	(4.43)
Volume (EUR Bn)	0.91	0.98	0.62	1.08
	(0.44)	(0.46)	(0.15)	(0.47)
Coverage Ratio	2.62	2.72	2.07	2.89
	(0.86)	(0.90)	(0.49)	(0.90)
Number of bids/bidder	5.03	4.52	6.85	3.88
	(2.03)	(1.45)	(1.19)	(0.62)
Maximum of number of bids	11.19	10.78	16.25	9.28
	(4.69)	(4.24)	(4.34)	(2.74)
HHI (Bids)	0.07	0.07	0.09	0.06
	(0.02)	(0.02)	(0.01)	(0.01)
HHI (Winning Bids)	0.15	0.15	0.15	0.15
	(0.08)	(0.09)	(0.02)	(0.10)
Time to Maturity	9.60	10.01	7.74	10.63
	(5.36)	(5.71)	(2.37)	(6.19)
Stop-out Yield (%)	5.51	4.96	6.89	4.43
	(1.54)	(1.23)	(0.81)	(0.68)
Average Winning Yield (%)	5.50	4.95	6.87	4.43
	(1.53)	(1.23)	(0.80)	(0.68)
Maximum Share Demanded	0.33	0.35	0.29	0.36
	(0.17)	(0.19)	(0.03)	(0.21)
Marginal Demand (Share of Issue Size)	0.33	0.27	0.43	0.22
	(0.30)	(0.27)	(0.26)	(0.25)
German Yields (%)	5.34	4.80	6.52	4.33
	(1.45)	(1.11)	(0.78)	(0.62)
Number of Observations	153	112	24	88

Note: This table reports the mean values of all our variables. Standard deviations are in parentheses below. Column (1) includes all auctions. Column (2) excludes auctions 1 to 14 and auctions in the transition period 1995 to 1997. Column (3) includes only auctions before 1995 (excluding auctions 1 to 14) and Column (4) includes only auctions after 1997. HHI is defined as the sum of the squared cumulative share demanded by each bidder relative to the sum of cumulative shares demanded of all bidders. The same is true for winning bids.

2.2 Increase in Bidder Numbers after EU Accession

Austria's financial markets have become substantially more exposed to competition from abroad in the context of EU accession in 1995. Only in 1991 capital controls were removed. By transposing relevant European directives and recommendations into national law, the "Finanzmarktanpassungsgesetz", passed in 1993, was instrumental. It contained a new Banking Act which provided for freedom of establishment and freedom of cross-border service. These provisions have resulted in a substantial increased presence of EU based banks in Austria (with EU subsidiaries holding

almost 20% of total bank assets in 2002).[6]

From 1991 to 1996 there were between 12 to 15 bidders per auction. Until the end of 1994 only Austrian banks were permitted to bid. EU common market regulations required opening participation in the bidding process for all European banks. As a consequence, the number of bidders increased to an average of almost 25 bidders in the years to follow. At the end of our sample there were 25 approved bidders, of which only six were Austrian.

The top panel in Figure 2 shows the evolution of the number of bidders over time. We plotted a vertical line when Austria joined the European Union in January 1995 and a second vertical line in January 1998 when the increase in the number of bidders came to an end. Although the approval of foreign banks started in 1995, we observe a sharp increase in the number of bidders only later in our sample. The reason for the late increase is that although three foreign banks were admitted in 1995, some Austrian banks merged. In 1996, one additional foreign bank was admitted. In 1997, nine additional foreign banks were admitted, and in 1998 four additional foreign banks. In later years, there were only one to two entrants per year, and some further banks exited due to mergers. We thus assume that the transition process is completed by the end of 1997 and in our further analysis we drop the observations for the years 1995-1997.

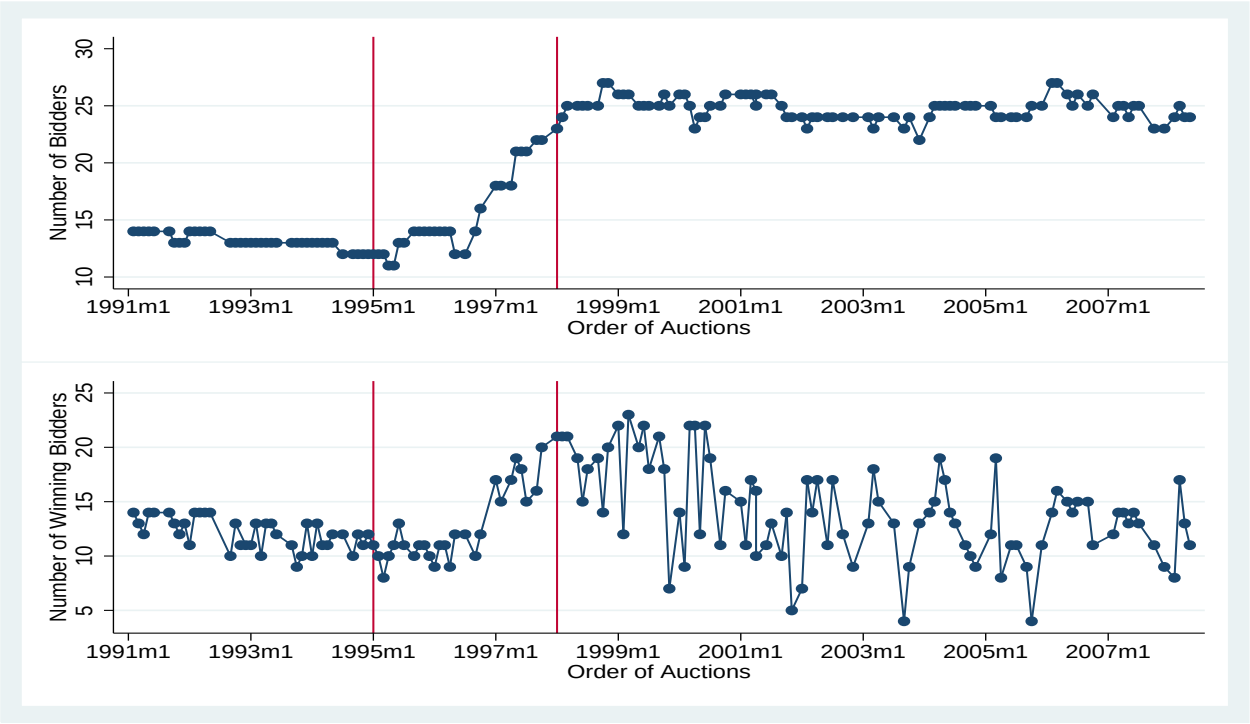
We also observe variation in the number of banks within a given year, although according to the rules all admitted banks were required to submit bids. One concern is therefore that this variation within years is not random. The main reason for this variation are again mergers. In addition, bidders sometimes faced technical difficulties resulting in bids not being transmitted or being transmitted too late. Apparently this has been the case, in particular, in earlier years when bids were still submitted by fax. In general, it seems over our observation period, late submission was random and did not concern specific bidders.[7] This means that there is no systematic bias other than mergers that causes the variation within years in our Figure 2. In particular, because of the randomness the other banks did not know whether rival banks failed to submit their bids on time. In Section 4, we will examine the robustness of our surplus estimates to this assumption.

The bottom panel in Figure 2 also shows the number of winning bidders. This number appears to have increased on average, and so has its variance. After 1997, it rarely happens that all bidders win a positive share in the auction.

[6]For details see Waschiczek (2005).

[7]Email conversation with Maria Kucera from the OeKB.

Figure 2: Number of Bidders (top panel) and Winning Bidders (bottom panel)



Note: Austrian Treasury auctions. Source Oesterreichische Kontrollbank.

2.3 Reduced Form Analysis

As the first step in our analysis, we run a difference-in-difference regression to assess the effect of increased competition on Austrian government bond yields. We compare Austrian and German government bonds and assume that the yields of German government bonds were not affected by Austria joining the EU. As Austria is a small country about a tenth of the size and population of Germany, we consider this to be a valid assumption. The German bonds are selected so that they are similar to the Austrian bonds with respect to their maturity. We then regress the yields of Austrian and German government bonds on a dummy variable for Austria, one for auctions after 1997 and an interaction between these two dummy variables. The interaction measures the effect of increased competition. To control for other determinants, we also include the maturity of the bonds, inflation, GDP growth, a time trend as well as the interaction of the time trend with auctions after 1997 in our regressions. To account for serial correlation, we include an autoregressive term of order one (Bertrand et al., 2004).

