How much is being a Primary Dealer Worth? Evidence from Argentinian Treasury Auctions*

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July 14, 2023

PRELIMINARY VERSION – DO NOT CIRCULATE

Abstract

We propose a dynamic model of bidding in treasury auctions, in which primary dealers explicitly take into account the possibility of losing their status due to not satisfying the annual minimum winning requirements. We show that dealers bid more aggressively the greater their shortfall in satisfying the requirement, thus sacrificing short-term profits in order to secure their status. Using this trade-off we develop a method for structurally estimating the value of being a primary dealer. We implement the methodology with data from Argentina from 1996 to 2001, during which period the primary dealer requirements were especially relevant. We estimate that the gain from being a dealer is in the same order of magnitude as short-term profits. Dealers who bid optimally retain dealer status with high probability, but may have to sacrifice a significant amount of short-term profits to do so.

JEL classification: D44; L10
Keywords: Dynamic multi-unit auctions; value of being primary dealer; treasury auctions; structural estimation

*The authors would like to thank Helmut Elsinger, Andrés Neumeyer, Philipp Schmidt-Dengler, Sergio Schmukler, Sebastián Vargas and seminar audiences at the Econometric Society World Congress, Oesterreichische Nationalbank, SED, Universidad Torcuato Di Tella, and University of Copenhagen. We acknowledge financial support from Comunidad de Madrid (Excelencia Profesorado EPUC3M12), Fundación Ramón Areces and the Spanish Ministerio de Cienca, Innovación y Universidades project PID2019-104649RB-I00 and Ayudas Ramón y Cajal. All remaining errors are our own.

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1 Introduction

Treasury markets around the world are typically organized around a small group of primary dealers. These financial intermediaries enjoy a special status: they have access to auctions of government debt (sometimes exclusive), which steers in their direction potentially large volumes of trade from other bidders who are interested in participating in the primary issuance.[1] The primary dealers can thus collect various trading, subscription or access fees, and at the same time this order flow is an important source of information that can lead to significant additional rents (Hortaçsu and Kastl, 2012). Furthermore, they typically have exclusive access to special liquidity providing facilities, which became especially important during the recent quantitative easing operations.

The access provided to primary dealers allows them to manage in a fairly efficient way the duration and interest rate risk of their portfolios. While these are clearly sizable benefits, there certainly are also sizable costs. Primary dealers are obligated to actively participate in the primary issuance of government debt. In most countries, they are required to bid "at reasonable prices" for at least a proportional share (typically $1/N$, where N is the number of dealers) of the issuance in every auction and thus win about $1/N$ of total issuance over the course of a monitoring period, typically a calendar year. They are also required to make the markets for these securities (i.e., be ready to buy and sell). Finally, and perhaps most importantly, primary dealers are subject to special regulation involving extra reporting and monitoring. Nevertheless, since many (but not all) of the largest banks choose to be primary dealers, it must be on the net a profitable proposition. From the point of view of a regulator, estimating the value of keeping the primary dealer status is important in order to be able to design the regulatory framework appropriately - without fear of going "too far" and pushing the primary dealer system to the brink.

In this paper, we try to quantify the net benefits of primary dealer status.[2] To achieve this goal we utilize the above-mentioned requirement on minimal winning share over a monitoring period. In order to satisfy this requirement, dealers should be willing to sacrifice direct auction surplus. How much of this surplus they are willing to give up should be informative about the underlying value of keeping the primary dealer status.

Figure 1 illustrates this. It shows the last 4 months of the monitoring year 1997-98, and maps the average bid functions for dealers who had already satisfied the requirement three months before the end of the fiscal year (dashed line) and dealers who were below 80% of the requirement by this time (solid line).[3] As can be seen in the figure, bidders below the requirement bid considerably higher quantities at the most competitive prices. This suggests that being behind on the requirement leads to more aggressive bidding, and it is precisely this feature that we will leverage to estimate the value of primary dealership.

This suggests that the equilibrium bidding strategy of each primary dealer is inherently dynamic and that, particularly during times when the minimum winning constraint

[1]In the United States, for example, the Primary Dealers Act (1988) establishes rules governing the status of primary dealers.

[2]Arnone and Iden (2003) discusses the experience of several countries with their primary dealer systems.

[3]If a bidder abstains in a given auction, we take that as a bid of zero quantity at all prices. Furthermore, to improve legibility of the figure we have excluded one very large bidder from the data.

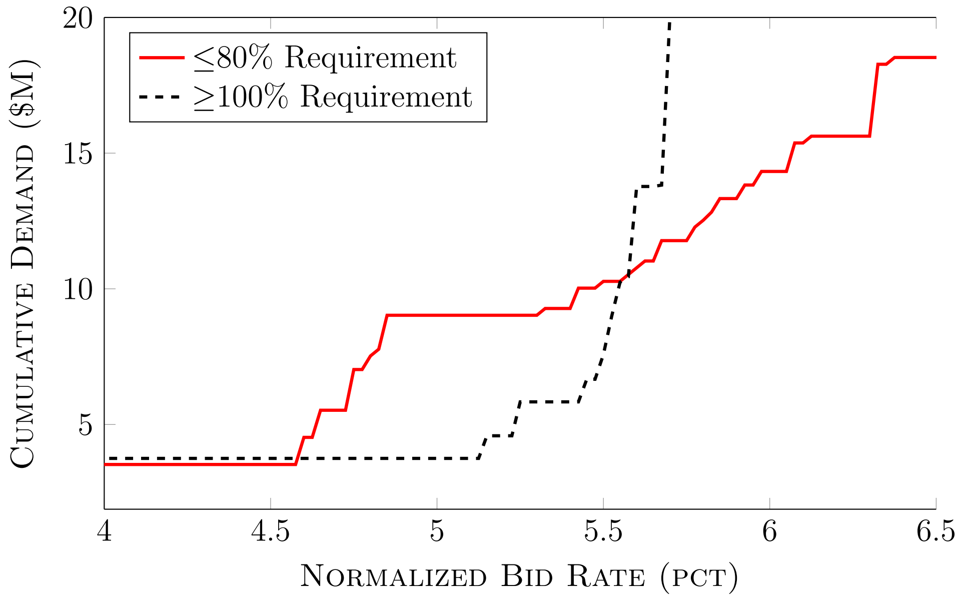

Figure 1: Average Bid Function (Dec 97 - Mar 98)

might bind, it might call for a substantially different bidding behavior than the regular equilibrium strategy in an isolated auction. We thus build on the literature analyzing auctions of government debt and extend it to a setting, in which auctions are dynamically linked. In static treasury auctions, bidders' strategies are mappings from private information into bid curves, and bidders optimally choose their bids so as to trade off the probability of winning and surplus. In our dynamic setting, an equilibrium strategy will depend not only on the private information, but also on how close the dealer is to violating the requirement. Our theory model shows precisely how the equilibrium strategy will be impacted through the dynamic constraint.

We estimate our model using a data set from Argentina from May 1996 until March 2001. We focus on a period in which the winning requirement for primary dealers alternated between 4 percent, 5 percent and 6 percent. We show in a preliminary regression analysis that in this period, having to win a larger proportion of the remaining supply to meet the requirement is correlated with more aggressive bids. Hence, the initial analysis suggests that there are periods in which the dynamic constraint is binding, and the bids therefore contain information about the value of continuing as a primary dealer.

Next we consider how to identify this value. We first define the state to be the dealers' cumulative winnings, and assume that dealers bid to maximize their payoffs based on their own state and beliefs about rivals' states that are consistent with the observed ones. Following similar arguments to Jofre-Bonet and Pesendorfer (2003) we show that by applying the usual step in empirical analysis of static auction markets, based on the insights from single unit auction analysis proposed by Guerre, Perrigne and Vuong (2000), we can obtain the *total marginal value* of the dealers at each step in their bid function. This total marginal value can be decomposed as follows:

$$\text{total marg. value} = \text{flow marg. value} + \beta \times \text{marg. continuation value},$$

where the marginal flow value measures the direct value of winning, the marginal continuation value measures the change in the increase in the probability of retaining dealer status times the discounted value of being a dealer, and β is the discount factor.

Our methodology then proceeds as follows. In order to separate the two components, we first make a guess of the value of being a dealer. This identifies the continuation value function in the last period, T, allowing us to back out the marginal flow value for T. Given the continuation value function and the marginal flow value, we can estimate the equilibrium bid of a given dealer for *any* state. But then, in turn, we can use the optimal bids to obtain the continuation value function at $T-1$. Iterating this procedure, we can estimate the continuation value function for each period. This gives us for each period a continuation value function and a set of flow values that are consistent with (a) the primary dealer value we have specified and (b) the bids. To assess our guess of the primary dealer value, we obtain an alternative estimate of the continuation value function in the following manner. Initially, we observe that the total marginal value for bidders who have already satisfied the requirement is equal to the marginal flow valuation, as these bidders have no dynamic concerns. Since the marginal flow values are drawn from the same distribution, regardless of the state of the bidder, then taking the difference between them should, in expectation, reveal the marginal continuation value. We thus have an alternative estimate of the marginal continuation value, and plugging this into the equilibrium relationship between the primary dealer value, we obtain an (output) estimate of the value. Finally, we search for a fixed point, i.e. an input guess that leads to the same output estimate.

The primary dealer value is only identified via the bids when there is a real possibility that the dealer will lose her status, should she not bid competitively enough. That is to say, we would never be able to identify the value if by bidding as if there were no dynamic incentives, the dealer could with near certainty retain her status. We assess identification using the estimated probability of retaining dealer status when bidding optimally respectively with and without dynamic incentives, and also analyze the estimated amount of flow utility given up to retain dealer status under the optimal bid. These figures together give us an idea about how well-identified the individual estimates are.

We estimate primary dealer value and normalize it by the total supply. We see that years 1996-97 and 2000-01 have low estimates (0.2 and 0.3 bps) whereas the remaining years have higher estimates (between 1.4 and 2.5 bps). The loss in flow utility experienced by dealers who bid optimally was significant in the years 1997-98 and 1998-99, at 0.9 and 0.8 bps. Thus, bidding to maintain dealer status was costly, but always compensated by the gain itself, as estimated by the model. When bidding optimally taking dynamic incentives into account, the probability of maintaining dealer status was very high, only dropping slightly in the final year (to 0.9176). Hence, our estimates suggest that there were gains from being a dealer, but that maintaining dealer status was not automatic and came at a cost, in terms of flow utility.

