When-Issued Markets and Treasury Auctions

Paulo Braulio Coutinho†

April 22, 2013

Abstract

Several empirical studies have documented that the price of Treasury securities are lower in the official auctions than in the forward market preceding it (the "when-issued market"). Nevertheless, the volume of when-issued securities being traded in the inter-dealer market is remarkably large, implying that some dealers are willing to take substantially large long positions despite the price gap. This paper builds up a dynamic model to show how the strategic interaction of dealers in the official auction gives them incentives to trade when-issued securities in the forward market and why the price gap arises in equilibrium. The model also implies that empirical papers relying on prices from the when-issued market as proxies for the true market value of securities may have underestimated the latter. Finally, from a social welfare perspective, I show that when-issued markets improve the allocation of uniform price auctions.

*I would like to thank Pedro Aratanha, Tony Bernardo, Sushil Bikhchandani, Simon Board, Bruce Carlin, Paulo César Coutinho, Darrell Duffie, Kyle Herkenhoff, Hugo Hopenhayn, Moritz Meyer-ter-Vehn, Kjell Nyborg, Marek Pycia, John G. Riley, Avanidhar (Subra) Subrahmanyan, Pierre-Olivier Weill, Randy Wright and seminar participants at UCLA, UCLA Anderson, University of Brasilia and the 5th South West Search and Matching Workshop. All remaining errors are mine.

†Department of Economics, University of California Los Angeles, Email: paulobraulio@ucla.edu.
1 Introduction

Investors set up transactions involving new Treasury Securities before they are effectively offered to the public. A commonly used financial instrument for these type of transactions are When-Issued (WI) securities. A when-issued security is simply a forward contract with a specific settlement day: the issuance date of the underlying Treasury security. The when-issued market is particularly active. Fabozzi and Fleming [2004] and Barclay et al. [2006] documented that it accounts roughly for six percent of the entire volume involving Treasury securities in the inter-dealer market in U.S.¹ This figure is even more remarkable when one takes into account that when-issued securities can be traded only during the small window between the Treasury’s official announcement and the effective issuance dates, usually consisting of five trading days.

Several studies have observed that the price of securities is relatively higher in the when-issued market than in the official Treasury auction.² The price gap, called underpricing, is observable on the same day and even within minutes to when the auction takes place. Surprisingly, some of these studies used data from inter-dealer markets. This means that some dealers, who actively participate in both Treasury auctions and when-issued markets, are willing to acquire a substantial amount at the when-issued market in spite of the price gap.

At first glance, these two empirical observations might seem puzzling. Why do dealers buy in the when-issued market instead of waiting a few minutes for the auction and paying a lower price for the same securities? In this paper, I show that the structure of the market can give rise to the observed patterns in prices and trading activity. Specifically, the way the Treasury auction is organized - as uniform price auction - gives dealers incentives to trade when-issued securities even in the presence of a price premium. Moreover, I show that underpricing arises as an outcome of equilibrium when the same set of dealers interact strategically in both Treasury auctions and when-issued markets.

I consider a model in the lines of Wilson [1979] auction of shares.³ The mechanism is similar to a Walrasian auction. The Treasury uses a uniform price auction to sell perfectly divisible securities to a finite number of dealers. The dealers simultaneously submit complete bid schedules determining the amount of securities they are willing to acquire for each possible

1Barclay et al. [2006] do not explicitly document this percentage in their article. However, they argued that "Approximately 93% of the trades in our sample have one-day settlement. The majority of the trades with nonstandard (longer than 1 day) settlement occur during the when-issued trading period ".
2e.g., Goldreich [2007]; Bikhechandani et al. [2000]; Simon [1994].
3Examples of other papers using this type of model are Kyle [1989], Back and Zender [1993], Ausubel and Cramton [2002], Wang and Zender [2002], Pycia et al. [2010] and Coutinho [2012].
price. The Treasury, then, aggregates the bids and determines the price that clears the market - the *stop-out price*. This price determines how much dealers pay for the bids and the amount of securities they get.

The existence of equilibria where auction participants strategically "shade" their bids is a well know property of this class of models. In order to artificially reduce the auction stop-out price, dealers submit bid schedules that understate their true valuation for the securities. The intuition is the same as in a simple monopsonist problem: dealers face the trade-off between buying larger quantities of the security at the expense of increasing the auction price. However, the price does not increase only for the additional securities, but also for the ones the dealer was already acquiring. In the end, dealers prefer to acquire a lower amount of securities and pay a lower price for them.

The difference between a dealer's true valuation and the bid he submits is often called *bid shading*. I show how *bid shading* can play a central role in giving dealers incentives to trade when-issued securities. When dealers are heterogeneous, the magnitude of their bid shadings will be different at equilibrium. As a consequence, the auction mechanism fails to distribute securities efficiently. Dealers acquiring relatively larger amounts will be more sensitive to price variations and as a consequence will have a higher incentive to shade their bids. In the end, larger/smaller dealers acquires less/more than they would get if the securities were distributed efficiently.

Dealers have incentives to find additional means to improve the way the auction is allocating securities. This paper focus on how they can use when-issued securities to improve the allocation. I extend the benchmark model to allow dealers to trade securities on a when-issued basis. I model the when-issued market as a uniform price auction, in a similar fashion as the auction stage. Dealers submit complete bid schedules determining the amount of when-issued securities they want to buy/sell to a central inter-dealer broker. The broker determines the when-issued price, which will be the price that clears the market, and distributes securities accordingly.

Underpricing will arise endogenously, as an outcome of the strategic interaction of dealers in both when-issued and auction stages. Specifically, larger dealers need to induce smaller dealers to take short positions in the when-issued market. The only way the smaller dealers would be willing to sell a when-issued security is if the price they get for it were larger than his valuation for the security. However, their valuation is larger than the auction price since dealers submit bids with *shading* in the auction.

---

4For a detailed discussion on the inefficiency of uniform price auctions, see Ausubel and Cramton [2002].
5Complete schedules in central markets can be attained by a combination of limit and stop orders.
The analysis has further implications on interpretation of empirical exercises. For instance, when-issued prices are frequently used to determine how much the Treasury is losing, in terms of revenue, due to the auction mechanism. The idea is that the when-issued price resembles the true market value of the underlying security, thus the price gap would give the loss, *per security*, for the Treasury. I show that, although the price of a security in the when-issued market is larger than in the auction stage, it still falls below the security’s true market value. Therefore, the magnitude of the underpricing is a lower bound for Treasury’s loss of revenue.

When-issued prices are also used in empirical papers as a benchmark to compare relative performances of different auction mechanisms. The idea is to compare the magnitude of the resulting underpricing when the auction follows different pricing and allocation rules (e.g. uniform vs. discriminatory auctions). While this paper does not consider other mechanisms besides uniform price auctions, the analysis below highlights the fact that the prices in the when-issued and auction stages are jointly determined in equilibrium. Indeed, dealers’ behavior in the when-issued market depends on how they will affect the outcome of the auction. However, the latter depends directly on the specific mechanism being used. That said, there is no straightforward reason why the equilibrium gap between the price in the two market stages is independent of the choice of the auction mechanism. It is also not straightforward that a higher underpricing implies lower revenues for the Treasury. Therefore, just comparing the magnitude of empirically observed underpricing might not be very informative about relative revenue and efficient performances across auction mechanisms.

**Related literature:** Despite the importance of the when-issued market for Treasury securities, the literature considering its relationship with auction outcomes is fairly incipient. From a theoretical perspective, I am aware of only two studies analyzing the strategic behavior of agents participating in a pre-market before an auction, and both follow an approach substantially different from the one considered in this paper. The first one, Chatterjea and Jarrow [1998], restricts market participants to submit a single bid for the entire quantity being supplied in the auction. Therefore, they do not analyze how the uniform price mechanism, per se, can give incentives to participants to trade in a when-issued market before the auction takes place. The second one, Nyborg and Strebulaev [2004], analyzes equilibrium of multiple unit auctions when dealers arrive with an *exogenous* set of positions from the when-

---

6By "true market value", I mean the price that would arise in equilibrium under perfect competition.
issued market.\footnote{Their focus is how the possibility of being squeezed in an after-auction market affects their strategy in the auction stage.} In the present paper, however, I allow market participants to \textit{endogenously} choose these positions, which pins down an equilibrium price for when-issued securities.

Outside the contexts of multiple unit auctions and the Treasury securities market, a number of papers have considered the interaction between spot and forward markets in the presence of market power. The pioneering work in this area is Allaz and Vila [1993]. They considered an environment where two duopolists can sell their products to final consumers in a Cournot spot market and in a forward market. In the context of energy markets, Powell [1993], Green [1999] considered an environment where generators can supply electricity in a forward and in a spot market. These studies focus on how firms can commit to behave more aggressively in the spot market by selling part of their supply to final consumers in forward markets. This paper adds to this literature by considering competition in bid schedules in both market stages, by highlighting why agents have incentives to trade securities \textit{among} themselves before the auction, which generates underpricing, and by considering the market for Treasury securities.

This paper is also related to literature on competition markets for financial securities where agents have market power. Following the seminal work of Kyle [1989], competition in demand (supply) schedules has been a commonly used framework to model markets where dealers recognize that their orders have an impact on the price of the underlying security. For instance, Vayanos [1999], Rostek and Weretka [2011] extended the benchmark model to a dynamic setting closely related to the one considered in this paper. The former uses a dynamic double uniform price auction mechanism to analyze how strategic traders adjust their holdings of a risk asset when they are subject to random endowment shocks in each period. Rostek and Weretka [2011], on the other hand, consider an environment similar to Vayanos [1999], but focus on the implications of strategic behavior of trader in the efficiency and arbitrage properties of equilibrium. This paper differs from their analysis by explicitly considering the Treasury auction, as well as considering different environments for the zero-sum pre-auction forward market (“when-issued market”), and by providing further comparative statics for the analysis of the Treasury securities market.

This paper points out an alternative reason bidders can benefit from participating in a pre-auction market. Pre-auction markets can be used as a mechanism to ensure efficient collusion among a subset of auction participants. In the context of single-unit auctions, McAfee and McMillan [1992] showed how participants (or a subset of participants) use the pre-auction stage to decide \textit{ex ante} which one of them will compete for the security in the auction stage.
auction. The reduced competition decreases the price of the good in the auction stage and participants can share the surplus extracted from the auctioneer among themselves. In the environment considered in the current paper, however, dealers are not trading on a pre-auction market (when-issued) to reduce the auction’s price. Indeed, here, the price of securities in the auction are invariant to their actions in the when-issued market. Even so, dealers can still benefit from participating in a pre-auction market as this market stage improves the final allocation of securities, and they can share the efficiency gains among themselves.

2 Example: Two Dealers, Two Units

In this section, I present a simple example that illustrates how the strategic behavior from dealers is consistent with underpricing. Suppose there are only two risk neutral dealers, \( N = 2 \), competing for two identical units of an indivisible Treasury security through a uniform price auction. For simplicity, I assume that their valuation for securities, defined as \( v_i > 0, i = 1, 2 \), is constant for both units, with (i) \( v_1 > v_2 \) and (ii) \( 2v_2 > v_1 \). We can express dealer \( i \)'s payoff if he acquires \( q \) units in exchange for a monetary payment \( m \) as:

\[
U_i(q, p) = qv_i - m.
\]

In the auction stage, dealer \( i \in I \) submits a bid \( \beta_i = (\beta_i^1, \beta_i^2) \in \mathbb{R}^2_+ \), representing how much he is willing to pay for the first security, \( \beta_i^1 \), and for the second, \( \beta_i^2 \). Without loss of generality, I assume that \( \beta_i^1 \geq \beta_i^2 \), i.e., the bid function should be weakly decreasing. The securities are allocated to the two highest bids. Dealers pay the stop-out price, \( p^{so} \geq 0 \), defined as the highest rejected bid. In case of a tie, the security goes to dealer 1.

For exposition motives, I focus on a specific equilibrium for the auction stage. One can use a standard argument to show that it is weakly dominant for dealers to bid their true valuation for the first security, i.e., \( \beta_i^1 = v_i \). Within the class of equilibria of the auction in which dealers are submitting their true valuation for the first unit, I will focus on the one which maximizes dealers’ payoffs. All other equilibria are Pareto dominated for both dealers.\(^8\)

We have the following result:

\( \text{Claim 1. There is an equilibrium of the auction with dealer } i \in I \text{ submitting } \beta_i^0 = (v_i, 0). \)

The equilibrium stop out price is \( p^{so} = 0 \) and \( i \)'s payoffs is \( U_i^0 = v_i \).