In Table 2, we report the difference-in-difference regression result. In column (1), we report the results of our basic specification. The time trend is negative indicating that yields have decreased over the years, while the time trend after the year 1997 is positive indicating that yields decline

in a less pronounced way. We also observe that the yields of Austrian government bonds are on average 0.441 percentage points (44.1 basis points) higher than the yields of German government bonds. The yields of all government bonds are by 2.021 percentage points lower after joining the EU. We also observe that maturity, inflation rate and GDP growth carry the expected signs. A longer maturity is associated with higher yields, i.e. an increase in the maturity of a bond by one year increases the yield by 0.038 percentage points. GDP growth and inflation also have a positive effect on yields. When inflation increases by one percent, the yields increase by 0.155 percent, whereas when GDP grows by one percent, the yields increase by 0.110 percent. The estimate of the AR(1) term is equal to 0.832 and significantly different from zero.[8]

Table 2: Difference-in-difference results

Variable	(1)	(2)	(3)	(4)
Constant	7.059	7.062	7.088	7.458
	(0.201)	(0.201)	(0.219)	(0.189)
Maturity	0.038	0.041	0.039	0.040
	(0.004)	(0.004)	(0.004)	(0.004)
Inflation Rate	0.155	0.151	0.173	0.080
	(0.032)	(0.031)	(0.033)	(0.030)
GDP Growth	0.110	0.108	0.102	0.096
	(0.017)	(0.017)	(0.018)	(0.015)
Time trend	-0.053	-0.053	-0.061	-0.057
	(0.004)	(0.004)	(0.007)	(0.004)
Time trend × Auctions after Austria joining EU	0.040	0.038	0.048	0.059
	(0.004)	(0.004)	(0.007)	(0.004)
Austria	0.441	0.438	0.439	0.400
	(0.076)	(0.079)	(0.095)	(0.069)
Auctions after Austria joining EU	-2.021	-1.831	-2.262	-3.638
	(0.211)	(0.197)	(0.290)	(0.253)
Auctions after Austria joining EU × Austria	-0.511	-0.498	-0.537	-0.403
	(0.096)	(0.097)	(0.140)	(0.098)
Auctions after Placebo Date			0.225	-1.001
			(0.173)	(0.101)
Placebo Date × Austria			0.028	-0.061
			(0.163)	(0.087)
AR(1)	0.832	0.815	0.830	0.839
	(0.039)	(0.039)	(0.039)	(0.037)
Observations	250	266	250	250
Adjusted R-squared	0.96	0.95	0.96	0.97

Note: The dependent variable is the yield of Austrian and German government bonds. Placebo dates are February 8, 1994 in Column (3) and April 6, 2004 in Column (4). In Column (2) we assume that the transition process was already finalized at the end of 1996. In all other columns, it is the year 1997. Consequently there are more observations in (2). Standard errors are shown in parentheses below the estimated coefficients.

We next examine the robustness regarding the definition of the transition period. In column (2), we assume that the transition process was completed in the year 1996. None of our results

[8] An interaction between the AR(1) term and Austria is insignificant. The same is true for a quadratic trend.

change significantly. The estimated effect of the increased competition on Austrian government bonds is -0.498, only slightly larger than in our preferred specification. In columns (3) and (4), we present the robustness of our estimates to placebo treatments. We might be concerned that the increase in bidder numbers picks up some additional unspecified time effect in Austria or Germany. In particular, we are concerned about the general convergence of interest rates in the Euro area at the time. To test for this, we use placebo treatments. Similar to Black et al. (2008) and Fort et al. (2011), we introduce such a treatment and add a hypothetical increase in competition before and after Austria actually joined the EU. These placebo reforms should not have had any impact on Austrian government bonds. If we find an impact, our results might be driven by other unobserved mechanisms. Adding placebos before (column 3) and after Austria joined the EU (column 4) slightly alter the estimates of the original treatment, but the estimated treatment effect is still strong and significantly different from zero.

To summarize, we find a significant reduction of about 50 basis points in Austrian government bond yields after 1997. This effect is rather large and a strong indication that competition may affect yields and prices. The question is, whether we can really attribute all to increased competition, as the reduced form approach does not account for changes in the underlying bidders' valuations. To isolate the effect of increased competition and shed light what may have happened in the absence of increased bidder numbers, we model the bidding process with the aim of estimating valuations separately before and after EU accession in the next section.

3 Model and Estimation

We estimate bidders' valuations of the auctioned bonds and calculate their surplus. In this section, we describe the theoretical bidding model and how we estimate bidders' valuations. We also show the basic estimation results and present evidence on estimated valuations for the pre-EU period and post-EU period. In Section 4, we then quantify the effect of competition.

3.1 Equilibrium Bidding in Share Auctions

We consider a model of bidding in the spirit of Wilson (1979). We closely follow Kastl (2011), Hortaçsu and McAdams (2010), and Hortaçsu and Kastl (2012) taking into account the discreteness of bids.

Auctions. There are T auctions. Each auction $t = 1, ..., T$ is a discriminatory auction of Q_t

arbitrarily divisible units.

Bidders. There are N_t bidders in auction t. Bidders in each auction are symmetric and risk-neutral with independent private values (IPV).[9]

Marginal Valuations. For every auction,[10] each bidder receives a private signal θ_i drawn from the distribution F. Signals are distributed independently across bidders as well as across auctions. The marginal valuation function has the form $v(q, \theta_i)$. It is increasing in θ_i and weakly decreasing in q. Hortaçsu and Kastl (2012) develop a formal method to test for the null hypothesis of private values in the Bank of Canada's three-month treasury-bill auctions, and do not reject private values in that application. Their test method relies on the specific institutional setup in the Canadian treasury market, which is not present here. We argue that their results provide support for our assumption of independent private values in the context of government debt auctions. It can reasonably be argued that banks have idiosyncratic shocks to their liquidity needs due to deposit flows and the corresponding reserve requirements. The assumption we impose in our empirical work is that these shocks are independent conditional on observed macro and secondary market conditions.

To examine the assumption of no unobserved auction heterogeneity, i.e. the information that a given bank has about other bank's bid is the same as that available to the econometrician, we regressed the quantity weighted mean bid of each bank in each auction non-parametrically on the same variables (date, maturity, number of bidders, and issue size) and same weights as in the kernel of the structural model. We then computed the conditional correlation of the residual bids for each bidder pair over the auctions.[11] We found an average correlation of 0.06 pre-95 and one of 0.04 post-97 and conclude that it is reasonable to maintain the assumption of no unobserved heterogeneity.

Gross Utility. $V(q, \theta_i) = \int_0^q v(u, \theta_i) du$ denotes bidder i's gross utility when she received signal θ_i and she obtains quantity q.

Action sets. Bidders are required to submit non-increasing bid-schedules $b_i(.)$. In particular, we assume that each bidder's action set is a triple $(\mathbf{b}_i, \mathbf{q}_i, K_i)$ where prices $\mathbf{b}_i$ and corresponding cumulative quantities $\mathbf{q}_i$ are vectors of dimension K_i and K_i is a finite natural number. We require for $1 \leq k < K_i$ that $q_{ik} < q_{ik+1}$ and $b_{ik} > b_{ik+1}$ and $q_{ik} \in [0, \bar{Q}]$ where $\bar{Q} \leq Q$ is the maximum

[9]The methodology in Kastl (2011) allows for asymmetries by introducing G different groups of bidders denoted by g such that $N_t = \sum_{g=1}^{G} N_t^g$. Bidders are then assumed to be symmetric only conditional on belonging to group g. In Section 4, we examine the robustness of our results by allowing for two bidder groups.

[10]In the sequel, we drop the index t whenever there is no risk of confusion.

[11]We thank an anonymous referee for this suggestion.

quantity bidders are allowed to bid for.