Related literature. The contribution of our paper is two-fold. First, we extend the literature on structural estimation of Treasury auctions by adding a dynamic component and showing how this can be estimated using the same resampling methods as the previous literature (Guerre *et al.*, 2000; Jofre-Bonet and Pesendorfer, 2003; Hortaçsu and McAdams, 2010; Kastl, 2011). We illustrate that whenever such dynamic considerations are important, ignoring them and proceeding with the estimation of values as in the usual

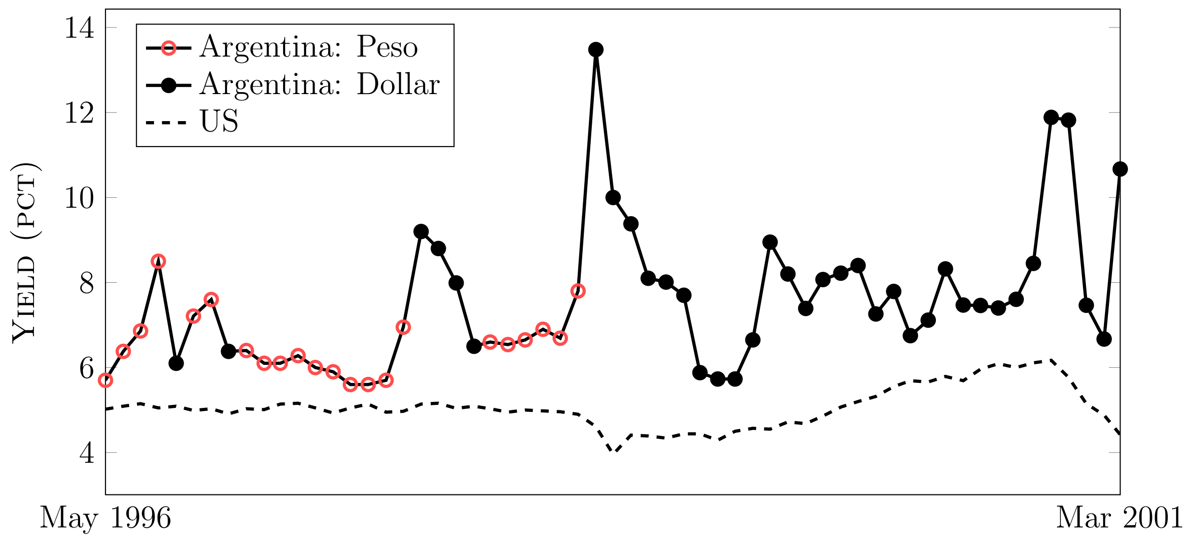

Figure 2: 3-Month T-bill Yield

static setup would typically lead to overestimating the marginal values. Second, we contribute to the limited literature on primary dealer systems by providing a first estimate of the value of being a primary dealer in Treasury bill auctions. In this sense, we are related to Hortaçsu and Kastl (2012) who estimate the informational advantage of dealers who observe clients' bids before making their own bids, but both our methodology and aim are very different. Finally, we are also related more generally to the literature on Treasury bill auctions (Nyborg and Sundaresan, 1996; Nyborg, Rydqvist and Sundaresan, 2002; Hortaçsu, 2002; Kang and Puller, 2008; Hortaçsu, Kastl and Zhang, 2018).

2 Data Description and Institutional Background

In April 1996, Argentina implemented a primary dealer system to auction public debt with the objective of developing a domestic treasury market with a liquid secondary market. A calendar with auction dates and format, security types, and volumes was published at the beginning of each fiscal year. At the time Argentina introduced this market, it had maintained a currency board with the peso at parity with the US dollar for more than five years and thus, the country had secured price stability at the cost of being exposed to external shocks. This can be seen in Figure 2 which features the cut-off yields for auctions of short-term bills (notice that there were auctions denominated in both US dollars and pesos in the first years of this period).[4] The figure shows that interest rates spiked during the Asian crisis in July 1997, when Russia defaulted on its sovereign debt in August 1998, and after Brazil devalued the real in January 1999. Besides these episodes, yields reveal political uncertainty when Domingo Cavallo was ousted as finance minister in July 1996, during the presidential campaign for the October 1999 presidential elections, and in the fall of 2000 after the minority party left the coalition government.[5]

[4]For Argentina, the yield in the graph is the monthly primary market auction average, for the United States it is the monthly average of the secondary market rate for 3-month T-bills.

[5]The vice-president resigned on October 6, 2000.

	Apr 1996	Apr 1997	Aug 1997	Aug 1998	Jan 2001
Dealer requirement	4%	4%	5%	4%	6%
Across instruments	No	Yes	Yes	Yes	Yes
Max no of dealers	Yes	Yes	No	No	No

Table 1: Main Changes in Dealer Regulations

2.1 Primary Dealer System

Twelve banks, among the largest in the financial system, were initially chosen to be primary dealers: Banco de Galicia, J. P. Morgan, Banco de Santander, Chase Manhattan Bank, Deutsche Bank, Banco Río, Banco Francés, Banco de Crédito Argentino, HSBC, Bank of America, Citibank, and Bank Boston.[6] In the subsequent years, there were two changes to the primary dealers. In April 1997, Banco de Crédito Argentino relinquished its dealer status as it was acquired by Banco Francés, which already had dealer status. ING, which had been ranked 4th in treasuries bought during the year, replaced Banco de Crédito Argentino as primary dealer.[7] In May 1997, Banco de Santander bought Banco Río, and as a consequence had to relinquish its market making activities by the end of the monitoring period. ABN, which had been ranked 12th by treasuries bought during the year, replaced Banco Santander as primary dealer.

Dealers acquired both rights and obligations. The main obligations consisted of participating in primary issues, quoting prices and trading in secondary markets. Performance was evaluated annually over the period April to March and banks that underperformed could ultimately lose their primary dealer status, although we cannot observe this directly in our sample. Dealers received fees that initially only depended on their participation in primary issues. Issues of 3-month bills paid 7.5 bps, whereas fees for 6-month bills were 15 bps and 40 bps for 5-year bonds. Dealers also had the right to participate in a 2nd round auction in which they could acquire an additional amount of the security at the clearing price of the 1st round auction. How much they could acquire in this 2nd round depended on how much they had acquired in previous auctions.

A number of regulatory changes made over the years help us identify the importance of primary dealer incentives. These changes are described in Appendix C and the main events that we use in our analysis are summarized in Table 1. In particular, we focus on the following events. First, changes in the requirement for dealers, which measures how large a part of supply a dealer must acquire to maintain her dealer status. This varies between 4%, 5% and 6%. Second, whether the requirement is calculated per instrument or across instruments. Initially it was calculated per instrument, but in April 1997 this was changed. Third, whether there is a maximum number of dealers. The number of dealers was capped at 12 at first, but in August 1997 this restriction is abolished.[8]

[6] Banks were chosen based on participation in primary and secondary markets during 1995, as well as assistance provided in the organization of the new market.

[7] Notice that our data set does not include April 1996, but in the period May 1996 to March 1997, ING was ranked fourth.

[8] It was only in May 2001 that the number of market makers increased to thirteen when a new bank, Credit Suisse First Boston, was granted primary dealer status.

	1996-97	1997-98	1998-99	1999-00	2000-01
# auctions	11	12	12	15	22
# bidders	27	21	20	18	21
# bids/bidder	6.6	8	8.3	11.7	15.2
# comp. steps/bidder	6.1	4.6	5.2	4.6	4.3
prop. bids with non-comp step	0.6	0.7	0.7	0.8	0.8
# 2nd round bids/auction	2.5	1.4	2.8	2.4	1.8
bid-to-cover	4	4	3.9	3.2	3.7
dealer quan.-weighted bid rate	6.1	6.1	7.7	7.9	7.3
dealer avg. max. quantity	92.1	109.7	92	76.9	88

Table 2: 3-Month T-Bills Auction Descriptive Statistics

2.2 Data

Our data set comprises bids in all Argentinian Treasury bill auction between May 1996 and March 2001. In our analysis, we focus on 3-month treasury bills. Until December 1999, auctions for 3-month bills took place on a monthly basis and the auction size was 250 million USD; afterwards, auctions were held at a higher frequency and the auction size increased to 350 million USD.[9] These securities represented between 34% and 46% of the annual stock of Treasury bills in our sample. Table 2 summarizes the data by monitoring year such that, for instance, 1997-98 represents the period April 1997 to March 1998.

We define a bidder as anyone who has made a bid, regardless of whether these were winning bids. Bids could be submitted either as non-competitive bids or competitive bids, with the former feature being used extensively, particularly by dealers. Notice that the dealers did not make extensive use of their right to submit 2nd round bids at the clearing price in this period: on average we observe less than three 2nd round bids per auction in all years. The bid-to-cover is between 3.2 and 4, with the vast majority of this made up by dealer bids.

For our analysis, we define a group of *augmented dealers*. These dealers comprise all banks that were dealers at some point in our data set, less Banco de Crédito Argentino and Banco Santander, who both relinquished their dealer status early in the period comprised by the data set. Our motivation is that the banks who eventually became dealers seem to have been bidding aggressively, expecting that there would be a possibility to become dealers. Conversely, the banks who gave up dealership will have known in advance that this would most likely happen, and would therefore not have had the same incentives as other banks. Our main analysis is carried out on a subset of these, which we refer to as *augmented normal dealers*. These consist of the augmented dealers less a very large dealer, who is the only dealer to buy at least twice the required amount in the first 4 years (in year 5, no dealer reaches this amount).

[9] In the first period, auctions were held around the second week of the month. In the second period, in some months auctions were held around the second and fourth week of the month.

Statistic	N	Mean	St. Dev.	Min	Max
shortfall	487	0.0236	0.0131	0.0001	0.0500
maxQNorm	487	0.2556	0.2708	0.0014	1.3000

Table 3: Summary Statistics

2.3 Preliminary Evidence on Bidding Dynamics

We begin by examining the relationship between bids and the primary dealer requirement.

In order to do this we define the variable *shortfall*, which captures how much of the remaining supply a bidder must acquire in order to meet the annual requirement. We then regress bids on this variable and interact it with the changes in the relevant primary dealer regulation. In particular, whenever the cumulative winning is smaller than the yearly requirement, then

$$\text{shortfall} = \frac{\text{yearly requirement - cumulative winning}}{\text{remaining supply}}.$$

When the cumulative winning is at least as great as the requirement, we set the shortfall to zero, reflecting that in this case, the requirement has been met and should no longer affect bidding. We further define the variable *maxQNorm* which captures the quantity demanded at the bid step with the highest rate, i.e. the highest quantity that can possibly be acquired by the dealer. This is normalized by the supply. Finally, the dependent variable *compAvgRate* is the quantity weighted average bid rate, taken into account only the competitive part of the bid.