\(^8\)This equilibrium selection criteria is used, for instance, in Pagnozzi [2010].
It is easy to see that dealers do not have incentives to deviate from the equilibrium. Both
end up acquiring one unit of the security and pay $p^{so} = 0$ for it. Since the stop-out price
is already in its lower bound, the only possible way a dealer could increase his payoff is by
increasing the number of securities he gets. Suppose that $i$ decided to deviate and acquire
both securities in the auction. The stop-out price would increase to $v_{-i}$. His payoff, in this
case, would be given by $\hat{U}_i = 2(v_i - v_{-i})$ which is strictly less than $U_i^0$ by the assumptions
on dealers’ valuations.

Note that there is bid shading in the equilibrium described above. $i$ submits $\beta_i^2 = 0$ even
though his true valuation for the second security is $v_i$. Dealers’ strategic behavior in the
auction leads to an inefficient final allocation: since $v_1 > v_2$, dealer 1 should be getting the
two securities instead of only one. However, she knows that her bid for the second unit will
directly affect the price she pays for the first unit. In this case, she does better by giving up
the second security in order to reduce the cost of acquiring the first one.

Is it possible that both dealers benefit from trading a when-issued security before the
auction takes place? The answer is yes. Suppose they enter into an agreement establishing
that dealer 2 will deliver one unit of the security to dealer 1 in exchange for pre-established
price $p^{wi} \in (v_2, v_1)$ after the auction takes place. This means that dealer 2 should acquire at
least one of the two securities being auctioned in order to fulfill his contract with dealer 1.\footnote{I am not allowing trade to occur after the auction takes place. This assumption is not necessary to get the qualitative results in this section (and in the following ones).}

I will make the hypothesis that there is an exogenous monetary penalty, $\pi \geq v_2$, to dealer
2 if he does not deliver the promised security to dealer 1. This assumption rules out cases
where $B$ optimally chooses to default in equilibrium. If dealers arrive in the auction with
this contract, we have the following result:

\textit{Claim 2. There is an equilibrium of the auction where dealers submit $\beta_1^{wi} = (v_1, 0)$ and
$\beta_2^{wi} = (\pi, 0)$. The equilibrium stop out price is $p^{so} = 0$ and payoffs are given by:}

\begin{align*}
U_1^{wi} &= 2v_1 - p^{wi}, \\
U_2^{wi} &= p^{wi}.
\end{align*}

As before, each dealer is acquiring one unit of the security in the auction stage and paying
$p^{so} = 0$ for them. However, now dealer 2 will have to transfer the acquired security in the
auction to dealer 1 in exchange for $p^{wi}$ as established in the when-issued transaction.

The simple environment considered in this section illustrates how strategic behavior of
dealers in both the auction and the when-issued market can generate the pattern observed
in the data. First, it illustrates that dealers can benefit by trading when-issued securities prior to the auction. Both dealers are better off after we allow them to trade the when-issued security compared to the case where they were not allowed.

Second, the equilibrium is consistent with underpricing. The price of a when-issued security must satisfy $p_{wi} \in (v_2, v_1)$, otherwise the trade would be blocked by one of the two dealers.\(^\text{10}\) Therefore, we have $p_{wi} > p^{so}$, i.e., the price dealers trade the when-issued security is higher than they pay for the securities in the auction. Appendix B shows that, if dealers compete for the when-issued security through a double auction, the equilibrium price satisfies $p_{wi} \in (v_2, v_1)$.

Third, dealers have incentives to acquire securities in the when-issued market even in the presence of the price premium. Dealer 1 has the incentive to acquire a security in the when-issued market even though the price she is paying is larger than the auction’s stop-out price. The argument is more subtle: if dealer 1, instead of acquiring the when-issued security, decided to acquire the second unit in the auction, she would actually pay a lower price for it. In this case, the stop-out price in the auction would rise to $\hat{p}^{so} = v_2$, which is still strictly lower than $p_{wi}$. However, in choosing to do so, she would affect the price she pays for the first unit she is acquiring in the same auction. On the other hand, if she decides to buy the additional security in the when-issued market, the auction stop-out price wouldn’t be affected. The overall cost for dealer 1 is lower when she adopts the latter strategy.

## 3 Main Framework

In this section I describe the basic model used in the rest of the paper. Treasury securities are simultaneously offered to dealers through a divisible good uniform price auction. Unlike auctions of a single indivisible good, in divisible good auctions, participants compete for shares of a positive quantity of the good being auctioned. A bid submitted by the participants of the auction is an entire schedule describing how many securities they are willing to acquire for all possible prices.

There are $N$ dealers in the economy with preferences over two goods: Treasury securities, $q$, and money $m$. The preference of a dealer $i \in I = \{1, \ldots, N\}$ is represented by a quasi-linear utility function $U_i : \mathbb{R}_+ \times \mathbb{R} \to \mathbb{R}$ such that $U_i(q, m) = u_i(q) + m$. For tractability, dealers’ marginal utility in respect to securities is assumed to be linear, $u_i : \mathbb{R}_+ \to \mathbb{R}_+$ satisfies:

**Assumption 1.** $\frac{\partial u_i(q)}{\partial q} = v_i - \rho q$.

\(^{10}\)I am assuming that they prefer not to trade a when-issued security if they are indifferent to do so.
Figure 3.1: Payment and allocation rules on a uniform price auction. Individual bid schedules are represented by dashed lines. Aggregate demand and supply are represented by solid lines. For a given realization of $Q$, the stop-out price is defined as the one that clears the market, and each dealer gets the amount of securities submitted at the stop-out price.

Dealers have complete information, so $v_i$ is common knowledge.

The Treasury uses a uniform price auction to sell an exogenous quantity, $Q$, of a perfectly divisible security. Dealer $i \in \mathcal{I}$ submits a bid schedule, $q_i^A(p, h)$, $q_i^A : \mathbb{R}_+ \times \mathcal{H} \to \mathbb{R}_+$, specifying the quantity demanded for each possible price and when-issued history $h \in \mathcal{H}$, which will be described later. The bid $q_i^A(p, h)$ is left continuous and weakly decreasing in the first argument. After collecting all individual bids, the Treasury determines the stop-out price, $p^{so}$. The stop-out price is defined as the highest value of $p \geq 0$ such that the aggregate bid is larger than or equal to the realized supply, i.e., $\sum_{j=1}^{N} q_j^A(p^{so}, h) \geq Q$ ($p^{so} \equiv 0$ if $\sum_{j=1}^{N} q_j^A(0, h) < Q$). Dealer $i$ gets $\psi_i^A \equiv q_i^A(p^{so}, h)$ units of the good, i.e., the amount he bid for at $p^{so}$ and pays the stop-out price for all units he acquires, $p^{so} \times \psi_i^A$.

A history is defined as vector $h = (p^{wi}, \{\theta_i^{wi}\}_{i \in \mathcal{I}})$ specifying the price of when-issued securities, $p^{wi}$, and a set of positions $\{\theta_i^{wi}\}_{i \in \mathcal{I}}$ dealers bring from the when-issued market. I am assuming a complete information environment, so all dealers know $h$ when submitting their bids in the auction.

Even though agents submit strictly decreasing bids in all equilibria described in this paper, we need to specify a tie-breaking rule for the cases where the aggregate demand is
greater than the supply at the stop-out price, i.e. when we have \( \sum_j q^A_j(p^{so}, h) > Q \). In this case, there is no alteration in the way the securities in the segment of the aggregate demand curve strictly above the stop-out price are allocated. The remaining units, given by \( Q - \lim_{p \to p^{so}} \sum_j q^A_j(p,h) \) will be distributed to the bidders on a pro-rata basis.\(^{11}\)

The total supply being auctioned, \( Q \), is stochastic with a support \([Q, \overline{Q}]\). As discussed in Back and Zender [1993], a noisy supply in the auction considerably reduces the set of equilibria for uniform price auctions. From a dealer’s perspective, a noisy supply is realistic in the context of the Treasury auctions. For instance, in these auctions, there are two ways participants can submit their bids: competitively or non-competitively. Competitive bids take the form of weakly decreasing schedules like the ones described in the paragraph above. A Non-competitive bid is simply a quantity a bidder wishes to acquire independently of the value of the stop-out price. It can be interpreted as an agent submitting a perfectly inelastic bid schedule. The Treasury first subtracts non-competitive bids from total supply before allocating the remaining securities to competitive bidders. Dealers may only submit competitive bids. Since they do not know ex ante the total amount of non-competitive bids, they perceive the supply in the auction as a stochastic variable.\(^{12}\)

Let \( \gamma \equiv \frac{N-2}{N-1} \) and \( \bar{\upsilon} \equiv \sum_j \upsilon_j \). I will make following restrictions on the support of \( Q \):

**Assumption 2.** The bounds of the support of \( Q \) satisfy:

- \( \bar{Q} \leq \frac{2}{\rho} \bar{\upsilon} \).
- \( \frac{Q}{N} \geq -\frac{2}{\rho} \min_i \{ \upsilon_i - \bar{\upsilon} \} \).

The assumption in the upper bound guarantees that the equilibrium stop-out price in the linear equilibrium described below is non-negative. The restriction on the lower bound is made in order to assure that all dealers are acquiring a positive quantity of the securities. In other words \( \psi_i^A \geq 0 \) for all \( i \in \mathcal{I} \) in equilibrium.

**When-Issued Market:** Prior to the auction, dealers can trade when-issued securities amongst each other. A when-issued security is promise to buy/sell a Treasury security after

---

\(^{11}\)Kremer and Nyborg [2004] compare equilibria of uniform auctions with different tie-breaking rules.

\(^{12}\)Indirect bidders, who purchase roughly 22\% of the entire supply of securities being auctioned (Fleming [2007]), also do not appear to be playing strategically (submitting strictly decreasing bid schedules). These type of bidders are mainly formed by foreign institutions which might demand a specific reserve of US securities not too sensitive on their price. Therefore, their bids also contribute to stochasticity of the total supply perceived by direct bidders.
the auction for a pre-established price. For instance, if dealer \( i \) sold \( q^{wi} \) when-issued securities to \( j \) for a price \( p^{wi} \), it means that \( i \) will have to deliver \( q^{wi} \) units of Treasury securities after the auction takes place and \( j \) will pay \( p^{wi} \times q^{wi} \) for them. The contract is established in the when-issued market, but the actual exchange will materialize only after the auction takes place and dealers have received the securities from the Treasury. There are no physical transfers, either of securities or money, at the time the contracts are negotiated.

I consider two different structures for the when-issued market. In the first, a perfect competitive market, dealers take the price of when-issued securities as given and simply choose how many when-issued securities they wish to acquire (sell). In the second environment, I model the when-issued market as a uniform price auction as well. In latter environment, dealers submit demand schedules representing their desire to acquire (or sell) when-issued securities in a similar fashion to how they submit bid schedules in the auction stage. Dealers submit left continuous, weakly decreasing demand schedules \( q^{wi}_i(p) : \mathbb{R} \rightarrow \mathbb{R}, i \in \mathcal{I} \) specifying the quantity of when-issued securities they wish to buy (sell) for all possible prices. A central inter dealer broker collects all individual schedules and forms the aggregate bid, \( \sum_{j=1}^{N} q^{wi,t}_j(p) \). Since the when-issued market is a zero-supply market, the stop-out price \( p^{wi} \) is defined as the highest value of \( p \geq 0 \) such that the aggregate bid is larger or equal to zero, i.e., \( \sum_{j=1}^{N} q^{wi,t}_j(p) \geq 0 \). As in the auction stage, the excess demand will be split in a pro-rata base if the inequality is strict.

The outcome for Dealer \( i \in \mathcal{I} \) from the when-issued market is a forward contract establishing that he will receive \( \theta^{wi}_i \equiv q^{wi}_i(p^{wi}) \) units of the security in exchange to a payment of \( p^{wi} \times \theta^{wi}_i \) as soon as the auction takes place. He is said to be taking a long (short) position at this round if \( \theta^{wi}_i > (<) 0 \). There is a per-unit monetary penalty, \( \pi \), in case a dealer fails to deliver the security. The penalty is assumed to be big enough in order to avoid dealing with cases where dealers optimally chooses to default in equilibrium.

For tractability, I will restrict the maximum position a dealer can take in the when-issued market. In all periods \( t \), we have that:

**Assumption 3.** \( \theta^{wi}_i \leq \tilde{\theta}_i \) for \( i \in \mathcal{I} \), where \( \tilde{\theta}_i = \frac{Q}{N} + \frac{1}{p} [v_i - \bar{v}] \).