Bid functions. Bidders use symmetric pure strategies. Bidder i's pure strategy is a mapping from private signals to the set of weakly decreasing bid functions with K_i steps. A bidder submits a non-increasing step function $y(p|\theta_i) = \sum_{k=1}^{K_i} q_{ik}\mathbb{I}(p \in (b_{ik+1}, b_{ik}])$, where $\mathbb{I}$ is the indicator function (note that b_{ik} is decreasing in k) and $b_{iK_i+1} = 0$. The function specifies how much a bidder of type θ_i demands at price p.

We make two additional assumptions consistent with the actual auction procedure. First, we assume that whenever the market clearing price is not unique, the auctioneer uses the most favorable price from her perspective. Second, bids at the lowest price accepted (stop-out price) may be subject to pro rata curtailments to allocate the exact announced issue size.

Expected payoff. Let all other bidders use strategies $\{y(\cdot|\theta_j)\}_{j\neq i}$, and bidder i of type θ_i use interim strategy $y(\cdot|\theta_i)$ such that the vector $\mathbf{y}(\cdot|\theta) = [y(\cdot|\theta_1), \ldots, y(\cdot|\theta_N)]$ denotes the vector of submitted bid schedules. Let $Q_i^c(\theta, \mathbf{y}(\cdot|\theta))$ denote the quantity bidder i obtains given state θ and that bidders are using strategy $\mathbf{y}(\cdot|\theta)$. Bidder $i's$ interim expected payoffs are given by

$$\begin{aligned}
\Pi_i(\theta_i) &= E_{\theta_{-i}} \int_0^{Q_i^c(\theta,\mathbf{y}(\cdot|\theta))} v(u, \theta_i)du \\
&- \sum_{k=1}^{K_i} \mathbb{I}(Q_i^c(\theta, \mathbf{y}(\cdot|\theta)) > q_{ik})(q_{ik} - q_{ik-1})b_{ik} \\
&- \sum_{k=1}^{K_i} \mathbb{I}(q_{ik} \geq Q_i^c(\theta, \mathbf{y}(\cdot|\theta)) > q_{ik-1})(Q_i^c(\theta, \mathbf{y}(\cdot|\theta)) - q_{ik-1})b_{ik}, \qquad (1)
\end{aligned}$$

where $q_{i0} = 0$. The first term is the gross-utility the bidder obtains, the second term is what she pays for quantities on which she is not rationed, and the last term is what she pays on quantities on which she is rationed. We assume that supply is non-random, although the OeKB reserves the right to withdraw supply entirely. This happened once during the sample period, when the yield resulting from the auction exceeded that of Belgian yields.[12]

Equilibrium. The equilibrium concept we use is Bayesian Nash equilibrium. A vector of strategies $\mathbf{y}(\cdot|\theta)$ constitutes a Bayesian Nash equilibrium, if for all bidders i, $y(\cdot|\theta_i)$ maximizes her expected utility $\Pi_i(\theta_i)$.

[12]Belgium had historically higher yields because of a considerably higher debt to GDP ratio than Austria.

3.2 Estimation of Marginal Valuations

In this section, we describe how we infer the bidders' marginal valuations v. Let $P^c(\theta, \mathbf{y}(\cdot|\theta))$ denote the market clearing price associated with type vector θ**.** Kastl (2012) shows that for all steps k but the last step K_i a bidder's bid function has to satisfy:[13]

$$v(q_{ik}, \theta_i) = b_{ik} + \frac{Pr(b_{ik+1} \geq P^c)}{Pr(b_{ik} > P^c > b_{ik+1})}(b_{ik} - b_{ik+1}) \tag{2}$$

and at K_i:

$$b_{iK_i} = v(\bar{q}_i, \theta_i) \text{ where } \bar{q}_i = sup_{\theta_{-i}} Q_i^c(\theta_i, \theta_{-i}, \mathbf{y}(\cdot|\theta)). \tag{3}$$

To infer the valuations at the bid steps, we follow the resampling approach proposed by Hortaçsu and McAdams (2010) and Kastl (2011). The idea is to use observed bid functions to estimate the distribution of the market clearing price P^c. Since the bid steps b_k are also observed, this allows us to infer marginal valuations $v(q_{ik}, \theta_i)$ using (2).

1. We fix bidder i and her bid function $y(p|\theta_i)$ in auction t.

2. Draw $N-1$ bid functions with replacement from all bids and compute the residual supply $Q - \sum_{j=1}^{N-1} y(p|\theta_j)$. We separate between the period before 1995 and the period after 1997. Within each period, the bids are sampled using a four-dimensional Gaussian kernel including auction-date, issue size, remaining maturity, and bidder numbers in the kernel weights.[14]

3. Compute the market clearing price P^c given bidder $i's$ bid function $y(p|\theta_i)$ and whether bidder i would have won quantity q_{ik} at bid b_{ik} for all k.

4. Repeat 2.) and 3.) S times. This gives a distribution of market clearing prices for every bid function $y(p|\theta_i)$ and hence a estimate of both the numerator and denominator of the fraction on the right hand side of equation (2).

[13] Rewriting the first order condition illustrates the trade-off a bidder faces at step k, equating the cost and benefit of demanding a lower quantity q_{ik}:

$$Pr(b_{ik} > P^c > b_{ik+1})(v(q_{ik}, \theta_i) - b_{ik}) = Pr(b_{ik+1} \geq P^c)(b_{ik} - b_{ik+1}).$$

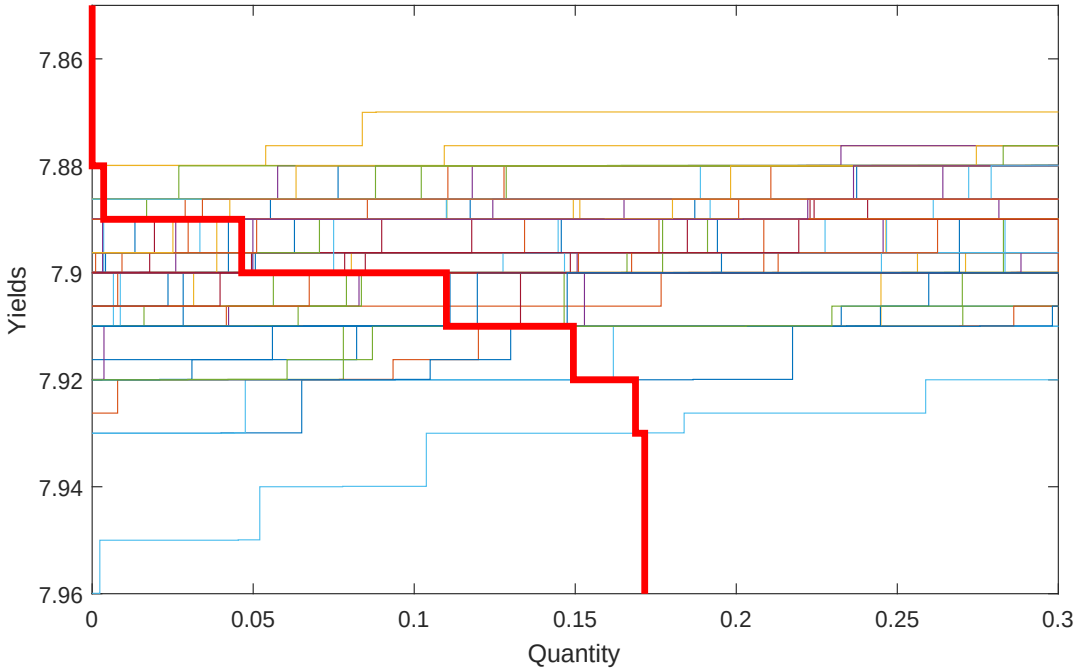
The cost is the loss of surplus $(v(q_{ik}, \theta_i) - b_{ik})$ in case the market clearing price P^c is between b_{ik} and b_{ik+1} and the benefit is the reduced payment $(b_{ik} - b_{ik+1})$ in case the market clearing price is below b_{ik+1}.