The data consists of bids for all 3-month auctions between May 1996 and March 2001, and we include bids with a shortfall strictly greater than zero. Table 3 summarizes the variables. Notice that the shortfall at the beginning of the year is exactly equal to the dealer requirement. Therefore, the shortfall maximum is 0.05 reflects that the requirement at the beginning of the year 1998-99 was exactly 5 percent.[10] In January 2001 the requirement rose to 6 percent, but at this point most dealers had already secured a substantial amount, and so the shortfall remained low.

Table 4 presents the results of the regression analysis. Observe that since the dependent variable is the demand rate, a positive coefficient should be interpreted as a less aggressive bid (higher rate, lower price) and a negative coefficient should be interpreted as a more aggressive bid (lower rate, higher price). In all the three models, the coefficient on the variable *shortfall* is negative and significant, suggesting that a higher shortfall (needing to purchase more of remaining supply to meet the requirement) is associated with a lower bid rate, that is to say, a more aggressive bid. The maximum demand, *maxQNorm*, has a positive and significant coefficient, suggesting that bidders who make larger bids (which may be taken as a proxy for larger bidders) also make less competitive bids.

In conclusion, the regression analysis suggests that bidding is affected by the dynamic incentives introduced by the dealer requirement.

[10] In theory, shortfall could go above 0.05 in this year if a dealer had fallen significantly behind and thus needed to acquire more than 5 percent of the remaining supply, but this did not occur in our data.

	Dependent variable:		
	compAvgRate		
	(1)	(2)	(3)
shortfall	-14.895^{***}	-29.491^{***}	-27.029^{***}
	(5.196)	(9.567)	(9.553)
maxQNorm			0.860^{***}
			(0.329)
Month/Year/Bank FE	No	Yes	Yes
Sample	All	All	All
Observations	487	487	487
R^2	0.017	0.318	0.328
Adjusted R^2	0.015	0.279	0.288
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4: Bidding and Shortfall

3 A Dynamic Model of Bidding

In this section we model a sequential auction setting where two types of bidders are present: *dealers* and *others*. Dealers must acquire a certain proportion of supply to retain their dealer status, and thus have dynamic incentives on top of the flow utility they receive from each auction; others only receive flow utility.[11] The static part of the model is based on the share auction model of treasury bill auctions based on Kastl (2011)'s discrete-bid version (finitely many steps in bid function) of Wilson (1979)'s share auction model with private information.

3.1 Setup

Our analysis focuses on a single monitoring period (a year in our application).

Sequential auction market. Let $t = 1, ..., T$ index the auction with $t = 1$ denoting the beginning of the monitoring period and $t = T$ the end of the monitoring period. There is a common discount factor β between adjacent auctions. Throughout the paper, we will drop the indexes for clarity of the exposition, unless it is important for distinguishing the timing. Each auction is for a perfectly divisible good of Q_t units.

Dealers. There are N potential *dealers* (in index set $\mathcal{D}$). We assume that N is commonly known. Indeed, in our empirical application all participants have to register with

[11] In our empirical application we will consider also bidders who become dealers at a later stage (potential dealers) and divide the set of dealers into subsets for resampling purposes, but for now we treat them as one set.

the Bank of Argentina before the auction as dealers and non-dealer bidders and the list is thus publicly available every year. Prior to every auction, each dealer receives a private signal which determines the valuation she attaches to the security. We describe this in more detail below.

Others. To simplify the analysis, we model the other bidders as being non-strategic. In particular, we assume that their joint demand is given by the function $x(p; S_{0,t})$, where $S_{0,t}$ is a random variable with commonly known distribution and $x(\cdot; S_{0,t})$ is decreasing for all $S_{0,t}$. The assumption that other bidders are non-strategic is of no consequence to our analysis of dealers. It would go through unchanged even with other bidders being strategic if we also assume random supply, but the assuming other bidders are non-strategic greatly simplifies exposition.

3.2 Assumptions

We now describe the assumptions we impose on the game. First, we assume that dealers each receive a private signal which governs their valuation (to be defined later) and which is independent of the signals of other bidders.

Assumption 1. *Dealers' private signals, $S_{1,t}, ..., S_{N,t}$, are independent and identically distributed according to the atomless distribution function $F_t(S)$ with density function $f_t(S)$, and support $[0, 1]$. Furthermore, $S_{n,t}$ is independent of $S_{0,t}$ for all $n > 0$ and t.*

Strictly speaking, independence is not necessary for our characterization of equilibrium behavior in this auction, but we impose it in our empirical application as our estimator relies on it. Let $S^t := (S_{0,t}, S_{1,t}, ..., S_{N,t})$ be the vector of all private signals in period t.

Dealers receive a flow value from winning q units of the security according to a marginal valuation function $v_n(q, S_{n,t})$. We assume that the marginal valuation function is symmetric such that $v_n(q, S_{n,t}) = v(q, S_{n,t})$. We impose the following restrictions on the marginal valuation function.

Assumption 2. *Dealers' marginal valuation $v(q, S_{n,t})$ is non-negative, bounded, strictly increasing in (each component of) $S_{n,t}$ for all q and weakly decreasing in q for all $S_{n,t}$.*

Note that this assumption implies that learning other bidders' signals does not affect one's own valuation – thus using auction terminology we focus on the case of "private values." This assumption is not restrictive in the context of Argentine treasury auctions as the secondary market was highly illiquid.[12]

Define a *state* of dealer n in period t as $a_{n,t} \equiv \sum_{s<t} q^c_{n,s}$, where $q^c_{n,s}$ is the allocation, i.e., market clearing quantity, that n obtained in period s. In order to retain dealer status, $a_{n,T} + q^c_{n,T} \geq \underline{a}$, where $\underline{a}$ is the dealer requirement set by regulation. We make the following simplifying assumption.

Assumption 3. *A dealer who loses the dealer status never regains it.*

[12]This can be inferred from the increasing importance given to secondary market performance in the regulations and its proceedings, see table 7 and appendix C.

Suppose that the state defined as past winnings of all rivals up to that point is known and given by $a^t = (a_{1,t}, ..., a_{N,t}) \in \mathcal{A}$. Dealers' pure strategies are mappings from private information and states to bid functions $\sigma_n : [0, 1] \times \mathcal{A} \to \mathcal{Y}$, where the set $\mathcal{Y}$ includes all admissible bid functions. Given the symmetry assumption, we will assume that the bidding data is generated by an equilibrium of the game in which dealers submit bid functions that are symmetric up to their private signals, i.e. $y_n(p; S_{n,t}, a^t) = y(p; S_{n,t}, a^t)$ for all $n = 1, ..., N$.

Since in most divisible good auctions in practice, including the Argentinian treasury bill auctions, the bidders' choice of bidding strategies is restricted to non-increasing step functions with an upper bound on the number of steps, $\overline{K}$, we impose the following assumption:

Assumption 4. *For all $S_{n,t}$, we assume that $y(\cdot; S_{n,t}, a^t)$ is a non-increasing step function with $K \leq \overline{K}$ steps, where $\overline{K}$ does not depend on $S_{n,t}$. Denote by $b_{n,t,k}$ and $q_{n,t,k}$, respectively, the prices and demands corresponding to the steps $k = 1, ..., K$ of $y(\cdot; S_{n,t}, a^t)$.*

When bidders use step functions as their bids, rationing occurs except in very rare cases; thus we will assume, consistently with the application, pro-rata on-the-margin rationing, which proportionally adjusts the marginal bids so as to equate supply and demand. Also, in situations where multiple prices clear the market, we assume that the auctioneer selects the highest market clearing price.

3.3 Value functions

The key source of uncertainty faced by the bidders in the auction that forms our stage game is the market clearing price, which maps the state of the world into prices through equilibrium strategies. This random variable is summarized by a function $P^c(S^t, a^t)$, which we will sometimes abbreviate as P^c. Its distribution, $H_t(p, q; a^t) \equiv \mathbb{P}(P^c \leq p | q_n = q, a^t)$, is determined by the distribution of the private information of rival bidders as well as the strategies they employ. Let $S_{-n,t}$ be the set of all private signals at t but that of n. We can then calculate H_t as

$$H_t(p, q; a^t) = \mathbb{P}_{\{S_{m,t}\}} \left(Q - \sum_{m \in \mathcal{D} \backslash n} y(p; S_{m,t}, a^t) - x(p; S_{0,t}) \geq q \right). \qquad (1)$$

Dealer i's knowledge of the states affects H via the optimal bids of the rival dealers. The more aggressive the rivals need to be to satisfy the requirements, the higher the prices.

We normalize the payoff that bidders derive from other sources than auctions of government debt to 0. We denote by C the payoff of a dealer who fails to retain dealer status at the end of $t = T$. That is to say, C measures the flow profit that a dealer obtains when bidding to maximize flow profit. We assume that at the beginning of a monitoring period dealers receive a lump sum outside payoff (over and above that of other bidders) of g and we denote the present value at the end of $t = T$ of remaining a primary dealer by $C + G$, such that G is the gain from remaining a dealer. Note that this value implicitly takes into account the probability that a dealer might lose her status in the future, as well as the loss in flow profits that the dealer must sustain in the future to retain dealer status. First we describe the expected flow utility of a dealer. Define by $Q^c(P^c, \hat{y})$ the bidder assignment given the schedule and clearing price P^c. The only way in which the states a^t influence this expectation is precisely through the distribution of prices H_t. In particular, this becomes

$$U_t(\hat{y}, S_{n,t}, a^t) \equiv \int_0^\infty \left[v\left(Q^c\left(p,\hat{y}\right), S_{n,t}\right) - p \cdot Q^c\left(p,\hat{y}\right)\right] dH_t\left(p, \hat{y}(p); a^t\right). \tag{2}$$

Now we are ready to state the Bellman equation associated with the dealer's optimization problem in period $1 \leq t < T$. The dealer payment g does not affect the optimization problem, and therefore we assume that it is received before period 1 starts. Let $Q^c_{n,t}$ denote the winning of n in period t, and let $Q^{c,t}$ denote the vector of the winning of all dealers in period t. We let $V_{n,t}(S_{n,t}, a^t)$ denote n's value of entering period t with signal $S_{n,t}$ and state vector a^t. Hence, for $t < T$ the equation becomes

$$V_{n,t}(S_{n,t}, a^t) \equiv \max_{\hat{y}} \left\{ U_t\left(\hat{y}, S_{n,t}, a^t\right) + \beta \mathbb{E}_{\{Q^c_{n,t}, S_{n,t+1}\}}\left[V_{n,t+1}(S_{n,t+1}, a^t + Q^c_{n,t}) | a^t, \hat{y}\right] \right\}. \tag{3}$$

Notice that the value function $V_{n,t}$ takes the entire vector of states, a^t as an argument, because the expectation of outcomes depends on this, but is indexed by n, as the state $a_{n,t}$ is the only state that matters for n's probability of retaining dealer status. Then, for the last period:

$$V_{n,T}\left(S_{n,T}, a^T\right) \equiv \max_{\hat{y}} \left\{ U_T\left(\hat{y}, S_{n,T}, a^T\right) + \beta \mathbb{E}_{\{Q^c_{n,T}\}}\left[\mathbb{I}\left(a_{n,T} + Q^c_{n,T} > \underline{a}\right) G + C | a^T, \hat{y}\right] \right\}. \tag{4}$$

Hence, in the final period, the maximization takes place over the flow utility and a step function which measures whether the bidder reaches the threshold state.