Assumption 3 guarantees that all dealers acquire a positive amount of securities in the linear equilibrium of the auction described in the next sections.\(^{13}\)

\(^{13}\)According to the "Administration of Relationships with Primary Dealers": "(...) the New York Fed will expect a primary dealer to bid in every auction, for, at minimum, an amount of securities representing its pro rata share, based on the number of primary dealers at the time of the auction, of the offered amount,
A dealer’s final holdings of securities is given by the sum of what he acquires in the when-issued and auction stages. For example, if \( i \) arrives with \( \theta_i^{wi} \) from the when-issued and acquires additional \( \psi_i^A \) in the auction, he will end up with \( \psi_i^F \equiv \psi_i^A + \theta_i^{wi} \).

4 Assumptions

I make three main assumptions in order to get the results of this paper. First, dealers must have market power in the auction stage. Bid shading, which plays a central role on the analysis made here, will arise in equilibrium only if dealers take into account that their bid choices affect the auction price. Second, dealers should have heterogeneous demands for Treasury securities. With this assumption, dealers will end up acquiring different amounts of securities in the auction stage. Together with bid shading, this implies that the auction mechanism will fail to distribute securities efficiently, which gives dealers incentives to trade when-issued securities. The third assumption of the paper is the absence of asymmetric information among dealers, which will be assumed for tractability reasons.

There are a couple of facts corroborating the market power assumption. First, Primary Dealers, which are the only institutions allowed to trade directly with the Federal Reserve System in the secondary market, absorbs roughly 70\% of all securities being auctioned by the Treasury [Fleming, 2007]. In fact, even among the Primary Dealers, the market is fairly concentrated. For instance, in the first quarter of 2012, five dealers were responsible, roughly, for 50\% of the total outright volume of transactions involving Treasury securities by the Primary Dealers.\(^{14}\) Second, in order to get the status of a Primary Dealer, the Fed requires that a financial institution participate in all auctions for Treasury Securities.\(^{15}\) This costly requirement illustrates the extent to which the Fed is worried about fomenting competition in the auctions.

There are many reasons why dealers have heterogeneous demand for a specific Treasury security. For instance, dealers might differ in their endowments of a correlated security, inventory costs, outside investment opportunity costs and on their financial constraints. Moreover, primary dealers often submit bids on behalf of their clients.\(^{16}\) Idiosyncrasies its bid prices should be reasonable when compared to the range of rates trading in the when-issued market (\(...\))\(^{17}\). This assumption could be dropped if we allowed dealers to acquire negative positions, i.e. sell securities, in the auction stage.

\(^{14}\)See Primary Dealers Statistical Releases, fed of New York.
\(^{15}\)See "Administration of Relationships with Primary Dealers".
\(^{16}\)For example, China, one of the largest holder of U.S. Treasury securities, submitted their bids through dealers until 2011. Other big players, as Japan, still uses the primary dealers to do it. See, for example,
from these network of clients will also be reflected in their demand for the Treasury security. These characteristics are specific to each dealer and are not necessarily related to the intrinsic fundamental value of the security.

In the specific case of the Treasury market, asymmetric information is not as relevant as for other types of securities. The type of information that affects the fundamental value of a Treasury security mainly takes the form of public macroeconomic announcements.\footnote{CPI, PPI, etc. See Fleming and Remolona [1999].} Many authors have suggested that differences in the ability to interpret public information could actually be a source of asymmetric information among dealers (Fleming and Remolona, 1999, Green, 2005). However, the impact of such announcements in the market are almost completely absorbed a few hours after they are released and do not endure until the auction period.

5 No Market Power

This section considers the benchmark Walrasian equilibrium of the environment described above. Here, dealers take the prices of securities as given in both market stages. We have the following result:

**Proposition 1.** If dealers have no market power, they submit their true valuation function as a bid in the auction:

\[ q^W_i (p, h) = \frac{1}{\rho} (v_i - p) - \theta_i^w i \in \mathcal{I}. \]  \hspace{1cm} (5.1)

For any history \( h = (p^w, \{\theta_i^w\}_{i}) \) and realization \( \hat{Q} \), the equilibrium stop-out price in the auction is:

\[ \hat{p}^W = \bar{v} - \rho \frac{\hat{Q}}{N}. \]  \hspace{1cm} (5.2)

Moreover, the equilibrium price in the when-issued market is given by:

\[ p^{wi} = E [p^W]. \]  \hspace{1cm} (5.3)

Dealers are indifferent between their holdings of when-issued securities which implies that any set \( \{\theta_i^{wi}\}_{i} \) satisfying Assumption 3 and \( \sum_{i} \theta_i^{wi} = 0 \) could hold in equilibrium.

A dealer’s optimal strategy is to equate his marginal valuation to the security’s price.

\textit{ Reuters.}
Although \( p^W \) is not known by the time dealers place their bids, they are able to do so for all realizations of \( p^W \) by submitting their true marginal valuation functions as their bid schedules. To see that, we can invert the bid schedule (5.1) above to get:

\[
\beta^W_i(q, h) = u'_i(q + \theta^{wi}_i).
\] (5.4)

Dealers’ final allocations are efficient and independent of the specific history from the when-issued market. It is clear from the proposition above that only the positions \( \{\theta^{wi}_i\}_I \) affect the auction outcome. However, it is also clear that these positions affect the way securities are distributed in the auction, but not their final allocation. An increase in \( \theta^{wi}_i \) is completely canceled out by a decrease in the amount dealer \( i \) acquires in the auction, as can be seen in (5.1). In the end, this dealer ends up holding the same amount of securities he was holding before the increase in his when-issued position.

Since \( \psi^W_i \) is independent of \( h \), the price of securities in the when-issued market should be equal to the equilibrium price in the auction, in expected terms. If \( p^{wi}_i < E[p^W] \), all dealers would take upper bound position \( \theta_i \) and the market would not clear. Conversely, if \( p^{wi}_i > E[p^W] \), all dealers would have incentives to take strictly negative positions. Therefore, when dealers do not have market power, the equilibrium price in the when-issued market must be the same as in the auction in expected terms. In other words, there is no underpricing.

Since the price of when-issued securities satisfies (5.3), dealer \( i \) is indifferent between any position \( \theta^{wi}_i \in \mathbb{R} \). This implies that any set \( \{\theta^{wi}_i\}_I \) satisfying Assumption 3 and \( \sum_I \theta^{wi}_i = 0 \) can be sustained as an equilibrium for the when-issued market. A special set satisfying these conditions has \( \theta^{wi}_i = 0 \), for \( i \in I \), the case which the when-issued market is shut down. In fact, these would be the unique equilibrium positions if we made the additional assumption that there are arbitrarily small transactions costs in the when-issued market.

## 6 Equilibrium with Market Power

In this section, I will characterize an equilibrium where dealers take into account that the auction’s stop-out price is a function of the specific bid schedule they submit. As will be shown below, dealers will strategically submit bid schedules strictly below their true marginal valuation, i.e., they will 'shade' their bids. For tractability, I focus on equilibrium where investors submit linear bid schedules in both market stages, which restricts dealers to have strictly decreasing valuation functions, i.e. \( \rho > 0 \).


6.1 Auction

Suppose dealers arrive in the auction stage after a given history $h \in \mathcal{H}$ from the when-issued market satisfying Assumption 3. An equilibrium of the auction sub-game is a set of bid schedules $\{q_i(p, h)\}_{i}^{I}$ and a random variable $\tilde{p}^{so}$ such that $q_i^A(p, h), i \in I$ solves:

$$
\max_{q_i(\cdot)} E \left[ u_i \left( q_i(p^{so}, h) + \theta^{wi}_i \right) - p^{so} q_i(p^{so}, h) \right].
$$

(6.1)

given the other dealers are submitting $\{q_j(p, h)\}_{I-i}^{I}$ and, for each realization of the supply, the stop-out price satisfies the market clearing condition $\sum_{I} q_j(\tilde{p}^{so}, h) = \tilde{Q}$.

Suppose, for a moment, that dealers know the realization of the supply of securities in the auction, $\tilde{Q}$. Let $y_i(p, h) \equiv \tilde{Q} - \sum_{I-i} q_j^A(p, h)$ denote the residual supply faced by dealer $i$. Given the other dealers’ bid schedules, $y_i(p, h)$ gives the amount of securities $i$ receives as a function of the auction price. Dealer $i$’s optimization problem is reduced to one of choosing the auction stop-out price that solves:

$$
\max_{p^{so}} u_i \left( y_i(p^{so}, h) + \theta^{wi}_i \right) - p^{so} y_i(p^{so}, h).
$$

Suppose also that each $j \in I-i$ submits differentiable and strictly decreasing bid schedules. The first order condition of the problem above is:

$$
u'_i \left( y_i(p^{so}, h) + \theta^{wi}_i \right) = p^{so} + \frac{1}{\partial_p y_i(p^{so}, h)} y_i(p^{so}, h).
$$

(6.2)

Dealer $i$’s problem is similar to one of a monopsonist facing a positive sloped residual supply. He faces a trade-off between increasing the quantity of securities he acquires in the auction at the cost of increasing the price he pays, not only for the additional security, but for all the ones he was already acquiring. At optimum, the dealer equalizes the marginal expenditure to the marginal benefit he gets from acquiring an additional security. The marginal expenditure, the term in the right hand side of the equation above, has two components: (i) the payment for the additional security, $p^{so}$, and (ii) an increase in the payment of all infra-marginal units due to an increase in the stop-out price.

The equilibrium described in the proposition below is found by making the above optimality condition hold for each realization of the supply $\tilde{Q}$. This equilibrium is ex post efficient in the sense that dealers are acquiring the optimal quantity of securities for all realizations of the stochastic supply.

\[\text{\textsuperscript{18}}\text{See Milgrom [2004] for a detailed discussion.}\]
Proposition 2. In the unique linear equilibrium of the uniform price auction, dealers submit the following bid schedules:

\[ q_i^A (p, h) = \frac{\gamma}{\rho} (v_i - p) - \gamma \theta^w_i, \quad i \in \mathcal{I}. \]  

(6.3)

where \( \gamma = \frac{N-2}{N-1} \). For a given realization \( \tilde{Q} \), the equilibrium stop-out price is:

\[ \tilde{p}^{so} = \tilde{p}^W - \frac{1 - \frac{\gamma}{\rho}}{\gamma} \frac{\tilde{Q}}{N}. \]  

(6.4)

Let’s take a closer look at how we arrive at the above expression for the equilibrium bid schedule. If \( j \in \mathcal{I} - i \) are submitting bid schedules like (6.3), the residual supply \( y_i (p, h) \) has a constant slope in its first argument given by \( \frac{1}{1 - \frac{\gamma}{\rho}} \). We can rewrite the first order condition in (6.2) as:

\[ v_i - \rho \left( y_i (p^{so}, h) + \theta^w_i \right) - p^{so} - \rho \frac{1 - \frac{\gamma}{\rho}}{\gamma} y_i (p^{so}, h) = 0. \]

Solving for \( y_i (p^{so}, h) \) gives exactly the quantity on the bid schedule 6.3 and the price on 6.4 for a given realization of the supply \( \tilde{Q} \).

In equilibrium, dealers are optimally "shading" their bids. The magnitude of the bid shading can be seen if we invert the equilibrium bid schedule (6.3) of dealer \( i \):

\[ \beta_i^A (q, h) = u'_i \left( q + \theta^w_i \right) - \rho \frac{1 - \frac{\gamma}{\rho}}{\gamma} q. \]

The inverse of the bid schedule is equal to \( i \)'s marginal valuation minus the bid shading term. As long as dealer \( i \) acquires a positive amount \( q \) of securities in the auction, the bid schedule he submits will lie strictly below his marginal valuation curve.

6.1.1 (In)efficiency:

The magnitude of bid shading is strictly increasing in the quantity a dealer is acquiring in the auction. This is intuitive. If the auction price increases by a given amount, the impact on dealer \( i \)'s total payment is higher if he is acquiring a relatively larger amount of securities. Consequently, dealers will bid less aggressively for larger amounts of securities. The left panel of Figure 6.1 depicts the marginal valuation function and the bid schedules from two different dealers when they arrive in the auction with a null position from the when-issued market. For both dealers, the marginal valuation curve and the bid schedule coincides for the first unit of the security since the price impact component is zero. However, as dealers
Figure 6.1: Left panel: The solid lines represent dealers’ demand for securities. The dashed lines represent dealers’ equilibrium bid schedules when both dealers arrive with a null position from the when-issued market. Right: Dashed lines represent the equilibrium bid schedules when dealers arrive in the auction with net positions $\theta_L = 2 = -\theta_S$ from the when-issued market.