[14] The bandwidth parameters are set such that for auction t only bids from auctions within $t-1$ and $t+1$ are sampled with positive probability. The number of bidders in these auctions must not differ by more than 2 from N_t. The remaining time to maturity has to be in the range of $+/-2$ years of the auctioned bond. Finally, the issue size has to be within a $+/-500$ million Euro range. In the period before 1995 we draw on average from 1.67 auctions and in the period after 1997 from 1.2 auctions. In Section 4.1 we examine the robustness of our results to varying bandwidths.

We perform steps 1 to 4 for every bidder and every auction. We normalize bids by the secondary market yield of either the auctioned security or a close substitute. We use $S = 5000$ resamples to estimate the distribution of market clearing prices.

Figure 3 shows 100 randomly drawn residual supply curves and the demand curve of bidder 12 in auction 16. Since we are considering yield-tenders, we have reversed the y-axis to be consistent with the exposition of the model. The figure clearly shows that positive winning probabilities lie within a fairly narrow range. The picture becomes even clearer in Figure 4, which shows that the distribution of the stop-out price on the left-hand panel has positive density over a range of 7 basis points. About 90 percent of the mass, however, are over a range of 2 basis points only.

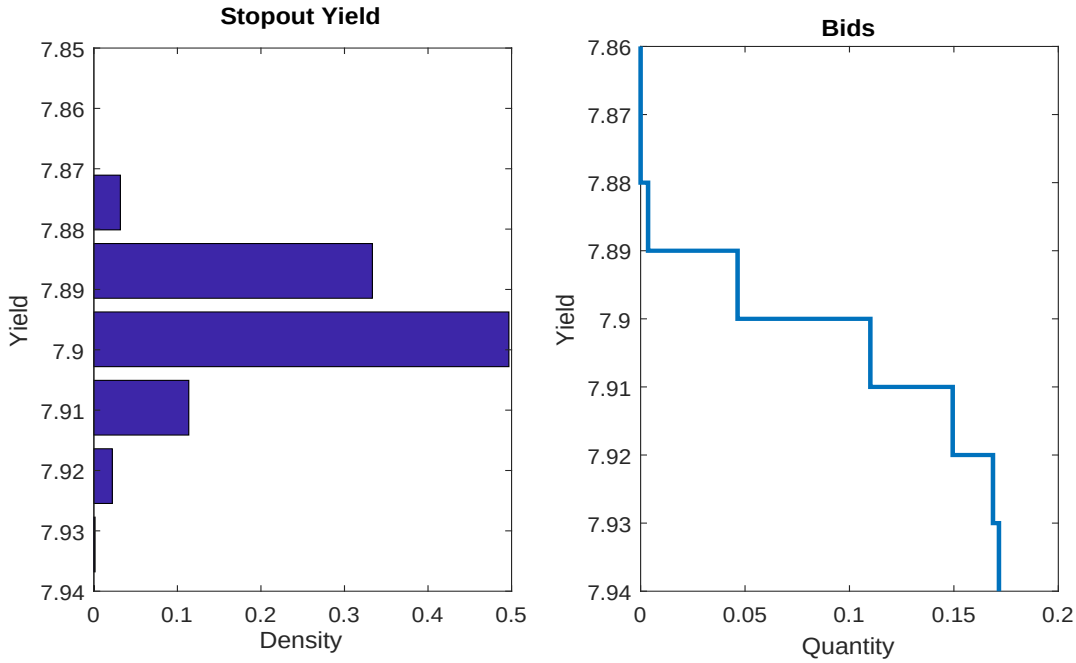
Figure 3: Bid Function and Random Residual Supplies



Note: This figure shows 100 randomly drawn residual supply curves and the demand curve of bidder 12 in auction 16. The y-axis is reversed to be consistent with the exposition of the model.

Figure 5 illustrates the estimated probability of winning at a specific quantity-yield combination. Again, the probability of winning declines very steeply over a very small range of yields, while for a large range that probability is very close to zero or one. Figure 6 shows a specific bidder's bid function and her valuations in auction 16. Valuations for this bidder are up to 4 basis points above her bid. We calculate standard errors of marginal valuations using a bootstrap. The reported standard errors in the paper are from a sample of 100 estimates generated by repetitions of the

Figure 4: Stop-out Yields, Bids



Note: The left panel of this figure shows the distribution of the stop-out price of bidder 12 in auction 16; the right panel shows this bidder's bid schedule. The y-axis is reversed to be consistent with the exposition of the model.

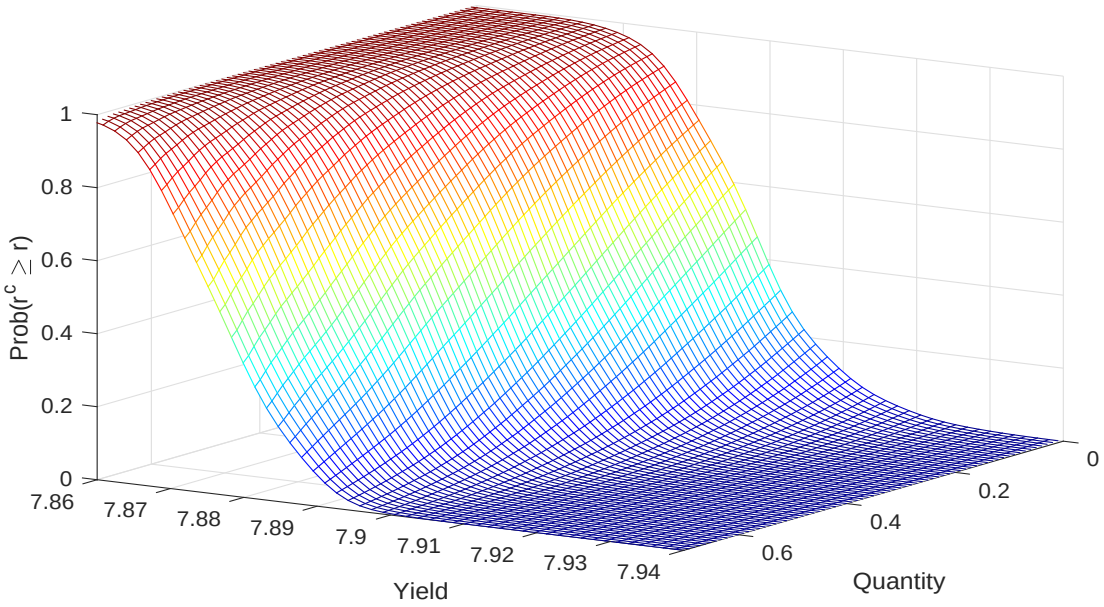
estimation procedure with a new bootstrap sample of bid functions for the whole sample (see e.g. Table 3).

We also present evidence on the estimated valuations for the pre-EU period and post-EU period in Figure 7. This figure shows an estimate of the density of bidders' quantity weighted valuations over all auctions, separately for the two sub samples and minus the reference interest rate, which is the rate of the corresponding German bonds. The valuations of each bidder (from Figure 6) are quantity weighted. We observe a sharp distinction between the two periods and that the difference between valuations and the German benchmark yield in the latter time period is substantially smaller than before Austria joined the EU.