3.4 Equilibrium

Since bidders only observe the history of their own state (i.e., cumulative allocation in the previous auctions), they need to integrate over the other bidders' cumulative allocations. (3) thus becomes:

$$\begin{aligned} V_{n,t}(S_{n,t}, a_{n,1}, \ldots, a_{n,t}) = \max_{\hat{y}} \{ & \mathbb{E}_{A_{-n,t}}\left[U_t\left(\hat{y}, S_{n,t}, a^t\right) | a_{n,1}, \ldots, a_{n,t}\right] + \\ & \beta \mathbb{E}_{\{Q^{c,t}, S_{n,t+1}, A_{-n,t}\}}\left[V_{n,t+1}(S_{n,t+1}, a^t + Q^{c,t}) | a_{n,1}, \ldots, a_{n,t}, \hat{y}\right] \}. \end{aligned} \tag{5}$$

Notice that the expectations in (5) essentially say that the expected payoff corresponding to a particular bid $y^*_t(p; \cdot)$ is chosen to be optimal taking into account not only that the market clearing price is random due to private signals of other bidders, but also since their states, i.e., their cumulative allocations, are also privately observed, hence random from other bidders' perspectives. These states, in turn, impact the equilibrium bidding strategies of rival bidders, in addition to their private signals.

To simplify the problem we will impose a reasonably weak assumption that the current (private) state a_t is a sufficient statistic for the private history of past purchases.

Assumption 5.

$$E_{Q^c, A_{-n,t}}[x | a_{n,1}, ... a_{n,t}] = E_{Q^c, A_{-n,t}}[x | a_{n,t}]$$

This assumption rules out, for example, cases where some past private histories that lead to the same private state (i.e., quantity won) might be associated with different states of rivals. For example, those in which some or all rivals are more likely to be close to being "priced-out" from the market, i.e., that they might give up on retaining the primary dealer status, which would in turn impact their bidding behavior and thus the distribution of the market clearing prices. While theoretically possible (and in principle testable and implementable), we do not observe any sufficiently "wide" swings in private histories and the subsequent bidding behavior that it would warrant modeling such aspects explicitly.

We can now define a *Symmetric Bayesian Nash Equilibrium*, or *equilibrium* for short, as a set of bid functions y^* satisfying the following:

- At each t and $s_{n,t}$, $y_t^*(p; s_{n,t}, a_{n,t})$ solves

$$V_{n,t}(s_{n,t}, a_{n,t}) = \max_{\hat{y}} \Big\{ \mathbb{E}_{Q^c_{n,t}, A_{-n,t}} \left[U_t\left(\hat{y}, s_{n,t}, a^t\right) | a_{n,t} \right] + \beta \mathbb{E}_{\{Q^c_{n,t}, S_{n,t+1}\}} \left[V_{n,t+1}(S_{n,t+1}, a_{n,t} + Q^c_{n,t}) | a_{n,t}, \hat{y} \right] \Big\}. \tag{6}$$

- $a_{n,t+1} = a_{n,t} + Q^c_{n,t}$ with beliefs about $Q^c_{n,t}$ being consistent with $y^*(p; s_{n,t}, a_{n,t})$.[13]
- At each t, beliefs about $A_{-n,t}$ are consistent with $y^*(p; s_{n,t}, a_{n,t})$ and $a_{n,t}$.

Using this equilibrium concept thus allows as to convert the dynamic part of the bidder's maximization problem into a single-agent problem by fixing the bidder's expectation of future states (and hence the distribution of bids) by other bidders. It is convenient to define the ex ante value function $W_T\left(a_{n,T} + Q^c_{n,T}\right) \equiv \mathbb{I}\left(a_{n,T} + Q^c_{n,T} > \underline{a}\right) G$, which for $1 \leq t < T$ becomes $W_t(a_{n,t}) \equiv \mathbb{E}_{\{S_{n,t}\}} \left[V_{n,t}(S_{n,t}, a_{n,t}) \right]$. For $t \leq T$ we obtain that $V_{n,t}(s_{n,t}, a_{n,t})$ equals

$$\max_{\hat{y}} \Big\{ \mathbb{E}_{\{Q^c_{n,t}, A_{-n,t}\}} \left[U_t\left(\hat{y}, s_{n,t}, a^t\right) | a_{n,1}, \ldots, a_{n,t} \right] + \beta \mathbb{E}_{\{Q^c_{n,t}\}} \left[W_t(a_{n,t} + Q^c_{n,t}) | a_{n,t}, \hat{y} \right] \Big\}. \tag{7}$$

We next state a preliminary result that will be useful in the analysis. The following proposition is a dynamic corollary to Proposition 1 of Kastl (2011) and characterizes the necessary conditions for equilibrium bidding:

Proposition 1. *Under assumptions 1-5, in any Equilibrium of a Uniform Price Auction with Dynamic Constraints, in which ties at market clearing price occur with zero probability, for a bidder of type $S_{n,t}$ in state $a_{n,t}$ every step k in the equilibrium bid function $y_t^*(\cdot; S_{n,t}, a_{n,t})$ for $t < T$:*

$$\mathbb{P}\left(b_{n,t,k} > P^c > b_{n,t,k+1} | S_{n,t}, a_{n,t}\right) \left[\tilde{v}_t\left(q_{n,t,k}, S_{n,t}, a_{n,t}\right) - \mathbb{E}_P\left(P^c | b_{n,t,k} > P^c > b_{n,t,k+1}, S_{n,t}, a_{n,t}\right) \right] = q_{n,t,k} \frac{\partial \mathbb{E}_P\left(P^c I\left[b_{n,t,k} \geq P^c \geq b_{n,t,k+1}\right] | S_{n,t}, a_{n,t}\right)}{\partial q_{n,t,k}} \tag{8}$$

where $\tilde{v}_t\left(q_{n,t,k}, S_{n,t}, a_{n,t}\right) = v\left(q_{n,t,k}, S_{n,t}\right) + \mu_t\left(a_{n,t} + q_{n,t,k}\right)$ *and*

$$\mu_t\left(a_{n,t} + q_{n,t,k}\right) = \beta \frac{\partial W_t(a_{n,t} + q_{n,t,k})}{\partial q_{n,t,k}}. \tag{9}$$

[13]The initial state is $a_{n,1} = 0$.

We will henceforth refer to $\tilde{v}_t$ as the *pseudo flow value*. For all $t < T$ the "dynamic correction" term $\mu_t(\cdot)$ captures the impact of a marginal change of $q_{n,t,k}$ on the (discounted) expected continuation value through its impact on the state transition. It is exactly this term that will inform us about the value of being a primary dealer. At $t = T$, i.e., in the last period, either $\mu_T(a_{n,T} + q_{n,t,k})$ is zero for $a_{n,T} + q_{n,t,k} \neq \underline{a}$ but undefined for $a_{n,T} + q_{n,t,k} = \underline{a}$.[14] Notice that for $\beta = 0$, the problem becomes static and the solution reduces to that of Kastl (2011).

4 Estimating Primary Dealer Gain

In this section we describe a procedure for estimating the primary dealer gain, G. Our identification argument follows a natural sequence of steps. First, we write an identification equation. We then discuss how to obtain the different parts of the equation. Some parts will come directly from the data, whereas others will come from an estimate of the optimal bid function of the dealers, based on our estimates of their flow valuations. Combining these with the identification equation then gives us a "moment condition" we can estimate. To make it clear from where each component of this moment condition comes, we will use the following superscripts: e for variables that are merely the result of resampling together with equilibrium conditions, and o for variables that come from the application of the optimal demand function that we will estimate.

An identifying equation. We first consider how to write up a relationship between identifiable variables and G, the unobserved variable we wish to estimate. In order to do this, it is convenient first to identify continuation flow utility for $t < T$ as

$$Z_t(a_{n,t}) \equiv \mathbb{E}_{\{S_{n,t},a_{n,t+1}\}} \left[U(y^*(\cdot; S_{n,t}, a_{n,t}), S_{n,t}, a_{n,t}) + \beta Z_{t+1}(a_{n,t+1}))|a_{n,t} \right], \qquad (10)$$

with $Z_T(a_{n,T}) \equiv \mathbb{E}_{\{S_{n,T}\}} \left[U(y^*(\cdot; S_{n,T}, a_{n,T}), S_{n,T}, a_{n,T})|a_{n,t} \right]$. This is the present value of the expected flow utility received in the remainder of the monitoring period, conditional on following the equilibrium bid function y^*. Let $\Pi_t(a_{n,t})$ denote the equilibrium probability in period t that bidder n retains dealers status given state $a_{n,t}$.

With the two aforementioned definitions in hand, we can break down the continuation value at any time as the sum of the continuation flow value and the present value of future monitoring periods, which is given by C plus G times the probability of retaining dealer status. This gives us

$$W_t(a_{n,t}) = Z_t(a_{n,t}) + \beta^{T-t}(\Pi_t(a_{n,t})G + C). \qquad (11)$$

Notice that since we have substituted the optimal bid function everywhere, this equation captures (7). In the algorithm, we set $C = 0$, as C merely shifts utility vertically and therefore does not matter for optimal choices. We now turn to how to estimate the different components.

[14] Thus, $\mu_T(\cdot)$ is proportional to a Dirac delta distribution with $\int_{-\underline{\delta}}^{\bar{\delta}} \mu_T(x)dx = G, \forall\ 0 < \underline{\delta} \leq \underline{a},\ 0 < \bar{\delta}$.