The fact that bid shading is increasing in quantity has implications on how the auction allocates securities among dealers. Given the heterogeneity in demand intercepts and when-issued positions, the amount of securities acquired in the auction will not be the same across dealers. This implies that dealers with higher demands, who end up acquiring larger amounts, end up with higher marginal valuations when evaluated at the final allocation of securities. This property of the equilibrium is illustrated on Figure 6.1. For a given realization of $\tilde{p}^{so}$, the dealer with the highest demand acquires more securities in the auction and ends up with a higher marginal valuation than the smaller one. The following corollary summarizes this property.

**Corollary 1.** In the linear equilibrium of the auction we have that $v_i - \rho \theta_i^{w_i} > v_j - \rho \theta_j^{w_i} \iff u'_i(\tilde{\psi}_i^F) > u'_j(\tilde{\psi}_j^F)$ for all dealers $i, j \in \mathcal{I}$ and realization of the supply $\tilde{Q}$.

The auction does not distribute securities in an efficient way. The larger a dealer’s demand for securities, adjusted for his when-issued position, the higher will be his marginal valuation evaluated at the final allocation $\{\tilde{\psi}_i^F\}_I$. Even though dealers with high demand are getting larger amounts of securities, they are getting less than if securities were distributed efficiently.
6.1.2 Relationship Between When-issued Positions and the Auction Outcome

As in the simple example analyzed in section 2, dealers can use the when-issued market to improve the auction allocation. Indeed, Proposition 2 implies that a dealer’s bidding behavior in the auction is directly affected by the position he carries from the when-issued market. They anticipate this relationship when choosing their strategies in the when-issued stage.

The following corollary gives the exact relationship between the auction and final allocation of securities and the history from the when-issued market.

**Corollary 2.** For any realization of \( \tilde{Q} \), history \( h \), and \( i \in \mathcal{I} \),

- \( \frac{d\tilde{\psi}^A}{d\theta_{wi}} = -\gamma \) and \( \frac{d\tilde{\psi}^F}{d\theta_{wi}} = (1 - \gamma) \).
- \( \frac{d\tilde{\psi}^A}{d\theta_{wi}} = \frac{d\tilde{\psi}^F}{d\theta_{wi}} = 0 \).
- \( \frac{dp^{so}}{d\theta_{wi}} = 0 \).

The first conclusion we can draw from the corollary above is that only a dealer’s own position, \( \theta_{wi} \), \( i \in \mathcal{I} \), will affect his allocation of securities. The way the remaining when-issued securities are distributed among \( j \in \mathcal{I}_{-i} \), or the specific when-issued price \( p_{wi} \) will not have any influence on the amount of securities \( i \) acquires in the auction and his final position. Second, the relationship between a dealer’s allocation and his when-issued position is independent of the specific realization of \( \tilde{Q} \) or the history \( h \) from the when-issued market. Finally, the last point states that the auction price is independent of the positions dealers carry from the when-issued market.

Suppose, for instance, that the dealer with the higher marginal valuation acquires a when-issued security from the dealer with the lower valuation. Corollaries 1 and 2 above imply that the gap between the dealers’ marginal valuations evaluated at the final allocation will be reduced. The price of a when-issued security will determine how these gains are split between dealers trading when-issued securities.

To what extent are dealers able to mitigate the inefficiencies coming from bid shading using when-issued securities? How do dealers share the rents from the allocational improvements? In other words, what will be the equilibrium price of securities in the when-issued market? These questions will be analyzed in the following subsection.
6.2 When-Issued Market

I continue the analysis by characterizing the equilibrium in the when-issued market. When choosing their strategies at this market stage, dealers anticipate the auction outcome will be determined by the equilibrium described in Proposition 2. Therefore, they internalize the relationship between their positions and the auction outcome given by Corollary 2.

I will focus on two particular equilibria for the when-issued market: a perfectly competitive equilibrium and a linear bid schedules equilibrium. In the perfectly competitive equilibrium, dealers take the price they pay for securities in the WI market as given (but not in the auction stage). This environment provides intuitions about how the price of WI securities is determined in equilibrium - thus, how underpricing arises. Moreover, it emphasizes that it is the market power in the auction stage alone that gives dealers incentives to trade when-issued securities. In the linear equilibrium, dealers take into account that they can affect the price of securities in the when-issued stage as well. They submit entire demand (supply) schedules for WI securities in the same fashion as they do in the auction stage.

As will be shown below, the outcome of the two equilibria share some characteristics. For instance, the prices of the security, in the auction and in the when-issued stages, are invariant between the two equilibria. Moreover, the final allocation of securities (and money) in the imperfect competitive equilibrium gets arbitrarily close to that in the perfectly competitive equilibrium as we increase the number of rounds in the when-issued market.

6.2.1 Competitive When-Issued Market

In this subsection, dealers take the price of when-issued securities as given when choosing their positions in the when-issued market. It is important to emphasize, however, that dealers do take into account how these positions will affect the auction outcome. They anticipate that the equilibrium in the auction will be the one described on Proposition 2. Therefore, they also anticipate the resulting relationship between when-issued positions and auction allocations.

Given a price $p^{wi}$ for the when-issued securities, dealer $i$’s problem is reduced to:

$$
\max_{\theta_i^1 \leq \theta_i} E \left[ U_i \left( \psi_i^F \right) - p^{so} \psi_i^A \right] - p^{wi} \theta_i^{wi}.
$$

(6.5)

where $\psi_i^A$ and $\psi_i^F$ are, respectively, the auction and final allocations of securities to dealer

---

19 As in the case of the auction sub game, there will be multiple equilibria in demand schedules. Linearity is chosen for tractability.
resulting from the auction equilibrium described on Proposition 2. Corollary 2 describes the exact relationship between \( \psi^A_i \) and \( \psi^F_i \) with \( i \)'s when-issued position, \( \theta_{wi}^i \).

We have the following result:

**Proposition 3.** Suppose that dealers anticipate that the equilibrium in the auction stage is the one described on Proposition 2. If the when-issued market is competitive, the equilibrium price and positions are given by:

\[
p^{wi,c} = (1 - \gamma) E[p^W] + \gamma E[p^{so}] . \\
\theta^c_i = \frac{1}{\rho} (\upsilon_i - \bar{\upsilon}) .
\]  

(6.6)  

(6.7)

where \( p^{so} \) and \( p^W \) are, respectively, the price of securities in the auction stage and the price that would arise if dealers had no market power in the auction stage.

**Efficiency:** Proposition 3 leads to the following corollary:

**Corollary 3.** If the when-issued market is competitive, the final allocation of securities is efficient: \( \psi^F_i = \psi^W_i \) for all \( i \in \mathcal{I} \).

Two conclusions can be drawn from the corollary above. First, dealers are able to eliminate all inefficiencies associated with the auction process if they take the right set of positions in the when-issued market. Note that this is true for any realization of \( \tilde{Q} \). Second, this set of positions, denoted by \( \{\theta^c_j\}^I_{j=1} \), is attained in equilibrium under perfect competition in the when-issued market.

If dealers arrive with \( \{\theta^c_j\}_{j=1}^N \) from the when-issued market, they will submit symmetric bid schedules in the auction stage. This can be readily seen by plugging back \( \theta^c_i \) on the equilibrium bid schedule 6.3. The resulting bid will not depend directly on \( i \)'s marginal valuation intercept, \( \upsilon_i \), but only on the average intercept across dealers \( \bar{\upsilon} \). As a result, all dealers end up with the same demand for securities in the auction. It follows from Corollary 1 from the previous subsection that this symmetrization property implies that all dealers end up with the same marginal valuation for the security evaluated at the final allocation.

**Underpricing:** The equilibrium of the environment considered in this subsection is consistent with underpricing. Indeed, the price of securities in the when-issued market, \( p^{wi,c} \), is given by a weighted sum of the expected values of \( p^{so} \) and \( p^W \) - the price of securities in the
The price of securities in the when-issued market is lower than the Walrasian price $p^W$. Dealers anticipate that they will be able to acquire the security for an artificially low price in the auction stage, which drives the price in the when-issued stage down as well. However, the price at the latter stage will not fully go down to the auction’s level, otherwise none of the dealers would have incentives to take short positions.

Let’s take a closer look at how we arrive at equation (6.6) for $p^{wi}$. Suppose dealer $i$ acquires an additional amount $\Delta$ of securities in the when-issued market. Since the price of securities is fixed in the WI market, the cost of the additional $\Delta$ will be simply $p_{wi,c} \times \Delta$. On the other hand, the gains are split in two effects - the first comes from an increase in his final allocation and the second comes from a reduction in his payment at the auction stage. Indeed, Corollary 2 implies that $\psi^F_i$ will increase by $(1 - \gamma) \times \Delta$ and $\psi^A_i$ will be reduced by $\gamma \times \Delta$. The sum of the two components is written as:

$$E [u'_i(\psi^F_i)] \times (1 - \gamma) \times \Delta + E[p^{so}] \times \gamma \times \Delta.$$  

However, evaluated at the equilibrium allocation, $u'_i(\psi^F_i) = u'_i(\psi^W_j) = p^W$ for all $i, j$. At the optimal, the marginal benefit from increasing the quantity acquired at this stage should be equal to the cost, which gives the expression (6.6) for the WI price.

The next corollary describes how the magnitude of the underpricing depends on the parameters’ values in equilibrium.

**Corollary 4.** The expected magnitude of the underpricing in the equilibrium described above is given by:

$$p^{wi,c} - E[p^{so}] = \frac{(1 - \gamma)^2}{\gamma} \frac{E[Q]}{\rho N}.$$  

Not surprisingly, the same set of parameters determining the magnitude of dealers’ bid shading in equilibrium will be the same determining the magnitude of the underpricing. This is not surprising since dealers trade when-issued securities in order to exploit the inefficiencies caused by bid shading. We can interpret the when-issued price as the way dealers share the trading gains from the when-issued market.

The above corollary implies that underpricing and auction size are positively related. It is clear from expression 6.4 that an increase in the total amount of securities per dealer being offered by the Treasury implies a larger gap between the Walrasian price, $p^W$, and the
auction price, $p^{so}$. Since the when-issued price is a convex combination of these two prices, the gap between $p^{wi}$ and $p^{so}$ is also going to be positively related with the size of the auction. Therefore, caeteris paribus, we should expect a positive correlation between the magnitude of underpricing and the quantity of securities being auctioned.

An increase in the number of dealers also reduces the magnitude of underpricing. We can split the effects of an additional dealer in two. The first is a reduction in the auction size - more dealers for the same amount of securities. The second is a decrease in the degree of competition - their ability to influence the price is diminished. Both effects imply a more aggressive bidding behavior by dealers at the auction stage. Their bids will be closer to their true marginal valuation function, which implies a smaller gap between $p^{W}$ and $p^{so}$. Consequently, the gap between $p^{wi}$ and $p^{so}$ will also be reduced.

**Sell high and buy low:** One may argue that the gap between the price of the securities in the two market stages creates an arbitrage opportunity. A dealer could sell securities in the when-issued market, where the price is higher, and buy them back in the auction, where the price is lower. Why can’t dealers profit from this simple 'sell high and buy low' strategy?

The answer lies on the impact on the auction price such a strategy produces. As discussed in the previous section, there are two effects coming from a marginal increase in the quantity acquired in the auction. The first is simply the cost of this additional unit, given by $p^{so}$. The second comes from the fact that the auction’s price will also increase, which affects the cost of all other securities this dealer was already acquiring. The net profit dealer $i$ gets if he takes this strategy is:

$$p^{wi,c} = \left( E[p^{so}] + \frac{1 - \gamma}{\gamma} \rho \times E[\psi_i^{A}] \right)$$

Substituting the equilibrium values in the expression above, one can show that the profit is given by $-(1 - \gamma) \rho \frac{E[Q]}{N}$. Therefore, the dealers’ payoff would actually decrease if they decided to take such strategy.

### 6.2.2 Imperfect Competition in the When-Issued Market

This section extends the above analysis to the case where dealers internalize their market power in the when-issued market as well. One may wonder whether equilibrium underpricing depends on the assumption of competition in the when-issued market. As will be shown below, this is not true. Indeed, underpricing will arise in equilibrium when investors do
take into account they can influence the price of when-issued securities. In fact, the gap in
the price from the two market stages will be exactly the same as in the previous section.
Moreover, it is not straightforward to justify why dealers internalize their market power in
the auction stage, but act as price takers in the when-issued market.