4 Quantifying the Effect of Competition

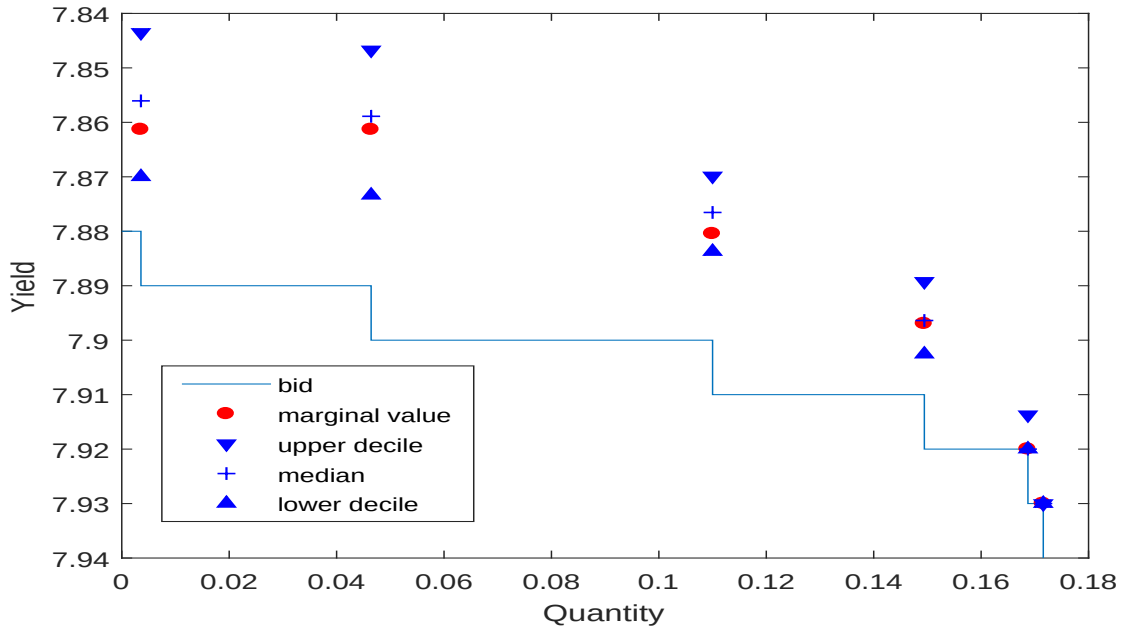
Based on our estimates of marginal estimates we now compute the surplus obtained by bidders in the two different time periods in subsection 4.1. We then examine the robustness of the surplus estimates. We reconcile the structural surplus estimates with reduced form results. We cannot perform the ideal counterfactual exercise describing what would have happened without EU accession. We do however examine whether the change in surplus could be explained by a change

Figure 5: Distribution function



Note: This figure shows the estimated probability of winning at a specific quantity-yield combination.

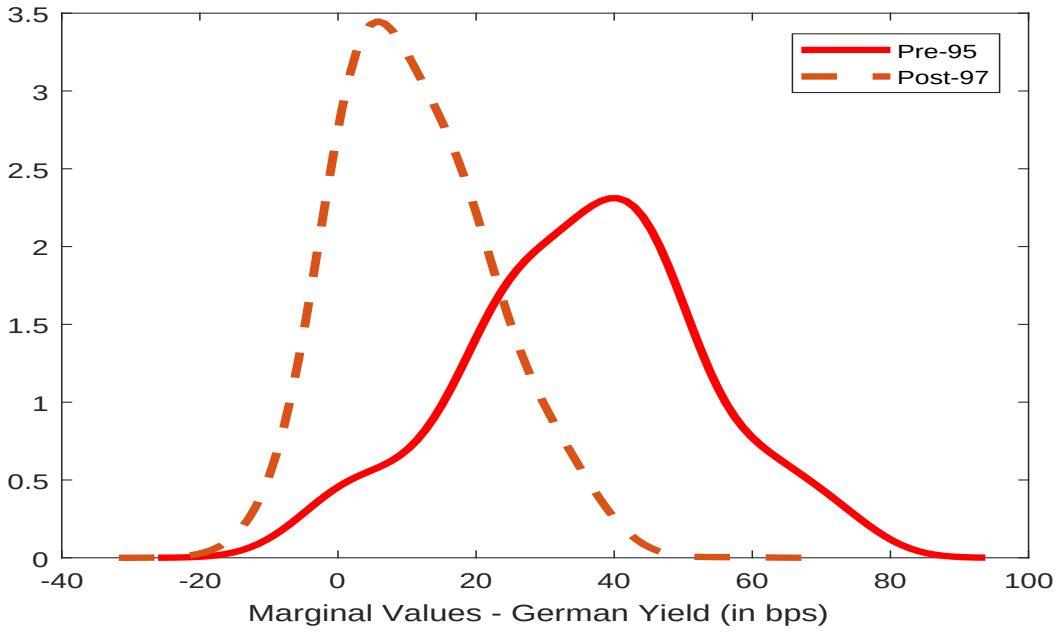
Figure 6: Bidder valuations



Note: This figure shows bidder 12's bid function and her valuations in auction 16. The y-axis is reversed to be consistent with the exposition of the model.

in bidder numbers alone, leaving bidder behavior and valuations unchanged. Similarly, we study the efficiency of the auction mechanism by comparing the observed outcome to the benchmark of a hypothetical uniform auction in subsection 4.2.

Figure 7: Distribution of Bidders' Valuations pre-EU Period and post-EU Period



Note: This figure shows an estimate of the density of bidders' quantity weighted valuations over all auctions, separately for the two sub samples and minus the rate of a corresponding German bonds.

4.1 Estimating Bidder Surplus

For all auctions $t = 1, .., T$, we estimate the ex-post surplus S_t earned by bidders. Let Q_i^c be the quantity allocated to bidder i and $\hat{v}(q_{ik})$ be our estimate of bidder i's valuation at quantity step q_{ik} in the corresponding auction. The estimate of the total ex-post surplus earned by bidders in each auction becomes

$$\begin{aligned} S_t &= \sum_{i=1}^{N_t}\sum_{k=1}^{K_i}\big[\mathbb{I}(Q_i^c > q_{ik})(q_{ik} - q_{ik-1}) \\ &+ \mathbb{I}(q_{ik} \geq Q_i^c(\theta, \mathbf{y}(\cdot|\theta)) > q_{ik-1})(Q_i^c(\theta, \mathbf{y}(\cdot|\theta)) - q_{ik-1})\big] \cdot (\hat{v}(q_{ik}) - b_{ik}), \end{aligned} \tag{4}$$

where we divide this by the issue size Q_t to make auctions comparable.

To calculate the interim surplus we use the resampling procedure again. For each bidder i in auction t, we keep the bid schedule $y(p|\theta_i)$ fixed and the 5000 residual supply curves as drawn before. For each of these draws we calculate the surplus using the estimated marginal values. Finally, we average across the draws to get the interim surplus of bidder i and add up all the bidders' surpluses in each auction.

Table 3 reports our estimates of both the interim and ex-post surplus, over the whole sample period as well as for the periods before and after EU accession. The interim surplus earned by

bidders has dropped by about 3.5 basis points or 82 percent (see Panel A). This is a measure in annual yields. Because average time to maturity and average volume increased after 1997, we also report the respective numbers in million Euro in Panel B. Here we convert the difference between valuation and bid in basis points into the volume weighted difference between valuation in Euro and price paid. According to this measure the interim surplus dropped from 1.6232 to 0.5426 million Euro or by 67 percent. The longer maturities and larger volumes thus result in a somewhat smaller proportional drop in surplus when measured in Euro. The results for the ex-post surplus are slightly more pronounced. Obviously, surplus per bidder, but also surplus per winning bidder, has declined even more. This is a sharp drop in surplus from a very high level before EU accession to a level very much in line with other studies (see Kastl (2011)).