STEP	DESCRIPTION	INPUT	OUTPUT
(a)	Estimate pseudo flow utility		$\tilde{v}_{n,t}$
(b)	Guess $\tilde{G}$ to obtain W^o_T	$\tilde{G}$	W^o_T
(c)	Derive bid step flow valuation	$W^o_{t+1}, \tilde{v}_{n,t}$	$v_{n,t}$
(d)	For all n, calculate optimal bid function	$W^o_{t+1}, v_{n,t}$	$y^*_{i,t}$
(e)	If $t > 1$: calculate W^o_t and return to (c)	$W^o_{t+1}, v_{n,t}, y^*_{n,t}$	W^o_t

TABLE 5: ALGORITHM FOR ESTIMATING CONTINUATION VALUE

An optimal bid estimate of the value function. In Appendix A, we describe an algorithm for estimating the optimal bid $y^*_{n,t}$ as a function of $v_{n,t}$, W_{t+1} and H_t. Again following Hortaçsu and Kastl (2012), we obtain an empirical estimate of H_t by resampling. The specifics of the resampling procedure are in Section 5.1. Table 5 summarizes our procedure for using the optimal bids to estimate flow valuations and, in turn, the value function, conditional on a guess $\tilde{G}$ of the dealer gain. We next describe each step in detail.

(a) We estimate the pseudo flow utility using the algorithm detailed in Appendix B.

(b) We make a guess of G which we denote $\tilde{G}$. This allows us to obtain an estimate W^o_T of the last-period continuation value, and we can now start the iteration.

(c) Suppose we know W^o_{t+1}, our next-period continuation value estimate. We can then identify the flow valuation from the pseudo flow valuation as

$$v^o_{n,t,k} \equiv \tilde{v}_{n,t,k} - \beta \cdot \frac{\partial W^o_{t+1}(a_{n,t})}{\partial a_{n,t}}. \tag{12}$$

.

(d) With W^o_{t+1} and $v^o_{n,t,k}$, we can calculate the optimal bid for bidder n at time t on a price grid with typical element p_k, using the algorithm in Appendix A for each a. Denote this $y^o_{n,t}(p; a)$.

(e) Let $\pi^e_{t,k}$ be the resampled probability that p_k is the clearing price, given y^o_t. Then, finally, for $1 \leq t < T$,

$$W^o_t(a) \equiv \frac{1}{N} \sum_n \sum_k \pi^e_{t+1,k} \left[y^o_{n,t+1}(p_k; a) \cdot (v^o_{n,t+1,k} - p) + W^o_{t+1}(a + y^o_{n,t+1}(p; a)) \right]. \tag{13}$$

Notice that $W^o_0(0)$ defines the value of being a dealer at the beginning of the monitoring period where all dealers have a state of zero. Similarly, set $Z^o_T(a) \equiv 0$ for all a, whereas

$\Pi_T^o(a) \equiv 1$ for all $a \geq \underline{a}$ and $\Pi_T^o(a) \equiv 0$ otherwise. Then, for $1 \leq t < T$,

$$Z_t^o(a) \equiv \frac{1}{N} \sum_n \sum_k \pi_{t+1,k}^e \left[y_{n,t+1}^o(p_k; a) \cdot (v_{n,t,+1k}^o - p) + Z_{t+1}^o(a + y_{n,t+1}^o(p; a)) \right]; \tag{14}$$

$$\Pi_t^o(a) \equiv \frac{1}{N} \sum_n \sum_k \pi_{t+1,k}^e \Pi_{t+1}^o(a + y_{n,t+1}^o(p; a)). \tag{15}$$

These three variables are the result of the same optimization process, and therefore (11) is identically true if we substitute them in. To turn (11) into a "moment equation" that we can estimate, we obtain a data-driven estimate of W_t that does (almost) not depend on the optimal bid.

An empirical estimate of the value function. We now consider how to obtain a direct estimate of W_t from the data and from the pseudo flow value, $\tilde{v}_t\left(q_{n,t,k}, S_{n,t}, a_{n,t}\right)$, obtained in Proposition 1. We describe the specifics of the resampling procedure we used in Section 5.1. Existing results in Hortaçsu and Kastl (2012) that build upon Guerre *et al.* (2000) argue that this value is identified using the bidding data and equation (8). Hence, in our setup, these pseudo flow values can readily be obtained. Denote by $\tilde{v}_{n,t,k}$ the flow valuation for the k'th step of bidder n in period t. We now argue that $\mu(a)$ is identified using $\tilde{v}_{n,t,k}$ and (sufficient) variation in a. To see this, consider the following thought experiment. Consider a dealer in period $T-1$, i.e., in the penultimate period, with some signal $\bar{s}$ but at two very different levels of the state variable, a and a'. Suppose that $a > \underline{a}$, i.e., that the dealer has already won enough to guarantee her status for the next monitoring period, and that $a' < \underline{a}$, but large enough that it allows for meeting the threshold if sufficiently high quantity were to be won in the remaining periods. This is equivalent to saying that $\mu(a) = 0$ and $\mu(a') > 0$. Hence taking the expectation of the difference identifies $\mu_t(a')$. In particular, using that $S_{n,t}$ is i.i.d. over n and t, we construct a function $\tilde{v}^e(q)$ by interpolating all $\tilde{v}_{n,t,k}$ such that $a_{n,t} \geq \underline{a}$. Then, our estimate of the dynamic correction term for bidder n in period t is given by

$$\mu_{n,t,k}^e \equiv \tilde{v}_{n,t,k} - \tilde{v}^e(q_{n,t,k}). \tag{16}$$

This immediately leads to an estimate of the derivative of W_t^e:

$$\frac{\partial W_t^e(a_{n,t} + q_{n,t,k})}{\partial q_{n,t,k}} = \frac{\mu_{n,t,k}^e}{\beta}. \tag{17}$$

In order to make an estimate of W_t^e, we need $W_t^e(0)$, which we cannot get directly from the data in the same manner However, we have another estimate, $W_t^o(0)$. Hence, using this we can estimate W_t^e as $W_t^e(a) = W_t^o(0) + (1/\beta) \cdot \sum_k (q_{n,t,k} - q_{n,t,k-1})\mu_{n,t,k}^e$, where we set $q_{n,t,0} = 0$.

Estimating dealer gain. With these estimates in hand, we can then rewrite (11) as follows

$$G = \frac{W_t^e(a_{n,t}) - Z_t^o(a_{n,t})}{\beta^{T-t} \Pi_t^o(a_{n,t})}. \tag{18}$$

For each input value $\tilde{G}$, we thus obtain an output G for each step of the submitted bid functions. We then start with a given input value and take the average of the implied output G's obtained with the bids of the last three months of bidding to obtain the next input value. We iterate this process until the change from input to output value is less than 0.1. We use only bids from the last three months to obtain the output value, as these bids contain the most information in the sense that the W function is steeper in these periods (see Section 6.2).

In order to back out the corresponding yearly dealer benefit, which we will denote g, we need a further definition. Let $\bar{Z}_t^o$ be defined analogously to Z_t^o as the flow utility that a dealer would obtain if she did not have dynamic concerns. I.e., this is the flow utility a dealer would obtain if she should lose her dealer status and no longer be able to obtain it. In practice, we can think of it as $\bar{Z}_t^o = Z_t^o(\underline{a})$. We can then define net present value of the yearly flow profit, $\bar{Z}^o$, and the beginning-of-year probability of remaining a dealer, Π^o, by extending the definitions in (14) and (15) to a fictional period $t = 0$, such that $\bar{Z}^o = \bar{Z}_0^o(0)$ as well as $\Pi^o = \Pi_0^o(0)$. Similarly for $\bar{Z}^o$. Let β_A be the annualized discount factor. We can then identify the annual dealer benefit as

$$g = G(1 - \beta_A \Pi^o) + (\bar{Z}^o - Z^o). \tag{19}$$

Notice that the first term is the annualized value of G, whereas the second term measures the loss in flow utility from being a dealer, since dealers do not bid exclusively to maximize flow utility such as non-dealers, but also to retain their dealer status.

5 Implementation

We now describe how we implement the algorithm described in the previous section. In particular, we choose grids for quantities, rates and states, and implement a resampling procedure to calculate the required probabilities and expectations.

5.1 Resampling of Price Distribution

For all resampling of price distributions, we use a single resampling auction. That is, all bids are resampled from the auction for which we are trying to estimate the price distribution. The first group is made up of very large primary dealers, which we define as dealers who buy at least twice the requirement in at least one of the auctions in the years we consider.[15] The next group are made up of normal-size dealers, and the final group is made up of bidders who are not primary dealers. Hence, $\sum_{s=1}^{3} N_s = N$, that is, all dealers belong to one and exactly one of the first three groups in each period. For each group, the participation probability is calculated.

We calculate $H_t(p, q; \bar{a}^t)$ for each group in the following manner. Suppose we are constructing the estimate of H_t for group s. First we draw a resample from all groups with $N_s - 1$ draws with replacement among bidders of group s, and $N_{s'}$ draws with replacement among bidders from groups $s' \neq s$. We then calculate the participation probability of bidders for each group, and draw among the resampled bids of a group

[15] In our application, we have one such large dealer. See Section 2.2 for details.

using this participation probability, to determine which bids participate or not. If a bid does not participate it is set to zero. From this we construct a residual supply curve. We then construct a loop over the price grid and quantity grid. At price p and quantity q, we now add a bid function with demand q for price up to p, and demand zero for prices above p. We then calculate the distribution of clearing prices implied by this resample. We smooth the distribution using a kernel density, and then calculate $H_t(p, q; \bar{a}^t)$ as the proportion of the smoothed density that is weakly below p.

The price distribution used to estimate the pseudo flow utility is calculated similarly by resampling a residual supply by group, and then adding to this the bid of the bidder whose pseudo flow utility is being estimated. We used 20,000 resampling draws for the resampling, and a perturbation of 1 quantity unit (one million USD) to calculate empirical derivatives.

5.2 Modelling Additional Uncertainty

We estimate the algorithm described in Table 5 on 3-month auctions in each evaluation year on a grid of initial $\tilde{G}$ input values and calculate the corresponding G value from (18). We consider the procedure to have converged whenever there is a crossing in $G - \tilde{G}$, and take as our estimate of G the $\tilde{G}$ value that minimizes the absolute value of this distance.