Given that all dealers \( j \in I_i \) are submitting \( \{\theta^{wi}_j (p)\}_{I_i} \), dealer \( i \)'s maximization problem in the when-issued market can be written as:

\[
\max_{\theta^{wi}_i} E \left[ u_i \left( \psi^F_i \right) - p^{so} \psi_i^A - p^{wi} \theta^{wi}_i (p) \right].
\] (6.8)

where \( \psi^F_i \) and \( \psi_i^A \) are related to \( \theta^{wi}_i \) accordingly Corollary 2, and the when-issued price satisfies the market clearing condition \( \sum_I \theta^{wi}_j (p^{wi}) = 0 \). We have the following result,

**Proposition 4.** Suppose that dealers anticipate that the equilibrium of the auction is the
one described on Proposition 2. In the unique linear Sub game Perfect Equilibrium (robust),
dealers submit the following bid schedules in the when-issued market:

\[
\theta^{wi}_i (P) = \frac{\gamma}{(1 - \gamma)^2} \rho \{ A_i - P \}, \quad i \in I.
\] (6.9)

where \( A_i \equiv p^{wi,c} + (1 - \gamma)^2 \rho \theta^c_i \). The equilibrium price and positions are given by:

\[
p^{wi} = p^{wi,c}
\]
\[
\theta^{wi} = \gamma \theta^{wi,c}
\]

The variables \( p^{wi,c} \) and \( \theta^c_i \) were defined on Proposition 3. They represent, respectively, the
price and \( i \)'s position of equilibrium when the when-issued market was perfectly competitive.

**Underpricing:** The equilibrium described above is consistent with underpricing. The
price of securities in the when-issued market is higher than their expected price in the auction.
In fact, the when-issued price when dealers submit complete demand/supply schedule at this
stage takes the exact form as in the competitive when-issued market case. Consequently,
the analysis made in the previous subsection about the relationship between the model
parameters and the magnitude of the underpricing can be extended to the equilibrium above.

At this point, a natural question arises: if market power is the source of a relatively
lower auction price, why doesn’t the price of when-issued securities change when we let
dealers make use of their market power in the when-issued market? Unlike the auction
Figure 6.2: The solid lines represent the future net payoff that buying/selling when-issued securities will bring to dealers. The dashed lines represent dealers’ bid schedule submitted in equilibrium.

Stage, both sides of the market have market power at the when-issued stage. At the auction, the Treasury is selling an exogenous quantity $\tilde{Q}$ and dealers, who are all on the buy side of the market, make use of their market power to reduce the price they pay for the securities. The when-issued market, in turn, is a zero supply market - dealers are trading securities amongst themselves. Dealers taking long positions will behave strategically to reduce the price of securities they are acquiring, and dealers taking short positions will also behave strategically, but in order to increase the price. The linearity of bid schedules implies that the two effects cancel out in equilibrium.

The intuition above can be readily seen on Figure 6.2. The future expected payoff that when-issued securities bring to dealers (their true demands for when-issued securities) are represented by the solid lines. However, dealers submit the dashed lines as their bid schedule in equilibrium. Whenever a dealer is taking a long position, his demand schedule will lie strictly below his valuation. This is the bid shading discussed previously - the dealer reduces the quantity he acquires in order to artificially decrease the price. However, when a dealer is taking a short position, his supply schedules will lie strictly above his true valuation. The shade goes in the other direction - he reduces the quantity he sells in order to artificially increase the price.
6.2.3 Sequential When-issued Market

In practice, the when-issued market is open for trade over the entire period between the announcement and the auction days. This section extends the model considered above to a multi-period environment in order to capture this dynamic characteristic from this market. Instead of a single period, dealers are allowed to trade when-issued securities in a finite number $T$ of rounds before the auction takes place. Each of these rounds works exactly the same as in the previous section. Let $t = 1, \ldots, T$ denote the number of rounds until the auction stage. Given a history up to period $t$, dealers submit a demand schedules $q_{i}^{ui,t}(p, h^{t+1}) : \mathbb{R} \times \mathcal{H}^{t+1} \rightarrow \mathbb{R}$, $i \in \mathcal{I}$ at each round $t$. The central inter-dealer broker determines the when-issued price and allocations for the specific round denoted, respectively, by $p^t$ and $\psi_{i}^{t} \equiv q_{i}^{ui,t}(p^t, h^{t})$.

Let $\theta_{i}^{t} \equiv \sum_{\tau=t}^{T} \psi_{i}^{\tau}$ denote dealer $i$’s net position on forward contracts at the end of period $t$, which is given by the summation of all his positions from the prior $T - (t + 1)$ rounds.\footnote{To simplify the notation, I am assuming $\theta_{i}^{t} \equiv 0$ for all $t > T$} After all rounds of the when-issued market have occurred, dealer $i$ arrives at the auction stage with a net position $\theta_{i}^{1}$. This means that, in the absence of default, this dealer will get $\theta_{i}^{1}$ securities in addition to the ones he ends up acquiring in the auction stage. For instance, if he acquires $\psi_{A}^{i}$ units in the auction, he will end up holding $\psi_{F}^{i} \equiv \psi_{A}^{i} + \theta_{i}^{1}$ securities on his portfolio. As will be discussed below, $\theta_{i}^{1}$ is sufficient to determine how the outcome of the $T$ rounds in the when-issued market will influence $i$’s final allocation. However, since the price of the when-issued security is specific to each round $t$, his payment will depend specifically on his transactions at each specific round. Indeed, the net payment $i$ promised to make after the when-issued contracts are settled is given by:

$$\sum_{t=1}^{T} p^{t} \left( \theta_{i}^{t+1} - \theta_{i}^{t} \right).$$

I will assume that dealers have complete information. Let $h^{t} \equiv \left( \left\{ \theta_{j}^{\tau+1} \right\}_{j=1}^{N}, p^{\tau+1} \right)_{\tau=t}^{T} \in \mathcal{H}^{t}$ be the history up to period $t$ from the when-issued market. On each round $t$, the history $h^{t}$ is common knowledge among dealers. These assumptions are made in order to isolate the relationship between market power in the auction stage and the incentives to trade when-issued securities.

Once more, I focus on the equilibrium where dealers submit linear demand (supply) schedules in all of the $T$ rounds of the when-issued market. We have the following result.
Proposition 5. **In the linear Subgame Perfect Equilibrium for the when-issued market,** dealers submit the following bid schedules on periods $t = 1, ..., T$:

$$ q_{wi,t} (P) = \frac{\gamma}{(1 - \gamma)^{2t} \rho} \left\{ A_{ti}^t - P \right\} - \gamma \theta_{ti}^{t+1}, \quad i \in I. \tag{6.10} $$

where $A_{ti}^t \equiv p^{wi,c} + (1 - \gamma)^{2t} \rho \theta_{ti}^c$.

Figure 6.3 depicts the equilibrium bid schedules for different periods in the when-issued market. As can be readily seen, the slope of the bid schedules decreases as dealers approach the auction. This result is intuitive. With a larger number of periods to go before the auction, dealers have more opportunities to revert any undesired position they might be holding at a specific period. Consequently, their true valuation function for when-issued securities will get more elastic the further they are from the auction.

Flatter valuation functions, per se, already give dealers incentives to submit flatter demand schedules. However, this effect is augmented by the interaction process that takes place in equilibrium. From an individual dealer’s perspective, the fact that all his competitors submit flatter demand schedules implies that the price of when-issued securities is less sensitive to the amount of securities he decides to acquire (sell). Therefore, he will have less incentives to try to manipulate the price by increase the shade in his bid at this stage. As a consequence, he will submit bids closer to his true valuation for the security - flatter bid schedules.
**Underpricing:** Proposition 5 implies the following corollary.

**Corollary 5.** The equilibrium price in the when-issued market satisfies $p_{wi,t} = p_{wi,c}$ for all $t = 1, \ldots, T$.

The above corollary states that the equilibrium described in this subsection is consistent with underpricing as well. As a matter of fact, the equilibrium price of securities in the when-issued and auction stages is exactly the same as in the case where the when-issued market was assumed to be competitive. Therefore, the relationship between the magnitude of underpricing and the underlying parameters from the model is exactly the same as in the previous subsection.

The corollary also highlights the fact that the price of securities does not change over the entire when-issued period. Even though dealers are submitting different demand schedules, the price clearing the market will be the same in all rounds. This implies that, in the absence of any shock on the underlying parameters, we should expect the price of when-issued securities to be constant over the entire when-issued period.

**Dealers’ Positions Over Time** How do dealers’ positions evolve over the when-issued market? Proposition 5 implies that they follow a simple recursive form.

**Corollary 6.** Suppose that dealers arrive in round $t$ with a set of positions $\{ \theta_{t+1}^i \}_{i=1}^N$. The equilibrium dealers’ positions by the end of round $t$ from the when-issued market are given by:

\[
\theta_t^i = \gamma \theta_t^c + (1 - \gamma) \theta_{t+1}^{i+1}, \ i \in I.
\]  

(6.11)

Positions are gradually formed over the when-issued market. In the absence of an exogenous shock, dealers taking (strictly) long positions at the first round will keep taking (strictly) long positions in all the remaining periods. Moreover, the sign of a dealer’s position depends only on the relative size of their demand in comparison to the demand of other dealers. This comes straightforwardly from the fact that $\theta_t^i$ is a multiple of $\theta_t^c$ for all periods $t$. As argued before, dealers use the when-issued market to exploit the inefficiencies created by their strategic behavior in the auction. However, the fact that dealers also have market power in the when-issued market implies that they do not exploit all trading gains on a single round. The remaining gains are exploited on following rounds.

At the end of round $t$, dealer $i$ will hold a net position given by a weighted average between his position in the previous round and the optimal position. The higher the market
power of dealers (the lower $\gamma$ is) the lower will be his adjustment in round $t$. In other words, the lower will be the amount of when-issued securities he acquires (sells) in this round. This comes from the fact that dealers bid less aggressively when they have more market power because his demand will have a higher impact on the price.

Corollary 6 also implies on a positive relationship between dealers positions in the when-issued market, $\{\theta^t_j\}_{j=1}^N$, and the amount they acquire in the auction $\{\psi^A_j\}_{j=1}^N$. Dealers taking long positions will be the ones acquiring larger amounts in the auction. This contrasts with the results when the when-issued market was competitive. When this was the case, we've seen that all dealers end up acquiring the same quantity of securities in the auction stage. However, dealers are not able to exploit all gains of trade when they have market power in the when-issued market. This implies that we would still observe dealers with higher intercepts on their valuation functions acquiring larger quantities at the auction stage. Furthermore, these are the same dealers taking the long positions in the when-issued market.

Efficiency: At a given round $t$ in the when-issued market, dealers will exploit the remaining gains of trade not exploited in the previous rounds. The next corollary states that, as the number of rounds gets arbitrarily large, the equilibrium allocation of securities among dealers converges to the efficient allocation.

**Corollary 7.** When $T \to \infty$, the equilibrium final allocation of dealer $i$ satisfies $\psi_i^F \to \psi_i^W$.

The result come straightforwardly from Corollary 6. Given the simple recursive expression that the positions of dealers evolve, it is not difficult to see that $\{\theta^1_j\}_{j=1}^N$ converges to $\{\theta^c_j\}_{j=1}^N$ as $T$ goes to infinity. However, we saw in the previous section that if dealers arrive in the auction holding $\{\theta^c_j\}_{j=1}^N$ the final allocation will be efficient.

7 Further Empirical Implications

7.1 Measuring the Cost of the Auction Mechanism

What is the cost for the Treasury, in terms of loss of revenue, due to the strategic behavior of dealers in the auction stage? This question is the subject of many empirical and theoretical papers analyzing Treasury auctions. A benchmark for how much the Treasury is leaving on the table is the difference between the highest price dealers would be willing to pay for the securities - their 'true value' - and the price they are actually paying in the auction. The magnitude of the gap between the true value and the auction prices is interpreted as the
cost, per security, of the auction for the Treasury. Unfortunately, in practice we observe only what dealers are actually paying in the auction, but not what they were willing to.

In order to deal with this problem, many empirical papers use the outcome of the secondary market surrounding auctions to estimate the securities’ true value. Specifically, the price at which securities are negotiated at the when-issued market has been frequently used as proxies for their true value. Since dealers trade in the when-issued market during the minutes surrounding the auction, using when-issued prices allow researchers to avoid problems concerning duration mismatches.