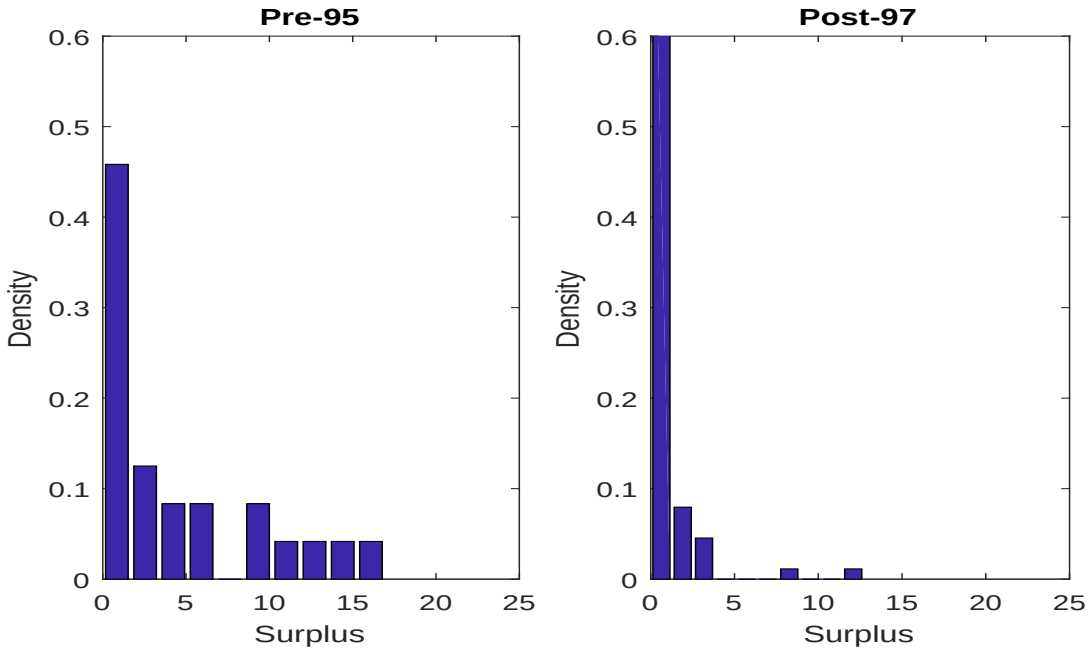
Table 3: Interim and Ex-Post Surplus Estimates

	Interim Surplus			Ex-Post Surplus		
	all	pre-95	post-97	all	pre-95	post-97
Statistic	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. in basis points						
Mean	1.5218	4.2805	0.7694	1.6578	4.5899	0.8581
Standard Error	0.1972	0.7720	0.1244	0.1713	0.6003	0.1422
95%	8.7715	15.4553	2.7820	11.3508	16.8094	3.1164
50%	0.2756	2.0274	0.2573	0.2847	1.7236	0.2083
5%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Panel B. in million Euro						
Mean	0.7741	1.6232	0.5426	0.8403	1.7868	0.5821
Standard Error	0.1055	0.2961	0.0982	0.0979	0.2450	0.0990
95%	4.4648	6.0676	2.5909	5.3313	6.5825	2.8925
50%	0.1915	0.6138	0.1605	0.1838	0.5353	0.1605
5%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
# of auctions	112	24	88	112	24	88

Note: Panel A reports estimates of bidder interim and ex-post surplus as the weighted absolute difference of bids and valuations in basis points. Panel B reports the corresponding volume weighted difference between Euro valuation and price paid. Standard errors are calculated using 100 bootstrap replications.

To investigate further what may be behind our results, we look at percentiles to obtain a more detailed picture. Even before EU accession most auctions resulted in very small surplus estimates. However, auctions where large surpluses have been obtained appear to have become less frequent after EU accession. Overall the variance of outcomes has been reduced. Figure 8 illustrates the distribution of outcomes as well. It shows that the increased competition has also stabilized government revenue.

Figure 8: Distribution of bidder surplus across auctions



Note: This figure shows the distribution of bidder surplus pre-95 and post-97.

Robustness

To assess the robustness of our results, we investigated further aspects. First, one concern with our results might be that the foreign banks that entered the bidding process after Austria joined the EU are substantially different than Austrian banks. We therefore relax the symmetry assumption and estimate the interim and ex-post surplus allowing for two different bidder groups. We re-estimate the model under the assumption that the primarily 'domestic' banks which participated in both periods draw their valuations from a different distribution function than the new entrants which participated only after EU accession. Hence, we estimate the valuations in the second period allowing for two groups. The bidders that participated only after EU accession could be labeled international competitors. We report the estimation results in the Appendix (Table A.1) and find an estimated interim surplus of 0.7429 basis points in the second period. These values are very close to the estimated interim surplus under symmetry (0.7694 basis points). Our results appear to be robust and seem to reflect that the market environment in the common EU market is the same for all banks. Consequently, we maintain the symmetry assumption.

Second, an explanation for the change in valuations is the adoption of the common currency in January 1999. There was no exchange rate risk with respect to the Deutsche Mark (DEM) prior to the introduction of the Euro as the Austrian Schilling (ATS) had been pegged to the DEM

since July 1976, although this was never officially announced. Between 1981 and the inception of the European Monetary Union, the average ATS/DEM exchange rate was stable at 7.034 with a standard deviation of less than 0.1% (Mooslechner et al. (2007)). Nevertheless, Austrian bonds being issued in the common currency can explain the increase in valuations upon EU accession for reasons other than the elimination of the exchange rate risk. Bonds being issued in Euros reduced the cost of trading (i.e. buying and selling ATS) and increased the liquidity of the bonds. To examine the effect of the common currency, we estimate the interim and the ex-post surplus for Euro auctions only. We find an average interim (ex-post) surplus for auctions in Euro of 0.8074 (0.9091) basis points (see Table A.2). This is a small, but not statistically significant change in surplus relative to the entire post EU accession period. The reason for this small difference is probably that we only observe 8 auctions (between January 1998 and December 1998) with foreign bidders but bonds still denominated in ATS.[15]

Third, we examined the role of the bandwidth of our kernel. If we vary the bandwidth, then the estimated surplus in the post-97 sample lies between 0.7 and 1 basis points. In the pre-95 sample, it increases to at most 5.6 basis points. From this analysis, we conclude that our estimated surplus before and after Austria joined the EU are conservative estimates.[16] Fourth, based on our conversations with OeKB, we concluded earlier that there was no systematic bias in bidder numbers other than mergers within a given year (see Figure 2). To examine the robustness of our assumption that bidders knew about the actual bidder numbers empirically as well, we estimated the surplus using the potential number of bidders rather than the actual number of bidders in every auction. In the pre-95 period the actual number of bidders always equalled the potential number of bidders. In the post-97 sample the difference in surplus is small at 0.05 basis points. Finally, one may ask whether the normalization by issue size following equation (4) is affecting our results as we observe that issue size is increasing over time. If we restrict the sample to those (smaller) post-97 auctions that are comparable in size to the pre-95 auctions, we still obtain a substantially smaller interim surplus of 1.47 basis point post-97.[17]

We conclude that there is robust evidence for a significant reduction in surplus. The reduced

[15] In addition, the publication of the Convergence Report (European Monetary Institute (1998)) in March 1998 sent a strong signal that Austria would be a member of the currency union. This was formally confirmed by the European Council's decision in early May 1998 (Jobst et al. (2016)). It was therefore clear early on that although the bonds sold in 1998 were denominated in ATS, they would be eventually traded in Euro from 1999 on.

[16] The estimation results for this and the two following robustness checks are available upon request from the authors.

[17] Without normalization, resampling bids from neighboring auctions $j \neq t$ requires the rescaling quantities in every neighboring auction j by Q(t)/Q(j). Employing this procedure, we get identical results for the interim surpluses.

form evidence showed that the estimated effect of increased competition on Austrian government bonds is -0.511 percentage points. This is a rather strong effect compared to the results from our structural analysis. The gap can be explained by the accompanied change in valuations that occurred between the two time periods, as documented in Figure 7. Valuations for Austrian treasuries increased after EU accession (yields have dropped) relative to German bonds. The modes of the two distributions are roughly 35 basis points apart, explaining the larger part of this gap. The difference-in-difference estimates fail to take this underlying improvement of the valuations into account. The change in valuations can be explained by Austrian bonds becoming more liquid and substitutable to other European bonds. This was also due to the adoption of the common currency. Joining the European Monetary Union did not only reduce transaction costs. Once Austrian bonds were denominated in the common currency, they serve the bidding banks as collateral to manage their liquidity (whereas prior to the introduction of the Euro only domestic government bonds were eligible at the National Central Bank in most cases). This is reflected by looking at where Austrian sovereign debt was held. Only 30%[18] of Austrian sovereign debt was held by foreign institutions in 1995. This number increased to 80% by 2008.[19] Finally, a sustained good fiscal position in order to fulfill the Maastricht requirements and subsequently the Stability and Growth Pact (Pagano and Von Thadden (2004)) was expected by investors.