Since we only use 3-month auctions, we compensate for the auctions of other maturities by adding to the dealer's demand function at t, $\{q_{n,t,k}\}_k$, the dealer's winnings in between auction t and $t+1$ (or for $t = T$ in between T and the finalization of the monitoring period). Denote this in-between winning by $\hat{q}_{n,t}$. When auctions are on the same day, we treat them as being sequential and ordered according to their auction number, and apply the same rule to calculate the in-between winning. To model the uncertainty attached to the winnings in these in-between auctions, we calculate the distribution of winnings in the in-between auctions and center it on zero. Denote the resulting variable by η_t. This is the noise term that captures uncertainty in unmodelled auctions. Hence, we replace W_t^o in the algorithm by the expected continuation value at t, which we calculate as

$$\mathbb{E}_{\{\eta_t\}}\left[W_t^o(a_t + q_{n,t,k} + \hat{q}_{n,t} + \eta_t)\right]. \tag{20}$$

For Z_t^0 and Π_t^o we make a similar adjustment.

Finally, since our data set lacks observations for April 1996, we impute these by assuming that in this month there was a single auction of 3-month bills and no other auctions, and in this auction dealers won exactly the required share.

5.3 Parameters and Other Modelling Choices

Discount rate. To estimate the discount rate we take the average yield on US 3-month Treasury bills and add the EMBI spread for Argentina for the same period to obtain an annual discount rate of 12.0 percent, which we transform to a by-period discount factor.[16]

[16] We use the period May 1996 to October 2000, in which the average yield of US 3-month T-bills was 5.1 percent and the average EMBI spread was 6.9 percentage points. We stop in October 2000 as in that month the Argentine vice-president resigned triggering a confidence crisis. Results are very similar if we use the full sample which leads to a slightly higher discount factor.

Grids. We normalize quantities to million USD and use the following grids: The quantity grid has steps of size 5, such that $\mathcal{Q} \equiv (0, 5, 10, ..., Q_t/2)$ for the bid demands. We only allow for bids up to half of the supply, as some bidders post very large bid steps (in the magnitude of the supply) at low prices. The bids have very low winning probability, but tend to disturb the algorithm. We therefore trim the real bid functions at half the supply, and estimate optimal bid functions where the maximum bid quantity is half supply. We normalize the state such that $\bar{a} = 1$ and use the following grid: $\mathcal{A} \equiv (0, 0.05, ..., 1.05)$.

The bid rates are normalized using the Argentinian interbank rate.[17] Then, for each period, we identify a lower bound $\underline{r}$ equal to the lowest bid rate in that period less 0.02, and an upper bound $\bar{r}$ equal to the highest bid rate in that period plus 0.02. The rate grid is then constructed using a decreasing step size 0.025, i.e. $\mathcal{R} \equiv (\bar{r}, \bar{r} - 0.025, \underline{r} - 0.050, ..., \underline{r})$. The price grid is calculated by converting the rates of the rate grid into prices according to $p = (1 + r/100)^{-m/360}$, where m is the maturity of the instrument.

Rationing. We considered rationing by everywhere replacing $q_{n,t,k}$ by the expected allocation, conditional on winning and $q_{n,t,k-1}$.

Direct dealer fees. We incorporated the direct dealers fees described in Section 2.1 by estimating the right-hand side of (12) as

$$\tilde{v}_{n,t,k} - \beta \cdot \frac{\partial W^{o}_{t+1}(a_{n,t})}{\partial a_{n,t}} - \text{fee}. \tag{21}$$

Since the direct dealers fees were proportional to winnings we can simply discount the fee from the valuation estimate.

6 Results

In this section we first present and discuss the model estimates of flow utility and primary dealer gain. We then discuss the continuation value.

6.1 Model Estimates

We estimate the model laid out in the previous sections for each of the five evaluation periods that we have data for, and present the results in Table 6. Notice that all quantities are annualized.

The first column reports our estimate of the dealer gain, the second the flow utility of a dealer bidding optimally when taking into account the dynamic incentives from maintaining dealer status, and the third the flow utility of a dealer bidding optimally without taking into account the dynamic incentives from maintaining dealer status (i.e. optimizing only flow utility). All three variables have been normalized by the supply of the auction and are reported in bps. The fourth column indicates the dollar amount of the

[17] In practice, we construct a variable that equals the Argentinian interbank rate for the currency corresponding to the auction (either ARP or USD) and then make this variable relative to the first observation, so that it becomes an index variable. We then construct the normalized bid rate by subtracting the interbank index rate variable from the original bid rate.

Year	g/Q_A (bps)	Z^o/Q (bps)	$\bar{Z}^o/Q$ (bps)	$g + Z^o_A$ ($M)	Π^o	Π^o_N	Q_A ($M)	g^D ($M)
1996-97	0.2	0.2	0.3	0.2	0.9996	0.2723	6,250	0.34
1997-98	1.4	-0.4	0.3	0.7	>0.9999	0.1291	6,500	0.56
1998-99	2.2	-0.5	0.7	1.1	0.9997	0.2967	6,875	0.62
1999-00	2.5	0.6	0.6	3.0	>0.9999	0.7122	9,772	0.97
2000-01	0.3	0.4	0.5	0.7	0.9176	0.1748	11,700	1.06

Table 6: Model Estimates of Dealer Gain and Flow Profit

total dealer profit, that is to say, the dealer gain plus the flow utility. The fifth column indicates the beginning-of-year probability of maintaining dealer status when bidding optimally taking dynamic incentives into account. However, to emphasize that this is a results of equilibrium bidding, column six, Π^o_N, indicates the probability of retaining dealer status conditional on optimal bidding *in the absence of dynamic incentives*. That is to say, if we estimate the optimal bids assuming $G = 0$. Column seven reports the total supply, and column eight the direct dealer payments (these two figures come directly from the data and are not estimated).

First, notice that we have two measures for identification of the model: (i) the difference between Π^o and Π^o_N, indicating how important it is to take dynamic incentives into account in the optimal bidding to maintain dealer status, and (ii) the difference between the flow utilities Z^o/Q and $\bar{Z}^o/Q$, which indicates the 'price' paid in terms of flow utility from bidding optimally to retain dealer status. Generally, the difference in (i) is large, but less so for the year 1999-00. The difference in (ii) is small in the years 1996-97 and 2000-01, which is in line with the small g estimates for those years, which would imply less incentive to bid aggressively. However, it is also small in year 1999-00. Hence, of all the estimates, the year 1999-00 seems to be the year where the result is the least identified. However, since it is in the same order of magnitude as the previous two years, we will still consider it. Finally, we notice that since the g estimate is small in years 1996-97 and 2000-01, we should naturally be careful in interpreting the numbers, as small g may imply that the identification is weak.

Looking at the dealer gain, we see that years 1996-97 and 2000-01 have low estimates (0.2 and 0.3 bps) whereas the remaining years have higher estimates (between 1.4 and 2.5 bps). The loss in flow utility experienced by dealers who bid optimally was significant in the years 1997-98 and 1998-99, at 0.9 and 0.8 bps. Thus, bidding to maintain dealer status was costly, but always compensated by the gain itself, as estimated by the model. When bidding optimally taking dynamic incentives into account, the probability of maintaining dealer status was very high, only dropping slightly in the final year (to 0.9176). Hence, the model estimates that there were gains from being a dealer but that maintaining this status was not automatic and came at a cost, in terms of flow utility. Next, we look at the size of the dealer profits. The total estimated profit per dealer was between 0.2 and

3.0 million USD. In the years 1996-97 and 2000-01, the estimated dealer profit is even lower than the direct profit, g^D, but as mentioned above, the small g estimated in these years may imply that the identification is weak.

6.2 Continuation value

We next look at the continuation value functions. To better interpret the function, we normalize it to take out the effect of varying flow utilities between the months, which we measure by $\bar{Z}_t^o$, since this value measures the maximized flow utility available to bidders. We also take out the non-dealer continuation value, C. Then

$$\tilde{W}_t^o(a) \equiv W_t^o(a) - \bar{Z}_t^o(a^M) - \beta^{T-t}C. \tag{22}$$

Figure 3 depicts the continuation value functions at $t = 12$, $t = 11$, $t = 10$ and $t = 6$ for the monitoring year 1997-98. In this year, there were 12 auctions of 3-month T-bills, and therefore $T = 12$.

The last-period continuation value, $\tilde{W}_{12}^o$, takes the shape of a step function by definition. Only dealers who meet the threshold are rewarded, and their future reward does not depend on their state conditional on being above the threshold. The continuation value of the penultimate period, $\tilde{W}_{11}^o$, is on the other hand highly dependent on the state (recall that the a in $\tilde{W}_{11}^o$ refers to the state coming into period 12). The requirement in the year 1997-98 was $\underline{a} = 425$. The 3-month auction had a supply of 250 and in addition there is an in-between auction before the monitoring year ends with a supply of 500. Hence, in theory it is feasible to make the requirement even coming into period 12 with a state of $a = 0$. Notice, however, that as is to be expected, the probability of winning such a large amount is practically zero and therefore $\tilde{W}_{11}^o(a) = 0$. In fact, $\tilde{W}_{11}^o$ does not start rising until just below the normalized state 0.4. Eventually, around normalized state 0.9, it is very close to the maximum.

Moving back one period, we observe that $\tilde{W}_{10}^o$ is greater than 0 for all a. It shows the same pattern of being convex for low a and concave for high a. Finally, $\tilde{W}_6^o$ is much smoother, reflecting that even for low a, there is a reasonably good chance to meet the threshold as there are plenty of supply left to bid for. This effect means that the lower t, the higher is $\tilde{W}_t^o$ for low a. On the other hand, discounting implies that for sufficiently high a, $\tilde{W}_t^o$ is increasing in t.

Notice that there are two components to the continuation value: the probability of reaching the requirement, and the flow utility. Figure 4 depicts the probability of reaching the requirement, and as can be seen it follows much the same pattern as the continuation value, with a few differences. First of all, since there is no discounting effect, $\Pi_t^o(a) \geq \Pi_{t'}^o(a)$ for all $t' > t$ and a. Second, notice that Π_t^o flattens out for high a earlier than $\tilde{W}_t^o$. This reflects that for a sufficiently high a, in equilibrium the dealer is almost certain to reach the threshold (implying Π_t^o is almost flat at 1 for high a), but increasing a further diminishes the cost of doing this in terms of lost flow utility (and therefore $\tilde{W}_t^o$ is still upward sloping). Similarly, looking at Π_{11}^o, this is less smooth in than $\tilde{W}_{11}^o$, reflecting that even though the continuation probability does not change much with a change in a, the continuation value might do so due to the effect of the flow utility.