The simple environment considered in this paper highlights that using when-issued securities for this purpose may be misleading. As showed in the previous sections, the equilibrium price at the when-issued market will not be equal to dealers’ true valuation for the security in the presence of market power. Dealers anticipate that the equilibrium price in the auction will be artificially below the underlying security’s true market value. This fact will drive the equilibrium price of when-issued securities down as well. Indeed, in the environment considered above, the highest value for the price such that dealers would be willing to absorb the entire supply - the securities "true value" - is the Walrasian price $p^W$. However, in equilibrium, the Walrasian and the when-issued prices satisfy:

$$E[p^{wi} - p^{so}] = (1 - \gamma) E[p^W - p^{so}].$$

(7.1)

Since $\gamma \in \left(\frac{1}{2}, 1\right)$, the gap between the auction and when-issued prices is strictly smaller than the gap between the auction price and the "true value" of the security. This means that using the when-issued prices as proxies would actually underestimate the revenue loss for the Treasury.

Equation (7.1) suggests a way to correct to the potential bias related to using WI prices as proxies. Note that the magnitude of the multiple factor $(1 - \gamma)$ depends solely on the number of participants in the market. Therefore, the average gap between the Walrasian and auction’s prices could be backed up straightforwardly from the average gap between the when-issued and auction’s prices.

One could also be interested in the gap between the two prices for a specific realization. Equation (7.1) proposes a way to back up the average revenue loss for the Treasury. Nonetheless, it does not say anything about the realized loss on a given auction. In other words, it tells us what $E[p^W - p^{so}]$ is, but not the value for a specific $\tilde{p}^W - \tilde{p}^{so}$. Getting the value for the latter would require an estimation of the value of $\tilde{p}^W$ for the specific underlying security. If we knew the dealers’ preferences for security, we could find the true value of
a given security using expression (5.2). Under the assumptions from the environment considered in this paper, this would require the knowledge or an estimation of the preference parameters $\bar{\upsilon}$ and $\rho$. However, the estimation of such parameters may be complicated or even impossible in practice. For instance, one would need data on multiple points of the auctions’ bid schedule (individual or aggregate) which might not be publicly available.\footnote{Only three points are made public by the U.S. Treasury.}

Fortunately, we can back up $p^W$ without the knowledge of preference parameters. It is clear from expressions (5.2), (6.4), (6.6) that the same set of parameters that determines the Walrasian price also determines the price in the auction with market power, and the price of securities in the when-issued market. We can rearrange these expressions to get:

\[
p^W = p^{so} + (1 - \gamma) \left( p^{wi} - p^{so} \right) + \frac{\gamma(2 - \gamma)}{1 - \gamma} E \left[ p^{wi} - p^{so} \right].
\]

Note that the variables that appear in the right hand side are $p^{wi}$, $p^{so}$, and $\gamma$. Therefore, the above expression implies that the true value for the security can be found if one knows the number of auction participants and has data on the price of the security in the auction and when-issued stages.\footnote{The parameter $\gamma$ depends solely on the number of dealers participating in the auction. The price of the auction $p^{so}$ is commonly made available by the Treasuries authorities throughout the world. Finally, data sets containing information relative to when-issued prices, $p^{wi}$, were used on many empirical studies, e.g., Bikchandani et al. [2000], Barclay et al. [2006], Nyborg and Sundaresan [1996], Goldreich [2007].}

### 7.2 Volume

The environment considered in the previous sections illustrates how uniform price auctions give dealers incentives to trade when-issued securities. Nevertheless, it also offers predictions on the relationship between the variables in the model and total amount of securities being traded in the when-issued market.

Let $\Upsilon \equiv \sum_{i,t} \left( q_{i,t}^{wi} \right)^2$ be the measure of interest for the volume per dealer in the when-issued market. The results from Corollary 6 imply that, in equilibrium:

\[
\Upsilon = s_v^2 \left( 1 - (1 - \gamma)^T \right)^2
\]

where $s_v^2 \equiv \frac{1}{N} \sum_{i,t} \left( \frac{\upsilon_i}{\rho} - \bar{\upsilon} \right)^2$ is the degree of heterogeneity among dealers’ true valuation for the securities.

Market power and the per investor volume in the when-issued market are negatively related. This can be readily seen from the the positive relationship between $\Upsilon$ and $\gamma$. The
intuition is the following. When dealers have a higher impact on the price of when-issued securities, they have incentives to behave less aggressively in the when-issued market. The larger the market power, the higher the shading at this market stage.

The volume is also positively related with the length of the when-issued period. As seen in Subsection 6.2.2, dealers do not exploit all the trading gains on a single round in the when-issued market. They always end up with a fraction of the optimal portfolio. However, as $T$ goes up, they have additional opportunities to meet up and exploit the remaining gains. Indeed, we saw that their positions converge to the optimal as $T$ gets arbitrarily large.

8 Resale

Dealers are not restricted from trading the underlying securities after the auction takes place. In fact, the post-auction market for U.S. Treasury securities is one of the most liquid markets in the world. This raises the following question: would the conclusions from the previous sections still hold if dealers were allowed to trade after the auction? In this subsection, a post-auction market is added to the model considered above in order to check the robustness of the results presented earlier. As will be seen, the addition of a resale stage does not change the conclusions.

Suppose that, after the auction takes place, dealers can trade securities in the same fashion as they did in the when-issued market. Dealers submit demand (supply) schedules to a central broker and the pricing and allocation rule are the same as the ones described on Section 3 for the when-issued market. I will denote the variables for the resale market with superscripts $R$. We have the following result:

**Proposition 6.** Suppose there is a resale and a when-issued markets. For a given realization $\tilde{Q}$, the prices of the resale, auction, and when-issued markets in the linear SPE are given, respectively, by:

\[
\hat{p}^R = \hat{p}^W
\]

\[
\hat{p}^{so,R} = \hat{p}^W - \frac{(1 - \gamma)}{\gamma} \frac{\tilde{Q}}{\rho N}
\]

\[
p^{wi,R} = (1 - \gamma) E[p^W] + \gamma E[p^{so,R}].
\]

The conclusions from the previous sections about the when-issued market are still valid. The equilibrium of the market is consistent with underpricing and dealers have incentives
to trade when-issued securities prior to the auction. Moreover, the relationship between
the magnitude of underpricing and the parameters of the model are unchanged with the
additional market stage. The gap is increasing on the number of dealers and decreasing in
the auction size and in the slope parameter of dealers’ demand.

At first glance, one might suspect that adding a resale stage would have the same equi-
librium properties as adding an additional round in the when-issued market. The set of
dealers submitting bids, the pricing and allocation rules are exactly the same in both market
stages. However, the timing at which dealers are trading the securities matters in equi-
librium. Specifically, in the when-issued market, dealers anticipate that the Treasury will
supply an inelastic amount of securities in the auction and that the resulting price will be
artificially low. This fact drives down the equilibrium price in the when-issued stage as well.
Dealers will not be willing to acquire securities for a price too far away from the auction
price. In the resale market, however, the auction have already taken place. Dealers know
that they will not have an opportunity to acquire securities for the low auction price any-
more. As a result, the equilibrium price at this stage will be higher than in the when-issued
market.

The addition of a resale market does not change the prices from the previous market
stages. The equilibrium values for the price of securities in the when-issued and auction
stages take the exact same form as in the previous sections where resale was not allowed.
Therefore, the analysis made before is robust to the inclusion of a resale stage after the
auction takes place.\footnote{See Coutinho \cite{Coutinho2012} for a more detailed analysis of equilibrium of divisible good auctions with a resale market.}

9 Conclusion

The model presented above shows how the structure of the Treasury market can give incen-
tives to dealers to trade when-issued securities. It shows how dealers can use this specific
forward contract in order to influence the behavior of their competitors, as well as his own,
during the auction stage and how this can be beneficial for them. Moreover, the resulting
equilibrium is consistent with two empirical facts from the inter-dealer market: underpricing
and high volume of transactions.

It is worth emphasizing that the results presented in this paper rely solely on the way the
market is structured. As pointed out above, the only reason dealers are trading when-issued
securities is to influence the outcome of the auction stage. Therefore, this paper offers an
alternative explanation for why dealers have incentives to enter into forward contracts instead of the more traditional speculation or/and hedging motives. Indeed, in the environment considered above, all market participants have symmetric and complete information.

A commonly used empirical strategy to measure the performance of an auction mechanism is the magnitude of the price gap from the when-issued and auction stages. The underlying assumption is that the price in the when-issued market is a good proxy for the true value of the security since dealers are trading in a free market environment at this stage. The price gap would then indicate the gap between how much dealers were willing to pay for the securities and how much they end up actually paying. However, for the specific case in which the auction follows a uniform pricing rule, I showed that the when-issued price is a biased proxy for the true value of a security. If one considers the security’s 'true value' as the one which would arrive in a perfect competitive market, the equilibrium price of a security when-issued price lies strictly below it since dealers anticipate they will be able to acquire it for a depressed price in the auction. A simple correction for the negative bias is proposed above.

The price gap between the two market stages is not used only to compare the performance of a specific auction, but also to compare the performance of different auction mechanisms. A recurrent question in the Treasury auction literature is whether uniform price auctions generate more revenue than discriminatory auctions. Although the analysis from this paper focused solely on the uniform price case, it did highlight how the dealers’ strategies on the two market stages, and thus the resulting prices, are jointly determined in equilibrium. There is no straightforward reason to believe that the when-issued price would be invariant to the choice of which auction mechanisms the Treasury decides to use. Consequently, simply comparing the price gap between the two markets without taking into account that when-issued prices are endogenously determined may lead us to wrong conclusions.

Finally, even though the analysis focused on the market for Treasury securities, the conclusions drawn in this paper can be straightforwardly applied to any other market where agents trade forward contracts on homogeneous goods to be auctioned through a uniform price auction. Examples of such markets are the market for energy, IPOs and CDS auctions.

References


A Proofs

A.1 Proposition 1

Given history $h$ satisfying assumption 2, dealer $i$ maximization problem at the auction stage can be written as:

$$\max_{q_i(t)} E \left[ u_i \left( q_i(p) + \theta_i^{wi} \right) - pq_i(p) \right].$$
Point wise maximization leads to the result of the proposition. To see this, assume that the realization \( \hat{p}^W \) is known prior to \( i \) choosing the quantity to acquire. In this case, his maximization problem is:

\[
\max_{q_i} u_i \left( q_i + \theta_i^{wi} \right) - \hat{p}^W q_i.
\]

The solution of this problem is given by \( q_i^A(\hat{p}^W) \), described on 5.1. Therefore, dealer \( i \) can acquire the ex post optimal quantity for all realizations by submitting the bid schedule \( q_i^A(\cdot) \).

A.2 Proposition 2

\textit{Proof.} Let’s consider the problem for dealer \( i \). Since we are searching for a linear equilibrium, it is natural to start assuming that the other dealers are submitting linear bid schedules:

\[
q_j(p) = \alpha_j - \beta_j p.
\]

for all \( j \neq i \).

Let \( b_{-i}(q) \) be the aggregate inverse bid schedule without considering dealer \( i \), i.e., \( \sum_{j \neq i} q_j (b_{-i}(q)) \equiv q \). If \( j \neq i \) submit bid schedules as above, \( b_{-i}(q) \) is uniquely determined for all \( q \in \mathbb{R} \) and has the following form:

\[
b_{-i}(q) = \frac{1}{\sum_{j \neq i} \beta_j} \left[ \sum_{j \neq i} \alpha_j - q \right]. \tag{A.1}
\]

Market clearing at the auction stage implies that \( \sum_{j \neq i} q_j (\tilde{p}^s) = Q - q_i (\tilde{p}^s) \), where \( \tilde{p}^s \) is the realized stop-out price. Thus, we can write the maximization problem of dealer 1 as:

\[
\max_{q_i^A(\cdot)} E \left[ u_i \left( q_i (p, h) + \theta_i^{wi} \right) - b_{-i} (Q - q_i (p, h)) q_i^A (p, h) \right] - \sum_{t=1}^{T-1} p^t \left( \theta_i^{t} - \theta_i^{t+1} \right).
\]

Since \( \theta_i^{t} \) and \( p^t \) are already given by the time the auction takes place for \( \tau = 1, \ldots, T \), we can ignore the last summation term of the objective function. As in the no market power benchmark case, I will use point wise maximization to characterize the solution from the above problem. For any realization \( \hat{Q} \), dealer \( i \) chooses \( q_i^A \) that satisfies:

\[
v_i - \rho \left( q_i^A + \theta_i^{wi} \right) + b_{-i}' \left( \hat{Q} - q_i^A \right) q_i^A - b_{-i} \left( \hat{Q} - q_i^A \right) = 0.
\]

Solving for \( q_i^A \) and using the fact that \( \tilde{p}^s = b_{-i} \left( \hat{Q} - q_i^A \right) \) and that \( b_{-i}' \left( \hat{Q} - q_i^A \right) = -\frac{1}{\sum_{j \neq i} \beta_j} \) we arrive on:

\[
q_i^A = \frac{1}{\rho + \frac{1}{\sum_{j \neq i} \beta_j} \left( v_i - \rho \theta_i^{wi} - \tilde{p}^s \right)}.
\]

Note that \( q_1^A \) is the optimal quantity for a given realization of \( \tilde{p}^s \). This price is not known before the auction takes place which, at first glance, would prevent agents to condition their
bids directly on $\tilde{p}^{so}$. However, they can do it indirectly by submitting the bid schedule:

$$q_i^A(P, h) = \frac{1}{\rho + \frac{1}{\sum_j \beta_j}} \left( v_i - \rho \theta_i^{wi} - P \right). \quad (A.2)$$

In a linear equilibrium we must have all dealers submitting bids in the above form. This implies that the $\beta$s should satisfy

$$\beta_i = \frac{1}{\rho + \frac{1}{\sum_j \beta_j}}.$$

for $i = 1, \ldots, N$. The unique solution of the above set of equations is symmetric and gives us $\beta_i = \frac{\gamma}{\rho}$ for all $i$. Substituting the equilibrium value for $\beta_i$ on A.2 implies that the intercepts of the bid schedules in the linear equilibrium are given by:

$$\alpha_i = \frac{\gamma}{\rho} \left( v_i - \rho \theta_i^{wi} \right).$$

Let $\tilde{\psi}_i^A(\theta_i^{wi})$ be the demand from dealer $i$ given a realization of $\tilde{p}^{so}$ as a function of his when-issued position $\theta_i^{wi}$. Condition 3 implies that $\tilde{\psi}_i^A(\theta_i^{wi}) \geq 0$ for all $i$.