The Role of the Number of Bidders

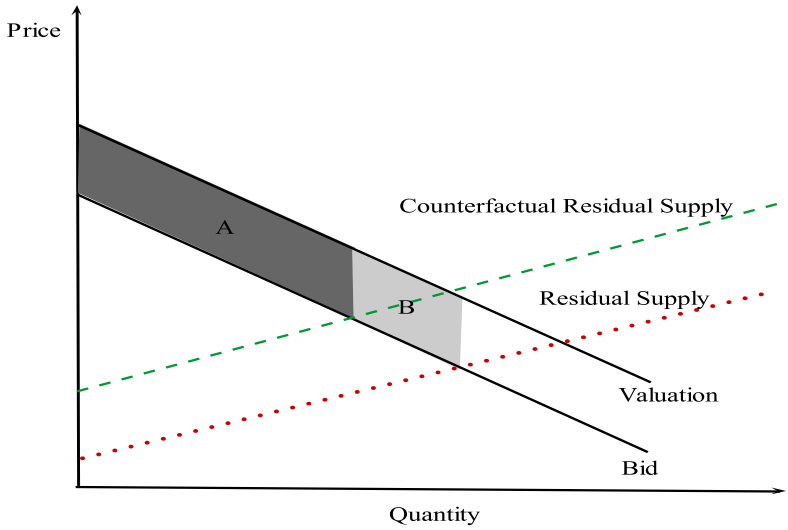
We further want to examine whether the increase in bidder numbers brought about a change in the nature of competition. Increasing the number of bidders also results in an increase in the number of draws of signals. Hence, even without more aggressive bidding there would be a change in surplus, simply because extreme draws from the distribution of valuations would become more likely and the resulting surplus being allocated among more bidders.

After Austria joined the EU, the number of bidders has increased on average by eleven, from roughly 13 bidders to an average of more than 24 bidders. To calculate a pure "statistical" effect for auctions before EU accession, we thus perform the following experiment. We employ again a resampling procedure, similar to the one used in estimating marginal values. For each bidder i and each auction t, we fix her demand. We randomly draw with replacement $N_t - 1 + 11$ observed demand curves and compute bidder i's surplus. We average this surplus across $S = 5000$ resamples.

[18] Annual Report of the Austrian Fiscal Advisory Council.
[19] ECB, Statistical Data Warehouse.

Summing over all bidders' surpluses gives an estimate of the surplus in auction t. The difference between the actual surplus earned and the surplus under the counterfactual with eleven more bidders is a pure statistical effect of increasing bidder numbers, as it ignores that bidding behavior will also change in response to increased bidder numbers. We also perform the corresponding experiment reducing the number of bidders by eleven for the period following EU accession. Figure 9 illustrates this statistical effect.

Figure 9: Statistical effect



For illustrative purposes, we use linear bid functions and assume that a change in the number of bidders only affects the intercepts and not the slopes of the residual supply function. When there are only 13 firms, the market clearing price is given by the intersection of a bidder's demand function and the residual supply (dotted line). Since this is a discriminatory auction, bidders' surplus is given by the difference between valuation and demand on items won, i.e. the sum of the dark grey area A and the light grey area B. Now increasing the number of bidders results in a reduced residual supply given by the dashed line, causing a higher equilibrium stop-out price (lower yield) and the bidder winning a lower quantity. Its surplus is given by the dark grey area A only. The reduction in surplus due to the statistical effect is thus given by the light grey area B.

Table 4 presents the results. Columns (1) and (2) illustrate the effect of increasing the actual number of bidders in each pre-95 auction by eleven. In Panel A, we find that just increasing bidder numbers without changing strategic behaviour before 1995 would reduce surplus by roughly 59 percent (going from 4.2805 basis points to 1.7457 basis points). Panel B provides the effect of increasing competition in bidder surplus in million Euro. Increasing the number of bidders

decreases their surplus by 60% (going from 1.6232 to 0.6562 million Euro). Columns (3) and (4) illustrate the effect of reducing the number of bidders in the post-97 auctions by eleven. Reducing bidder numbers by eleven after 1997 would increase surplus in basis points (in million Euro) by 35 (36) percent. Hence, the strategic effect through more aggressive bidding appears to account for a large fraction of the estimated change in surplus.[20]

Table 4: Interim and Counterfactual Surplus Estimates

	Increasing bidder # pre-95		Decreasing bidder # post-97	
Statistic	actual (1)	counter-factual (2)	actual (3)	counter-factual (4)
Panel A. in basis points				
Mean	4.2805	1.7457	0.7694	1.0358
Standard Error	0.7720	0.4272	0.1244	0.1461
95%	15.4553	7.9509	2.7820	3.1806
50%	2.0274	0.8527	0.2573	0.4539
5%	<0.0001	<0.0001	<0.0001	<0.0001
Panel B. in million Euro				
Mean	1.6232	0.6562	0.5426	0.7394
Standard Error	0.2961	0.1681	0.0982	0.1171
95%	6.0676	3.4711	2.5909	3.1038
50%	0.6138	0.2462	0.1605	0.3145
5%	<0.0001	<0.0001	<0.0001	<0.0001
# of auctions	24	24	88	88
# of bidders	12.79	23.79	24.77	13.77
# of winning bidders	9.62	13.33	12.54	10.15

Note: Panel A reports interim and counterfactual surplus as the weighted absolute difference of bids and valuations in basis points. Panel B reports the corresponding volume weighted difference between Euro valuation and price paid. Columns (1) and (2) illustrate the effect of increasing the number of bidders in the pre-95 auctions by eleven assuming bidding behaviour remains the same. Columns (3) and (4) illustrate the effect of reducing the number of bidders in the post-97 auctions by eleven assuming bidding behaviour remains the same. Standard errors are calculated using 100 bootstrap replications.

4.2 Evaluation of Auction Mechanism and Allocative Efficiency

Finally, we examine how increased competition has affected the efficiency of the auction mechanism. We ask how the discriminatory auction performs in terms of revenue (interest paid and funds raised) and surplus (left to bidders) relative to the widespread alternative mechanism, namely a uniform auction. As in a discriminatory auction, the uniform auction aggregates bids to find the market clearing price, but bidders pay the market clearing price for all units they purchase. Whether a discriminatory auction is superior to a uniform auction has been a long standing debate in the

[20] We also conducted the experiment for the entire range from 13 to 24 bidders in increments of one bidder. We find that surplus due to the statistical effect is monotonically decreasing in bidder numbers over the entire range.

literature. Theoretically, these auction formats cannot be ranked (see e.g. Ausubel et al. (2015)) and it therefore becomes an empirical question. While we cannot solve for the equilibrium strategies in a uniform auction, we consider a hypothetical uniform price auction with truthful bidding (i.e. assuming that bidders bid their marginal valuations) as in Hortaçsu and McAdams (2010).[21]

Table 5 shows the difference in performance between the hypothetical uniform auction and the discriminatory auction, both in terms of interest rates (basis points) and revenue (million Euro). Panel A illustrates the performance from the government's perspective, i.e. a reduction in basis points is a favorable result for the government, corresponding to increased revenue in Euros. Overall the hypothetical uniform auction does not perform significantly better in terms of revenue (interest paid in terms of basis points).[22] However, Panel A also shows that before 1995, the hypothetical uniform would have saved the government 1.4888 basis points (or increased its revenue by 0.50 million Euro). After 1997, the difference becomes significantly negative indicating an advantage for the discriminatory auction.

Panel B illustrates the effects of the alternative auction format on bidder surplus. The uniform auction leaves bidders a 0.4614 basis points higher surplus on average over the sample period. The difference in surplus is even larger under increased competition than before 1995. It may at first be surprising that the hypothetical uniform auction can improve both revenue for the government and increase bidders surplus as it is the case for the period before 1995. The reason is that under limited competition before EU accession bidders were regularly and heavily shading bids even below the market clearing price. This leads to a re-allocation of shares to bidders with high valuations but to bids below the clearing price in the discriminatory auction. Bidders' surplus increases, as they only pay the uniform price rather than their bid on inframarginal units won. The government benefits from the higher market clearing price. After EU accession increased competition results in bidders shading much less around the market clearing price. This limits the scope for improving efficiency through re-allocating units to bidders with high valuations at marginal units. Moving to a uniform

[21] Kastl (2011) shows that when bidders are constrained in the number of steps they bid, bidders may submit bids above their marginal valuations (in our case demand even lower interest on the government bonds). To provide a more conservative evaluation of the relative efficiency of the discriminatory auction, we also consider a hypothetical uniform auction where bidders bid $\tilde{b}_{k+1} = v_k$ at step $k+1$. As this is not defined at the first step, we assume that the first bid is $\tilde{b}_1 = v_1 + (v_1 - v_2)$. This results in even lower equilibrium interest rates paid, and therefore an improvement in the relative performance of the uniform auction. The detailed results for this experiment are available from the authors upon request.