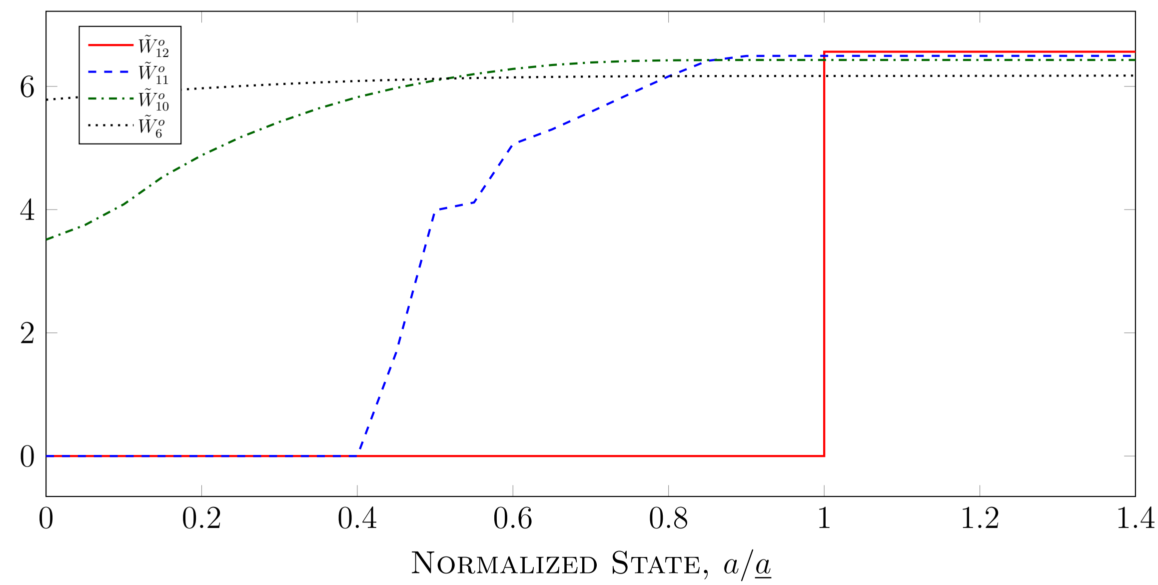

Figure 3: Normalized Continuation Value, 1997-98

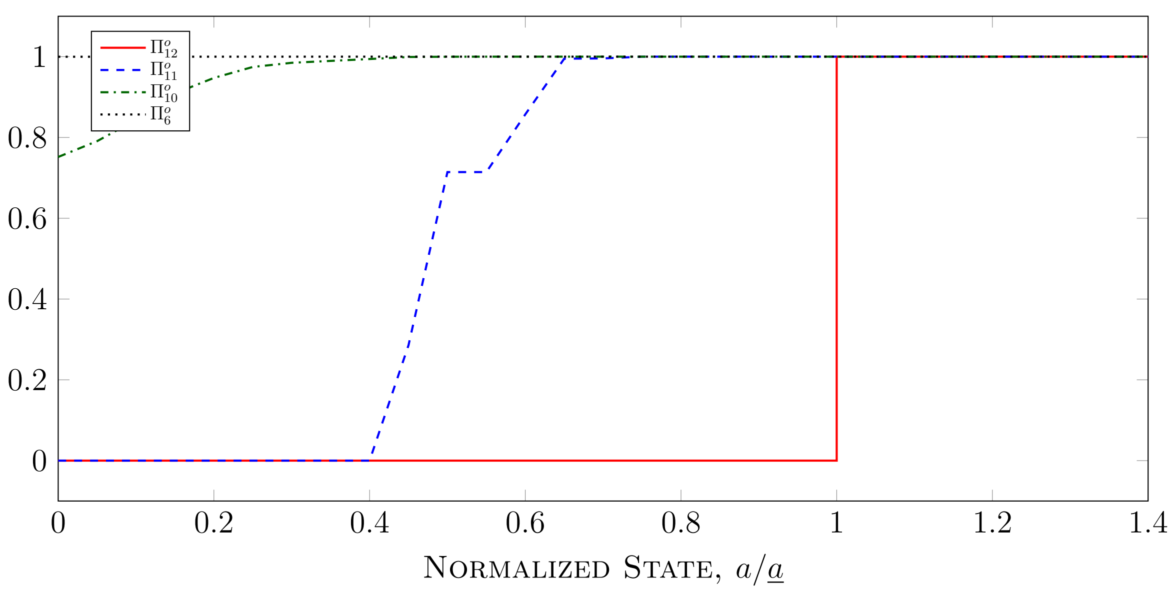

Figure 4: Continuation Probability, 1997-98

7 Conclusion

We present a dynamic model of auction bidding in which dealers must reach a threshold level of auction winnings to retain their status, and show how the model's equilibrium condition allows us to estimate the benefit to bidders from being dealers. We argue that the model approximates conditions in the Argentinian Treasury bill market in the years 1996-2001 and estimate the model on this data. Our results indicate that the benefits from being a dealer is in the same order of magnitude as the flow utility obtained by a bidder who does not bid to maintain dealer status. Bidders maintain dealer status with a high probability, but may have to give up a significant amount of flow profit to do so, thus eroding the total gains from being a dealer.

Appendix A Algorithm for estimating optimal bids

In this appendix we describe the algorithm for estimating the optimal bid of a dealer, given a value function and a distribution of residual demand.

A.1 Setup

We first describe the setup for the procedure. To keep notation simple, we suppress the subscripts n and t, since we will focus on a given bidder in a given period. Notice that the price grid is increasing, so the bid function is non-increasing.

Bid function. Suppose we have an increasing p-grid indexed by $i = 1, ..., I$, such that $(p_1, ..., p_I)$ with $p_i > p_{i-1}$. We want to find a non-increasing bid function $Q := (q_1, ..., q_I)$, i.e. $q_{i-1} \geq q_i$, where q_i represents the cumulative demand at p_i. Let the bid function up to step $i-1$ be denoted $Q_i := (q_1, ..., q_{i-1})$ with Q_1 being empty.

Clearing price. Let the clearing price P^c be defined as above, and suppress the dependence on a^t to write the price distribution as $H(p_i, q_i)$. For $i > 1$, let $\pi_i(q_i, q_{i-1}) = H(p_i|q_i) - H(p_{i-1}|q_{i-1})$ with $\pi_1(q_1) = H(p_1|q_1)$. Hence, when discreetizing the price distribution on the grid, we can think of $\pi_i(q_i, q_{i-1})$ as the probability that, on the grid, the clearing price is p_i, given q_i and q_{i-1}.

Objective function. Since we are considering the optimization problem for a given dealer at a given point in time, it does not matter whether utility derives from that period's flow valuation or the continuation value of future periods. Hence, we focus on $\tilde{v}(\cdot)$, which can be thought of as the "total marginal utility function". Then define the net total profit if the auction clears at step n as

$$\bar{v}_i(q_i) \equiv q_i \cdot [\tilde{v}(q_i) - p_i]. \tag{A.1}$$

Hence, the value function in this discreetized setting can be written as

$$V(Q) \equiv \sum_{i=1}^{I} \pi(q_i, q_{i-1})\bar{v}_i(q_i). \tag{A.2}$$

Let the solution to the problem $\max_Q\{V(Q)\}$ be denoted $Q^* = (q_1^*, ..., q_I^*)$.

A.2 Sequential formulation

We now wish to rewrite the dealer's optimization problem as a sequential optimization problem. For $1 < i < I-1$, let

$$w_i(q_i, q_{i+1}) \equiv H(p_i|q_i)\left[\bar{v}_i(q_i) - \bar{v}_{i+1}(q_{i+1})\right], \tag{A.3}$$

and let $w_I(q_I) := H(p_I|q_I)\bar{v}_I(q_I)$.

Next define the following auxiliary quantities. For $1 < i < I-1$, define:

$$V_i^{q_i}(Q_i) \equiv \sum_{j=1}^{i-1} w_j(q_j, q_{j+1}), \tag{A.4}$$

with $V_1(Q_1) = 0$. We can now rewrite the bidder's utility as

$$V(Q) = V_I^{q_I}(Q_I) + w_I(q_I). \tag{A.5}$$

Define the optimal utility for prices below p_i conditional on a q_i as

$$\hat{V}_i^{q_i} \equiv \max_{Q_i : q_{i-1} \geq q_i} \left\{ V_i^{q_i}(Q_i) \right\}. \tag{A.6}$$

A.3 Iteration

First, pick an arbitrary q_{i+1} and assume that we will pick $q_1, ...q_{i-1}$ optimally as a function of q_i. For $i < I$, the optimal q_i conditional on q_{i+1} and optimal $q_1, ...q_{i-1}$, is then

$$\hat{q}_i^{q_{i+1}} \equiv \arg\max_{q_i : q_i \geq q_{i+1}} \{ \hat{V}_i^{q_i} + w_i(q_i, q_{i+1}) \}. \tag{A.7}$$

Solving this iteratively from the lowest price gives a matrix of conditional optimal demand.

For most of our applications, we use $q_N = 0$, i.e we set demand at the highest price step to zero. In reality, q_N will not always be zero, but will be equal to the non-competitive demand of the bidder. However, since in the application of the algorithm we wish to estimate the optimal demand for different hypothetical states, in which the optimal non-competitive bid may be different from the one observed, we find it more logical to set $q_N = 0$. In practice, we observed very little difference between the two formulations.

Example. Suppose bidders can bid up to two units, so we have the quantity grid $(0, 1, 2)$. Let $w_i^{q_i, q_{i+1}} = w_i(q_i, q_{i+1})$. Implicitly we assume that $q_4 = 0$ (as discussed above), so we write $w_3^{q_3, 0}$ at price step 3. Schematically we can represent the iteration as in Figure 5. The figure shows how to obtain q_3^*. Once this is obtained, we can move backward through the conditional optimal demands described above to obtain $q_2^* = q_2^{q_3^*}$ and $q_1^* = q_1^{q_2^*}$.