To find the expression for the stop-out price, sum up equation (6.3) across all dealers. The aggregate bid schedule is given by:

$$\sum_i q_i^A(\tilde{p}^{so}, h) = \frac{\gamma}{\rho} (N \tilde{v} - N \tilde{p}) - \gamma \sum_i \theta_i^{wi}.$$

Since the when-issued market is a zero supply market in all periods, we must have that $\sum_i \theta_i^{wi} = 0$. Thus, the last term of the right hand side of the above equation can be ignored. Using the market clearing condition of the auction stage, $\sum_i q_i^A(\tilde{p}^{so}, h) = \tilde{Q}$, solving it for $\tilde{p}^{so}$ and using the definition of $\tilde{p}^{W}$, gives us 6.4.

A.3 Proposition 3

**Proof.** The first order condition from the maximization problem given by 6.5 implies that:

$$-p^{wi} + E \left[ u_i' \left( \psi_i^F(\theta_i^{wi}) \right) \left( \frac{d\psi_i^F(\theta_i^{wi})}{d\theta_i^{wi}} \right) - p^{so} \frac{d\psi_i^A(\theta_i^{wi})}{d\theta_i^{wi}} \right] = 0. \quad (A.3)$$
Using Corollary (2), summing up (A.3) across \(i = 1, ..., I\) and dividing the result by \(I\), gives us:

\[
p_{wi} = (1 - \gamma) E \left[ \bar{v} - \rho \frac{\sum_{j} \psi^F_j (\theta^vi)}{N} \right] + \gamma E [p^{so}].
\]

Market clearing, in the auction and when-issued stages, implies on \(\sum_{j=1}^{I} \psi^F_j (\theta^wi) = \bar{Q}\) for all realizations of \(Q\). Equation (6.6) follows directly from the definition of \(p^W\), given by (5.2). If we substitute \(p_{wi}\) of equilibrium in the first order condition, we get:

\[
(1 - \gamma) E [u_i (\psi^F_i (\theta^wi)) - p^W] = 0.
\]

for \(i = 1, ..., N\). Substituting (6.3) and (5.2) on the above expression and solving it for \(\theta^wi\), gives us the equilibrium positions described by \(\theta^c_i\) on equation (6.7).

\A.4 Proposition 5

Proof. I will use an inductive argument in order to prove the Proposition. First, I will find the linear equilibrium for \(t = 1\). Then, assuming that Corollaries 6 and 5 hold for all rounds \(t < \tau\), I show that there is a linear equilibrium at \(\tau\) where dealers submit bid schedules as in 6.10.

\(t = 1:\)

Suppose dealers arrive at \(t = 1\) holding positions \(\{\theta^2_i\}_{i=1}^{N}\) from the previous rounds of the when-issued market. As in the auction stage, I will focus on linear equilibrium. Therefore, I start assuming that all dealers \(j \neq i\) are submitting bid schedules at this round in the following form:

\[
q^\text{wi,1}_j (p, h^1) = \alpha^1_j - \beta^1_j p.
\]

Let \(b_{-i} (\cdot)\) be the aggregate inverse demand without dealer \(i\) at this round. Market clearing conditions imply that, at any round \(t\) of the when-issued market, \(\sum_{j \neq i} q^t_j (p^t, h^t) = -q^t_i (p^t, h^t)\). If dealers \(j \neq i\) are submitting the bid schedules above, the price at round 1 will be uniquely determined by the quantity dealer \(i\) decides to acquire, i.e., \(p^1 = b^1_{-i} (-q^1_i)\). Therefore, we can write dealer \(i\)'s problem as:

\[
\max_{\theta^1_i} E \left[ u_i (\psi^F_i (\theta^1_i)) - p^{so} \psi^A_i (\theta^1_i) \right] - b_{-i} (\theta^2_i - \theta^1_i) (\theta^1_i - \theta^2_i).
\]
Note that, for all realizations of $\bar{Q}$, $\bar{p}^{so}$ does not depend on $\theta_i^1$ at all, as seen by (6.4). Therefore, the FOC from the above maximization problem implies that
\[
E \left[ (v_i - \rho \left( \psi_i^F (\theta_i^1) \right)) \right] \left( \frac{d\psi_i^F (\theta_i^1)}{d\theta_i^1} \right) - p^{so} \frac{d\psi_i^A (\theta_i^1)}{d\theta_i^1} \right] + b'_{-1} \left( \theta_i^2 - \theta_i^1 \right) \left( \theta_i^1 - \theta_i^2 \right) - b_{-1} \left( \theta_i^1 - \theta_i^2 \right) \right).
\]
is equal to zero. The results from Corollary (2) and the fact that $p^1 = b_{-1} (\theta_i^2 - \theta_i^1)$ for all $i$ allow us to rewrite the above FOC as:
\[
(1 - \gamma) E \left[ v_i - \rho \left( \psi_i^F (\theta_i^1) \right) \right] + \gamma E \left[ p^{so} \right] + b'_{-1} \left( \theta_i^2 - \theta_i^1 \right) \left( \theta_i^1 - \theta_i^2 \right) - p^1 = 0.
\]
From Proposition (2), it is clear $\psi_i^F (\theta_i^1) = \psi_i^F (0) + (1 - \gamma) \theta_i^1$. Substituting this relationship into the above equation and solving it for $\theta_i^1$ gives us:
\[
\theta_i^1 = \frac{1}{(1 - \gamma)^2 \rho - b'_{-1} (-\theta_i^1)} \left( (1 - \gamma) E \left[ v_i - \rho \psi_i^F (0) \right] + \gamma E \left[ p^{so} \right] - b'_{-1} \left( \theta_i^1 - \theta_i^2 \right) \theta_i^2 - p^1 \right).
\]
Equation (A.1) implies that $b'_{-1} \left( \theta_i^1 - \theta_i^2 \right) = -\frac{1}{\sum_{j \neq i} \beta_j}$. Thus,
\[
\theta_i^1 = \frac{1}{(1 - \gamma)^2 \rho + \frac{1}{\sum_{j \neq i} \beta_j}} \left( (1 - \gamma) E \left[ v_i - \rho \psi_i^F (0) \right] + \gamma E \left[ p^{so} \right] + \frac{1}{\sum_{j \neq i} \beta_j} \theta_i^2 - p^1 \right).
\]
In a linear equilibrium, the above equation must hold for all $i = 1, ..., N$. Therefore, we have $I$ equations of the form:
\[
\beta_i^1 = \frac{1}{(1 - \gamma)^2 \rho + \frac{1}{\sum_{j \neq i} \beta_j}}, \quad i \in I.
\]
The unique solution for the $\beta_i^1$s gives us $\beta_i^1 = \frac{\gamma}{(1 - \gamma)^2 \rho}$ for all $i$. Substituting the equilibrium $\beta$ on the above equations and using the fact that $q_i^{wi,1} \equiv \theta_i^1 - \theta_i^2$, the intercepts of the bid function will be given by:
\[
\alpha_i = \frac{\gamma}{(1 - \gamma)^2 \rho} \left( (1 - \gamma) E \left[ v_i - \rho \psi_i^F (0) \right] + \gamma E \left[ p^{so} \right] \right) - \gamma \theta_i^2.
\]
From the equilibrium described on Proposition (2) we have that:
\[
v_i - \rho \tilde{\psi}_i^F (0) = v_i - \rho \tilde{\psi}_i^F (0)
= (1 - \gamma) \left( v_i - \rho \frac{\bar{Q}}{N} \right) + \gamma \bar{p}^{W}
= (1 - \gamma) \rho \theta_i^2 + \bar{p}^{W}. \quad (A.4)
\]
where I used (6.4) from the first to the second line. From the second to the third line, I added and subtracted $(1 - \gamma) \sum_{N} v_i$ and used the definition of $\bar{p}^{W}$. Substituting the above
expression into $\alpha_i$ and using the definition of $p^{wi,c}$, we find that the bid schedule at $t = 1$ satisfies (6.10).

t = \tau:

Suppose that for all $t < \tau$, 6 and 5 holds. The maximization problem of dealer $i$ at $\tau$ can be written as:

$$\max_{\theta_i(\cdot)} E\left[u_i \left( \psi_{i}^{F} (\theta_{i}^{1}) \right) - p^{so} \psi_{i}^{A} (\theta_{i}^{1}) \right] - \sum_{t=1}^{\tau} p^{t} \left( \theta_{i}^{t} - \theta_{i}^{t+1} \right).$$

(A.5)

The prices and positions for all $t > \tau$ are already given when $i$ chooses $\theta_{i}^{t}$. Moreover, the assumption that corollary 5 implies that $p^{t} = p^{wi,c}$ for all $t < \tau$, thus, we have that:

$$\sum_{t=1}^{\tau} p^{t} \left( \theta_{i}^{t} - \theta_{i}^{t+1} \right) = p^{wi,c} \left( \theta_{i}^{1} - \theta_{i}^{\tau} \right) + p^{\tau} \left( \theta_{i}^{\tau} - \theta_{i}^{\tau+1} \right).$$

Let $b^{\tau}_{-i}(q)$ be the inverse linear bid schedule without dealer $i$’s bid built in the same way as in the previous step of this proof. The FOC from (A.5) will be given by:

$$\left\{ E \left[ u'_{i} \left( \psi_{i}^{F} (\theta_{i}^{1}) \right) \frac{d\psi_{i}^{A} (\theta_{i}^{1})}{d\theta_{i}^{1}} \right] - p^{so} \frac{d\psi_{i}^{A} (\theta_{i}^{1})}{d\theta_{i}^{1}} \right\} \frac{d\theta_{i}^{1}}{d\theta_{i}^{\tau}} + p^{wi,c} \frac{db^{\tau}_{-i}}{d\theta_{i}^{\tau}} \times \left( \theta_{i}^{\tau} - \theta_{i}^{\tau+1} \right) - p^{\tau} = 0.$$

The term on chains can be rewritten as:

$$E \left[ u'_{i} \left( \psi_{i}^{F} (\theta_{i}^{1}) \right) \left( 1 - \gamma \right) + p^{so} \gamma \right] - p^{wi,c} = E \left[ (v_{i} - \rho \psi_{i}^{F} (0)) \left( 1 - \gamma \right) - \rho (1 - \gamma)^{2} \theta_{i}^{1} + \gamma p^{so} \right] - p^{wi,c}$$

$$= E \left[ (1 - \gamma) p^{W} + (1 - \gamma)^{2} \rho \left( \theta_{i}^{c} - \theta_{i}^{1} \right) + \gamma p^{so} \right] - p^{wi,c}$$

$$= (1 - \gamma)^{2} \rho \left( \theta_{i}^{c} - \theta_{i}^{1} \right)$$

$$= (1 - \gamma)^{\tau+1} \rho \left( \theta_{i}^{c} - \theta_{i}^{\tau} \right).$$

From the first to the second, I used equation (A.4). From the third to the fourth I used Corollary 6 which implies that:

$$\theta_{i}^{1} = \gamma \theta_{i}^{c} \sum_{t=0}^{\tau-2} (1 - \gamma)^{t} + (1 - \gamma)^{\tau-1} \theta_{i}^{\tau}.$$ 