[22] Overall revenue differences are negative both in basis points and Euro (Columns 1 and 4), which appears contradictory, as it suggests that the uniform format is good and bad for the government at the same time. This seemingly odd fact is however driven by larger auction volumes and to a lesser extent by longer times to maturity in the post-97 period (see Table 1), which are only accounted for when computing revenue in Euro. A decomposition illustrating the effects of volumes and maturities is available from the authors upon request.

Table 5: Auction mechanism

	in basis points			in Mill. Euro		
	all	pre-95	post-97	all	pre-95	post-97
Statistic	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Revenue difference						
Mean	-0.0355	-1.4888	0.3609	-0.1437	0.5015	-0.3197
Standard Error	0.1585	0.7163	0.0235	0.0589	0.2520	0.0193
95%	-2.5399	-12.9743	-0.0618	-1.2476	-0.8851	-1.2724
50%	0.2930	0.5061	0.2797	-0.2121	-0.0992	-0.2207
5%	1.5734	2.3674	1.3021	0.7425	4.7822	0.0130
Panel B. Surplus difference						
Mean	0.4614	0.2558	0.5175	0.3590	0.0775	0.4357
Standard Error	0.1316	0.5767	0.0515	-0.0587	-0.2116	-0.0448
95%	2.2651	5.0229	1.3289	1.4316	1.9805	1.3748
50%	0.4028	0.9671	0.3732	0.2883	0.2467	0.2967
5%	-0.9563	-7.5765	0.0994	-0.3683	-2.9224	0.0450
# of auctions	112	24	88	112	24	88

Note: This table reports the difference in performance between the hypothetical uniform auction and the discriminatory auction. Panel A reports the effect on government revenue; Panel B reports the effect on bidders' surplus. In columns (1) - (3), we report the difference in basis points, while columns (4) - (6) show the difference in million Euro valuation and price paid. Surplus in basis points is the weighed absolute difference of yield bid and valuation. Surplus in Euro is the corresponding volume weighted difference between Euro valuation and price paid. Standard errors are calculated using 100 bootstrap replications.

price has a smaller effect on the market clearing price. While bidders benefit from a lower price on the inframarginal units, this results in a loss in revenue for the government.

We finally look at the allocative efficiency of the discriminatory auction mechanism by re-allocating the shares won to the highest inferred valuations. That is, we re-arrange quantity bids by sorting them according to our estimates of marginal valuations (as the hypothetical uniform would do). The results are reported in columns (1)-(3) of Table 6. We find that this mechanism would on average reallocate 11% of quantities won. This amount seems substantial at first and does not change significantly with increased competition. We then look at the value weighted reallocated share of total surplus, and calculate the percentage change in efficiency due to the discriminatory auction in percent. The results are reported in columns (4)-(6) of Table 6. We see that the efficiency increase from truthful bidding is very small, 0.11% before 1995, and 0.01% after 1997. Our results for the post 1997 period are comparable to Hortaçsu and McAdams (2010), who report a value of about 0.02%. If we add the changes in bidders' surplus and revenues as reported in Table 5, we see that the efficiency loss equals on average $580,000$ Euro per auction before EU accession and $120,000$ Euro per auction after 1997.

Table 6: Allocative efficiency and total surplus

	Allocation			Total surplus		
			in percent			
	all	pre-95	post-97	all	pre-95	post-97
Statistic	(1)	(2)	(3)	(4)	(5)	(5)
Mean	11.4852	14.5929	10.6377	0.0316	0.1049	0.0116
Standard Error	0.7340	2.0036	0.7975	0.0061	0.0219	0.0041
95%	27.0842	49.1019	25.3932	0.1451	0.5458	0.0472
50%	10.1563	10.1463	10.4429	0.0049	0.0247	0.0040
5%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
# of auctions	112	24	88	112	24	88

Note: This table reports the percentage difference in allocation (columns (1) - (3)) and total surplus between the hypothetical uniform auction and the discriminatory auction (columns (4) - (6)). Standard errors are calculated using 100 bootstrap replications.

5 Conclusions

We use recently developed methods to estimate bidders' marginal values for the bonds purchased. Knowledge of the marginal valuations allows us to quantify the effect of increased competition on bidder surplus. We find that overall surplus decreases significantly, but by a much smaller amount than what reduced form regressions would have suggested. A shift in the distribution of marginal valuations indicates that Austrian bonds have also become a more attractive product upon EU accession. This increase in valuation is due to an improved liquidity and substitutability of the bonds once they were denominated in the common European currency. This reduced the cost of trading and allowed European banks to use them as collateral. This is mirrored by the fact that the share of Austrian sovereign debt held by foreign institutions increased by 50 percentage points between 1995 and 2008.

We cannot compute the counterfactual market outcome that would have been realized without EU accession with currently available tools. However, we show that the reduction in surplus following EU accession could not have been brought about by a mere increase in bidder numbers without a change in bidding behavior. Similarly, while we cannot compute counterfactual equilibria under alternative auctions formats, we compare the auction performance under discriminatory regime to that of a hypothetical uniform benchmark. We find that with limited competition before EU accession a change in the auction format may have improved surplus extraction and efficiency, but under increased competition the question of auction format becomes less important.

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A Appendix: Results for Two Robustness Checks

Table A.1: Interim and Ex-Post Surplus Estimates with Two Bidder Groups post-97

	Interim Surplus		Ex-Post Surplus	
	all	post-97	all	post-97
Statistic	(1)	(2)	(3)	(4)
Panel A. in basis points				
Mean	1.4776	0.7429	1.5984	0.8067
Standard Error	0.1955	0.1167	0.1613	0.1281
95%	8.7100	2.8637	10.9925	3.1173
50%	0.2772	0.2040	0.2566	0.1818
5%	<0.0001	<0.0001	<0.0001	<0.0001
Panel B. in million euro				
Mean	0.7761	0.5555	0.8356	0.5853
Standard Error	0.1012	0.0931	0.0876	0.0890
95%	4.3944	3.4358	5.3960	3.4997
50%	0.1744	0.1388	0.1623	0.1451
5%	<0.0001	<0.0001	<0.0001	<0.0001
# of auctions	112	88	112	88

Note: Panel A reports estimates of bidder interim and ex-post surplus as the absolute difference of bids and valuations in basis points. Panel B reports the corresponding volume weighted difference between Euro valuation and price paid. Standard errors are calculated using 100 bootstrap replications.

Table A.2: Interim and Ex-Post Surplus Estimates: Euro vs. EU accession

	Interim Surplus		Ex-Post Surplus	
	post-97	Euro only	post-97	Euro only
Statistic	(1)	(2)	(3)	(4)
in basis points				
Mean	0.7694	0.8075	0.8581	0.9091
Standard Error	0.1244	0.1380	0.1422	0.1586
95%	2.7820	2.8128	3.1164	3.1574
50%	0.2573	0.2604	0.2083	0.2357
5%	<0.0001	0.0001	<0.0001	0.0002
Panel B. in million euro				
Mean	0.5426	0.5627	0.5821	0.6086
Standard Error	0.0982	0.1077	0.0990	0.1091
95%	2.5909	3.0884	2.8925	3.3779
50%	0.1605	0.1825	0.1605	0.1660
5%	<0.0001	0.0001	<0.0001	0.0001
# of auctions	88	80	88	80

Note: Panel A reports estimates of bidder interim and ex-post surplus as the absolute difference of bids and valuations in basis points. Panel B reports the corresponding volume weighted difference between Euro valuation and price paid. Standard errors are calculated using 100 bootstrap replications.