	$q_{i+1}=0$			$q_{i+1}=1$		$q_{i+1}=2$
i	$q_i=0$	$q_i=1$	$q_i=2$	$q_i=1$	$q_i=2$	$q_i=2$
1	$\hat{V}_1^0+w_1^{0,0}$	$\hat{V}_1^1+w_1^{1,0}$	$\hat{V}_1^2+w_1^{2,0}$	$\hat{V}_1^1+w_1^{1,1}$	$\hat{V}_1^2+w_1^{2,1}$	$\hat{V}_1^2+w_1^{2,2}$
		$\downarrow$		$\downarrow$		$\downarrow$
		$\hat{q}_1^0$ and $\hat{V}_2^0$		$\hat{q}_1^1$ and $\hat{V}_2^1$		$\hat{q}_1^2$ and $\hat{V}_2^2$
2	$\hat{V}_2^0+w_2^{0,0}$	$\hat{V}_2^1+w_2^{1,0}$	$\hat{V}_2^2+w_2^{2,0}$	$\hat{V}_2^1+w_2^{1,1}$	$\hat{V}_2^2+w_2^{2,1}$	$\hat{V}_2^2+w_2^{2,2}$
		$\downarrow$		$\downarrow$		$\downarrow$
		$\hat{q}_2^0$ and $\hat{V}_3^0$		$\hat{q}_2^1$ and $\hat{V}_3^1$		$\hat{q}_2^2$ and $\hat{V}_3^2$
3	$\hat{V}_3^0+w_3^{0,0}$	$\hat{V}_3^1+w_3^{1,0}$	$\hat{V}_3^2+w_3^{2,0}$			
		$\downarrow$				
		q_3^*				

Figure 5: Optimal Demand Algorithm

Appendix B Algorithm for estimating pseudo flow utility

In order to estimate the pseudo flow utility function for each bidder, $\tilde{v}_{n,t}$, we develop an algorithm that builds on Kastl (2011). Let $i = 1, ..., I$ index the price grid.

(a) Specify initial flow utility function. Set $i = 1$.

(b) At price p_i, estimate using the methodology in Appendix A the optimal bid at p_i for each potential bid demand at price p_{i+1}.

(c) For the bid demand at p_{i+1} that corresponds to the real demand of the bidder, check if the optimal bid at p_i given the flow utility function equals the real bid at p_i. If so, move on to the next price $i+1$ and return to step (b). If not, move on to step (c).

(d) If flow utility at price p_i is lower than flow utility at price p_{i+1}, increase flow utility at p_i to make this step more 'attractive'.

(e) If flow utility at price p_i is equal to flow utility at price p_{i+1}, we cannot increase flow utility only at price p_{i+1}, as this would violate monotonicity. We therefore raise it at all p_j for $j \leq i$ such that flow utility at p_j is equal to flow utility at p_i.

(f) We then set $i = 1$ and return to step (b).

To this algorithm, we add a mechanism to make sure adjustments at each step are the smallest possible adjustments that make optimal demand equal to real demand, and also a mechanism to make sure that the algorithm moves on if it gets stuck at a given step without being able to match optimal and real demand.

Finally, we take the estimated flow utility and compare the estimated optimal demand for this flow utility with the real demand of the bidder and calculate the relative deviation at each price step, weighted by the probability that the clearing price falls at this price step. We use this measure to filter out bidders for which we were not able to construct a flow utility function which delivered an optimal bid close to the real bid.

Appendix C Primary dealer regulation in Argentina

We describe the main regulations of the newly created primary and secondary markets for Treasury instruments between 1996 and 2001.[18] The initial lineup of dealers was: Banco de Galicia, J. P. Morgan, Banco de Santander, Chase Manhattan Bank, Deutsche Bank, Banco Río, Banco Francés, Banco de Crédito Argentino, HSBC, Bank of America, Citibank, and Bank Boston. For the second auction year, ING replaced Banco de Crédito Argentino. In the third auction year ABN Amro replaces Santander. Finally, in June 2001 Credit Suisse First Boston joined the group as the thirteenth dealer.[19] Dealers collect fees that initially are calculated based on the amount bought in primary markets (see description of regulations below). These started at 0.075% and 0.15% for allocation of Letes with 90 and 180 days maturity respectively, and increase for longer bonds.[20] The main regulations are summarized in Table 7. We next describe each of them in turn.

Setup, auction year 1996–1997

Executive Power Decree 340/96 of April 1, 1996 establishes rules for primary issues of public debt intended for the domestic capital market. Debt may be denominated in pesos or in US dollars (usd). The "dealer" (creador de mercado) figure is created with the objective that these intermediaries significantly participate in primary and secondary markets. The Secretary of Finance (Secretaria de Hacienda) will be in charge of issuance of financial instruments, and is entitled to establish the requirements, rights and obligations of dealers.

Secretary of Finance Resolution 238/96 of April 8, 1996 determines criteria for dealers. It states that the initial roster of dealers will be determined based on participation in

[18]Most regulations taken from chapter IV.B. of the Argentine "Digesto de Normas de Administración Financiera y de Control del Sector Público Nacional" (Digest of Financial Administration and Control Rules for the National Public Sector) https://www.economia.gob.ar/digesto/pdf/cap04.pdf. We also used the government portal "Información Legislativa y Documental" (Legislative and Documentary Information), infoleg.gob.ar.

[19]Sources: La Nacion April 16, 1996, https://www.lanacion.com.ar/economia/cavallo-pide-250-millones-al-mercado-nid175008/, La Nacion April 22, 1997, https://www.lanacion.com.ar/economia/lanzan-bonos-por-us-600-millones-nid67525/, La Nacion March 5, 1998, https://www.lanacion.com.ar/economia/otro-banco-para-la-deuda-nid89571/, La Nacion May 30, 2001, https://www.lanacion.com.ar/economia/deuda-local-un-negocio-para-13-nid308844/.

[20]Source: La Nacion, February 7, 1997, https://www.lanacion.com.ar/economia/el-martes-renuevan-500-millones-en-letes-nid63307/ and La Nacion, July 7, 1998, https://www.lanacion.com.ar/economia/el-gobierno-obtuvo-1000-millones-mas-nid103685/.

Date	Regulation	Content
1996		
March	Res. 238/96	Buy at least 4% of securities sold, by type of instrument. Maximum number of dealers. Fees depend on participation in primary and secondary markets.
August	Prov. 10/96	Performance measured by arithmetic. Trade in secondary markets not quantified average of participation in primary and secondary markets.
1997		
March	Res. 155/97	Buy at least 4% of securities sold, regardless of type of instrument
July	Prov. 9/97	Performance measured by geometric average of participation in primary and secondary markets
July	Res. 323/97	Eliminates maximum number of dealers. Buying obligation raised to 5%.
1998		
July	Res. 370/98	Buying obligation reduced to 4%. Must account for at least 1.5% of traded volume.
August	Prov. 11/98	Transactions made through posting of bid and ask prices are given a higher weight in performance measure.
1999		
August	Res. 429/99	Splits payment of fees, such that a share is contingent on secondary trading. Posted bid and ask prices are audited.
2000		
Nov	Res. 187/00	Buying obligation increased to 6% and dealers must bid for at least quarterly average of 9% of supply. Applied from January 2001.

Table 7: Summary of Primary Dealer Regulations

primary and secondary markets during 1995, as well as assistance provided in the organization of the new market. Dealers must purchase at least 4% of the total yearly amount sold of each type of instrument (medium and long term instruments are excluded from this requirement), and must participate in secondary markets posting bid and ask prices. Criteria for assessing dealer performance, from which fees they collect will be determined, will be published within the following 90 days. Dealer status is granted for one year from April 1 each year for those intermediaries that fulfill the requirements in the previous year (April 1 to March 31). Dealer status will be lost in case of failure to meet requirements. Intermediaries that lose dealer status are barred from requesting readmission as dealer for two years.

Secretary of Finance Resolution 241/96 Annex B of April 11, 1996 establishes the blueprint for Treasury Auctions of Bills (Bonds are dealt in Resolution 230/96). In particular there will be two types of bidding: competitive and non-competitive with prices being determined in the competitive market (bids are expressed pairs of quantities and discount rates with two decimals). Authorized participants are dealers and brokers. Investors may bid through these. Minimum bids are 100000 pesos/usd in the competitive market and 10000 pesos/usd in the non-competitive segment. Auction format may be either uniform or discriminatory price, to be determined for each auction. The maximum amount to be allocated through the non-competitive segment to dealers is also determined for each auction. The Annex stipulates that the amounts allocated, as well as the clearing price, will be informed to the public through a press release.

Undersecretary of Finance Provision 10/96 Annex of August 2, 1996, formalizes the index to evaluate dealer performance. This is determined by an arithmetic average of primary market purchases and secondary market development with weights 80% and 20% respectively. Performance in primary market is measured as the arithmetic average of offers tendered over total offers tendered by all dealers and allocation over total allocation to dealers (in both cases counting competitive and non-competitive bids), with weights 1/3 and 2/3 respectively. For yearly performance weights are given according to amount sold in first (competitive) round and maturity of the security. Secondary market index takes into account share of purchases and sales in secondary market, weighted equally.

Auction year 1997–1998

Undersecretary of Finance Provision 5/97 of March 25, 1997, reaffirms that the maximum number of dealers for the coming year is twelve.

Secretary of Finance Resolution 155/97 of March 26, 1997, changes the requirement for primary participation to 4% of total issuance (including instruments of all maturities). It reaffirms that dealer status is lost if by performance criteria a dealer is not among the top twelve participants.

Undersecretary of Finance Provision 9/97 Annex of July 23, 1997, defines the index to evaluate dealer performance for the year. The new index is a geometric average of performance in primary and secondary markets with weights 80% and 20% respectively. Weights to measure performance in primary market are 1/4 and 3/4 for offers and allocations respectively. Secondary market index unchanged.

Secretary of Finance Resolution 323/97 of July 25, 1997, eliminates the maximum number of dealers and increases the primary requirement to 5% of total issuance.

Auction year 1998–1999

Secretary of Finance Resolution 370/98 of July 29, 1998, reduces primary requirement to 4% of total issuance. It introduces a new obligation relative to secondary market participation: dealers must intermediate at least 1.5% of total yearly volume transacted (volume understood as simple average of purchases and sales).

Undersecretary of Finance Provision 11/98 Annex of August 13, 1998, changes weights of performance in primary and secondary markets to 70% and 30% respectively. Transactions in secondary markets are weighted according to platform used (telephone or electronic) and whether the dealer is initiating or responding.

Auction year 1999–2000

Undersecretary of Finance Provision 15/99 Annex of August 11, 1999, changes weights of performance in primary and secondary markets to 60% and 40% respectively. Transactions in secondary markets are weighted according to platform used (telephone or electronic and within electronic if through given exchanges or other platform) and whether the dealer is initiating or responding.

Secretary of Finance Resolution 429/99 of August 13, 1999, establishes that dealers' fees will be paid in part at time of primary allocation (and other participants can collect these fees) and in part contingent on successfully meeting secondary market performance. If a dealer fails to qualify to collect this second part of their fees, the amount will be distributed among remaining qualifying dealers.

Auction year 2000–2001

Secretary of Finance Resolution 187 of November 28, 2000, increases primary requirement to 6% of total issuance. Dealers must significantly participate in bidding for at least a quarterly average of 9% of the amount tendered in each quarter. These new requirements will be applied from January 2001.

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