This same Corollary implies that $\frac{d\theta_{i}^{1}}{d\theta_{i}^{\tau}} = (1 - \gamma)^{\tau-1}$. Substituting these relationships on the FOC, we can use the same steps used to find a linear equilibrium at $t = 1$ to find that dealers submit bid schedules satisfying (6.10) for $t = \tau$. 

\[\square\]
A.5 Corollary 5

Proof. Remember that the when-issued market is a zero-supply market in each round, so \( \sum_I q_i^{wi,t} (p_i^{wi,t}) = 0 \) and \( \sum_I \theta_i^{t+1} = 0 \). Summing up (6.10) across all dealers and using the market clearing condition gives us:

\[
0 = \frac{\gamma}{(1-\gamma)^{2t} \rho} \left\{ I \times (p_i^{wi,c} - p^\tau) + (1-\gamma)^{2t} \rho \sum_I \theta_i^c \right\}.
\] (A.6)

But \( \sum_I \theta_i^c = 0 \), which implies that \( p^\tau = p_i^{wi,c} \).

\[\Box\]

A.6 Corollary 6

Proof. I will do the proof for dealer \( i \). Substituting the equilibrium stop-out price on his bid schedule gives us

\[
q_i^{wi,t} (p_i^{wi,c}) = \frac{\gamma}{(1-\gamma)^{2t} \rho} (A_i^t - p_i^{wi,c}) - \gamma \theta_i^{t+1}
\]

But \( \theta_i^t = q_i^{wi,t} (p_i^{wi,c}) + \theta_i^{t+1} \), which gives the result of the corollary.

\[\Box\]

A.7 Corollary 7

Proof. From Corollary 6, we have that, in the unique linear SPE, the position that dealer \( i \) arrives at the auction from the WI market is given by

\[
\theta_i^1 = \theta_i^c \left[ 1 - (1-\gamma)^T \right].
\]

Therefore, \( \lim_{T \to \infty} \theta_i^1 = \theta_i^c \), i.e., as \( T \) goes to infinity, \( \theta_i^1 \) converges to the position \( i \) arrives in the auction on the perfect competitive case. Nevertheless, we know from Corollary 3 that this specific position leads to an efficient allocation after the auction takes place and the WI contracts are settled.

\[\Box\]
A.8 Proposition 6

Proof. The characterization of the equilibrium with the additional resale market will follow the same steps as the ones used in proposition 5. The problem is very similar to the previous without resale market. With the exception of changes in the market clearing conditions, it is exactly the same as if we were adding a period in the when-issued market.

Resale market:

Let \( \{\theta^A_i\}_I \) be the positions that dealers arrive at the resale stage. Dealer \( i \)'s maximization problem at this stage is exactly the same as the auction’s in the case without the resale stage:

\[
\max_{q^R_i(\cdot)} u_i \left( q^R_i(p) + \theta^A_i \right) - pq^R_i(p).
\]

Therefore, the unique linear equilibrium has dealers submitting bid schedules as:

\[
q^R_i(P, \theta^A_i) = \frac{\gamma}{\rho} (v_i - P) - \gamma \theta^A_i.
\]

(A.7)

Using the market clearing conditions \( \sum_I q^R_i = 0 \) and \( \sum_I \theta^A_i = Q \), we get that equilibrium price in the resale stage is \( p^W \).

Auction:

Dealer \( i \) maximizes:

\[
\max_{q^A_i(\cdot,h)} E \left[ u_i \left( \psi^R_i + \theta^A_i \right) - p^R \psi^R_i - p^{so} q^A_i(p, h) \right].
\]

where \( \theta^\text{usi}_i \) is the position he arrives from the when-issued market and \( \theta^A_i \equiv q^A_i(p, h) + \theta^\text{usi}_i \). Once more, I use point wise optimization in order to characterize the equilibrium in the auction. For a given realization of \( \tilde{Q} \), the first order condition of the above problem satisfies:

\[
\left( v_i - \rho \left( \psi^R_i + \theta^A_i \right) \right) (1 - \gamma) + \gamma p^R - \frac{d p^{so}}{dq^A_i} q^A_i = p^{so}.
\]

(A.8)

Suppose that dealer \( j \neq i \) submits a linear demand schedule given by:

\[
q_j(p, h) = \alpha_j - \beta_j p
\]

Summing across \( j \neq i \) and using the market clearing condition, we have that the stop-out
price in the auction will satisfy \( p^{so} = \frac{1}{\sum_{j \neq i} \beta_j} \left( \sum_{j \neq i} \alpha_j - (Q - q^A_i) \right) \). This implies that:

\[
Q = q^A_i + \sum_{j \neq i} \alpha_j - p^{so} \sum_{j \neq i} \beta_j \tag{A.9}
\]

\[
\frac{dp^{so}}{dq^A_i} = \frac{1}{\sum_{j \neq i} \beta_j}. \tag{A.10}
\]

Substituting (A.10) and (A.12) into the FOC and rearranging the terms, we get:

\[
(v_i - \rho (1 - \gamma) \theta^w_i) (1 - \gamma) - \rho (1 - \gamma) \psi^R_i (0) + \gamma p^R - \left( \rho (1 - \gamma)^2 + \frac{1}{\sum_{j \neq i} \beta_j} \right) q^A_i - p^{so} = 0. \tag{A.11}
\]

where \( \psi^R_i (0) \) is the amount of securities \( i \) would acquire in the resale stage if he arrives with \( \theta^A_i = 0 \). Note, by (A.7), that

\[
\psi^R_i (\theta^A_i) = \psi^R_i (0) + (1 - \gamma) \theta^A_i. \tag{A.12}
\]

In the equilibrium of the resale stage, we have that

\[
\psi^R_i (0) = \frac{\gamma}{\rho} \left[ v_i - p^W \right] = \frac{\gamma}{\rho} \left[ v_i - \left( \bar{v} - \rho \frac{Q}{N} \right) \right] = \frac{\gamma}{\rho} \left[ v_i - \left( \bar{v} - \rho \frac{Q}{N} \left( q^A_i + \sum_{j \neq i} \alpha_j - p^{so} \sum_{j \neq i} \beta_j \right) \right) \right].
\]

where I used (A.9) in the last line. Substituting the above relationship on (A.11), and solving it to \( q^A_i \) gives us:

\[
q^A_i = \alpha_i - \beta_i p^A.
\]

where

\[
\alpha_i = \frac{1}{(1 - \gamma)^2 \rho + \frac{1}{\sum_{j \neq i} \beta_j} + \frac{\rho}{N} \left( 1 - (1 - \gamma)^2 \right)} \left[ (v_i - \rho \theta^w_i) (1 - \gamma)^2 + (1 - (1 - \gamma)^2) \left( \bar{v} - \frac{\rho}{N} \sum_{j \neq i} \alpha_j \right) \right]
\]

\[
\beta_i = \frac{\frac{1 - \frac{\rho}{N} \left( \left( 1 - (1 - \gamma)^2 \right) \sum_{j \neq i} \beta_j \right)}{(1 - \gamma)^2 \rho + \frac{1}{\sum_{j \neq i} \beta_j} + \frac{\rho}{N} \left( 1 - (1 - \gamma)^2 \right)}}.
\]
The symmetric solution from the above system of equations gives:

\[ \alpha_i = \frac{\gamma}{\rho} \left[ (v_i - \rho \theta_i^w) \omega + (1 - \omega) \bar{v} \right] \]
\[ \beta_i = \frac{\gamma}{\rho} \]

where \( \omega \equiv \frac{1 - \gamma}{1 - \gamma + \gamma (1 - \gamma)} \).

Finally, substituting the equilibrium values for \( \beta \) on A.10, and noticing that \( \sum_x (\psi_i^R + \theta_i^A) = Q \), averaging up the FOC described on A.8 gives us the equilibrium price for the auction as described in the proposition.

**When-issued market:**

The maximization problem in the WI market is written as:

\[ \max_{\theta_i^{wi}} E \left[ u_i \left( \psi_i^R + \theta_i^A \right) - p^R q_i^R - p^{so} \left( \theta_i^A - \theta_i^{wi} \right) \right] - b_{-i} \left( -\theta_i^{wi} \right) \times \theta_i^{wi}. \]

In the when-issued market, the realization of \( Q \) is not know yet. Therefore, the FOC from the above problem can be written as:

\[ E \left[ u_i' \left( \psi_i^R + \theta_i^A \right) (1 - \gamma) + \gamma p^R \right] (1 - \gamma) + \gamma E \left[ p^{so} \right] - b_{-i} \left( -\theta_i^{wi} \right) \times \theta_i^{wi} - p^{wi} = 0. \quad (A.13) \]

Note that

\[ \sum_\mathcal{I} u_i' \left( \psi_i^R \right) = \sum_\mathcal{I} \left( v_i - \rho \psi_i^R \right) = \sum_\mathcal{I} v_j - \rho Q = N \times p^W. \]

where I used the market clearing condition in the resale stage from the first to the second line. Using the above relationship and the market clearing condition in the WI market \( \left( \sum_x \theta_i^{wi} = 0 \right) \) we get the equilibrium price of the WI market by summing up (A.13) across dealers and solving for \( p^{wi} \).

\[ \square \]
B Example Continued

How is $p^{wi}$ determined in equilibrium? We’ve seen that both agents are better off by trading the when-issued security if $p^{wi} \in (v_2, v_1)$. But how would investors get into an agreement about $p^{wi}$? I will consider a very simple environment for the when-issued market that leads to this result. Suppose that dealers compete for an unit of a when-issued security through a double auction game. Each player $i$ submits a bid $b_i$ in this stage. The dealer who submitted the lowest bid will supply a when-issued security to the other dealer, who submitted the higher bid in exchange for a payment of $p^{wi} = \frac{(b_i + b_j)}{2}$. In case of a tie, the when-issued security goes to 1. Moreover, I will assume that after bids are computed, one or both dealers can decide to withdraw from the when-issued market without any cost.

Before characterizing the equilibrium for the full game, I need to determine what would happen in the auction for all possible positions dealers can arrive from the when-issued market. The case where 1 acquired one unit of the when-issued security was illustrated in the previous section. In that case, the payoff of the two dealers were given by:

$$U_1^{wi} = 2v_1 - p^{wi},$$
$$U_2^{wi} = p^{wi}.$$

What would happen if 2 was the winner of the when-issued security instead? As in the main text, I will assume that dealers will play the Pareto dominant equilibrium of the game:

**Claim 3.** There is an equilibrium of the auction where dealers submit $\beta_1^{wi} = (\pi, 0)$ and $\beta_2^{wi} = (v_2, 0)$. The equilibrium stop-out price is $p^{so} = 0$ and payoffs are given by:

$$U_1' = p^{wi},$$
$$U_2' = 2v_2 - p^{wi}.$$

If one of the dealers decides to withdraw from the market, then there is no when-issued trade. The equilibrium of the auction in this case was described in Claim 1 and dealers get the payoff:

$$U_i'' = v_i.$$  

It is straightforward to see that there is a continuum of equilibria with $b_1 = b_2 \in (v_1, v_2)$. Dealer $i \in I$ would not have an incentive to pay more than $v_i$ for the when-issued security. Moreover, $i$ would benefit from withdrawing the when-issued market whenever $p^{wi} \leq v_i$, where I am assuming he prefers to withdraw when he is indifferent from trading the when-
issued security. Any price between these two values is an equilibrium for the game described above. Dealer 1 would get the when-issued security and neither of them would benefit from withdrawing from when-issued market.
## Underpricing

<table>
<thead>
<tr>
<th>Discriminatory</th>
<th>Uniform</th>
<th>Benchmark</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underp.</td>
<td># Obs.</td>
<td>Underp.</td>
<td># Obs.</td>
</tr>
<tr>
<td>1.3</td>
<td>364</td>
<td>-</td>
<td>Quotes</td>
</tr>
<tr>
<td>0.37</td>
<td>66</td>
<td>-</td>
<td>Quotes</td>
</tr>
<tr>
<td>0.27</td>
<td>76</td>
<td>0.09</td>
<td>15</td>
</tr>
<tr>
<td>0.55</td>
<td>66</td>
<td>0.21</td>
<td>44</td>
</tr>
<tr>
<td>0.8</td>
<td>130</td>
<td>-</td>
<td>Quotes</td>
</tr>
<tr>
<td>0.61</td>
<td>105</td>
<td>0.40</td>
<td>178</td>
</tr>
</tbody>
</table>

**Table 1:** Undepricing = Avg Auction Yield - When-Issued Yield. All values are in units of basis points.