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Bidding Behavior in Italian Treasury Auctions: The Role of Top-ups

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Bidding Behavior in Italian Treasury Auctions: The Role of Top-ups
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ABSTTACT:
In response to rising global government debt, sovereign debt management offices (DMOs) are increasingly refining their issuance methods to optimize investor engagement and minimize borrowing costs. This paper evaluates the effectiveness of a two-stage Treasury auction design that incorporates a supplementary non-competitive 'top-up' component, assessing its potential to enhance bidder performance. Utilizing detailed microdata from Italian Treasury bill auctions and employing a Difference-in-Differences analytical framework, the paper investigates how these supplementary top-up auctions influence bidder behavior in terms of requested quantities and offered prices during the main competitive auction. The analysis demonstrates that the introduction of top-ups promotes more aggressive bidding, especially among marginal bids, leading to higher cumulative bid values in the primary competitive phase. These findings suggest that top-up auctions can effectively boost auction coverage and may contribute to lower government borrowing costs by strategically shaping bidder incentives and behaviors.

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WORKING PAPERS

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Contents

Glossary

Average Winning Price: The average winning price in Treasury auctions is the weighted average price at which Treasury securities are awarded to successful bidders during an auction. This is calculated by multiplying each winning bid's price by the quantity of securities associated with that bid, summing these products across all winning bids, and then dividing by the total quantity of securities allocated.

Bid Shading: Bid shading refers to the practice where bidders submit bids lower than the value they believe the auctioned good is worth. This issue is relevant in Treasury auctions, often considered *common value* models. In these models, the value of the good for sale is the same for every bidder, though it is unknown at the time of bidding. Since the winners are those who make the highest guesses on the common value, the estimates of the common value by winning bidders are upward biased (*winner's curse*). This creates an incentive for bidders to place bids lower than what they believe the common value to be.

Clearing Price: The clearing price in Treasury auctions is the price at which the total amount of securities offered is exactly matched by the total amount of bids. This price is determined through the auction process and is the highest price among those submitted by bidders that ensures that the cumulated demand up to that price is equal or greater than the supply.

Common Value Auction: Common value auctions are auctions in which the item being sold has a single, unknown value that is the same for all bidders, but each bidder may have different estimates of that value. The actual value will be the same for everyone once it is known, but before the auction, bidders must rely on their own information and judgments to form their estimates.

Discriminatory Auction Format: Discriminatory auctions, also known as pay-as-bid auctions, are auctions in which each winning bidder pays the price they bid for the items they win. In this type of auction, different bidders may pay different prices for the same item based on their individual bids.

Non-Competitive Placement: Non-competitive placement in Treasury auctions refers to a bidding process where investors can purchase government securities without having to specify the yield or price they are willing to accept.

Primary dealer: Firm that buys government securities in the primary market with the intention of reselling them to others, thus acting as a “market maker” of government securities. The government may regulate the behavior and number of its primary dealers and impose conditions of entry. Some governments sell their securities exclusively to primary dealers; some sell them to others authorized operators as well.

Top-ups: Non-competitive placements where admitted participants have the right (but not the obligation) to buy additional quantities of Government securities at a price settled on the date of the base competitive auction.

Uniform Auction Format: Uniform auctions, also known as single-price auctions, are auctions where all winning bidders pay the same price, known as the clearing or stop-out price, which is determined at the point where demand and supply are equal.

Winner's Curse: Well-documented phenomenon in auction theory, relevant in common value settings, where the value of the good for sale is the same for every bidder, though it is unknown at the time of bidding. Since the winners are those who make the highest guesses on the common value, the estimates of the common value by winning bidders are upward biased ("winner's curse"). This creates an incentive for bidders to place bids lower than what they believe the common value to be.

Executive Summary

The growing volume of outstanding government marketable debt has prompted sovereign debt offices worldwide to refine issuance strategies and auction techniques to attract investors, enhance auction performance, and prevent market disruptions. This paper examines whether a specific issuance design—a two-stage placement featuring a supplementary non-competitive auction ("top-up") following the main competitive auction—can improve bidder behavior in Treasury auctions by mitigating the traditional incentive to underbid ("bid shading"). It explores the key design features of this mechanism and their potential impact on investors' bidding strategies in the primary auction.

The empirical analysis leverages bidding data from Italian Treasury auctions for 12-month notes, for which the Italian Treasury introduced top-ups reserved for primary dealers in February 2009. Using a Difference-in-Differences methodology, the study assesses whether top-ups have reduced bid shading and encouraged more aggressive bidding—measured by higher requested quantities and offered prices. The findings indicate that, despite conflicting incentives introduced by top-ups, the dominant and statistically significant effect has been to stimulate more aggressive bidding, particularly for marginal bids. This has led to increased requested quantities and cumulative bid values in the main auction.

This paper makes three key contributions. First, it provides the first detailed microdata analysis of bidding behavior in Italian Treasury auctions using a unique dataset of individual bids. Given Italy's substantial borrowing needs relative to GDP among OECD countries, ensuring the efficiency of its auction system—particularly the incentives and obligations for primary dealers—is critical to preventing mispricing and ensuring full subscription of auctions. Second, from a policy perspective, the analysis suggests that top-ups can serve as an effective tool for sovereign debt management. By boosting demand and improving auction coverage, top-ups can enhance the credibility of debt issuance, strengthen investor confidence, and potentially lower future borrowing costs. Finally, this study contributes to the broader understanding of bidder behavior in common-value auctions, demonstrating how specific auction design features can mitigate underbidding and optimize auction outcomes.

I. INTRODUCTION

The primary objective of Debt Management Offices (DMOs) globally is to minimize the cost of meeting the government's financing requirements and debt service obligations over the medium to long term, consistent with a prudent degree of risk. This entails determining the optimal strategy for issuing sovereign debt, including the format of sales, investor incentives, and the allocation of debt across various instruments and maturities.

This objective has become increasingly relevant. The outstanding central government marketable debt in OECD countries stood at USD 54 trillion at the end of 2023, reflecting an increase of USD 14 trillion (35 percent) since the COVID-19 pandemic's onset. Rising debt levels and interest rates have driven gross borrowing needs from USD 12.1 trillion in 2022 to USD 14.1 trillion in 2023, with projections indicating a further rise to USD 15.8 trillion in 2024, surpassing the previous 2020 record of USD 15.4 trillion [OECD, 2023, 2024]. Compounding this issue, central banks are reducing their sovereign bond holdings, leading to increased market supply and a shift towards more price-sensitive investors.

Similar to the post-Global Financial Crisis period in 2008 [Blomenstein, 2009], the current environment has led sovereign debt offices in several countries to adjust issuance strategies and techniques [OECD, 2022; 2023; 2024]. While not a substitute for sound fiscal policy, skillful adjustments of the debt management strategy can reduce borrowing costs and address market absorption challenges. In this context, auction theory, by providing insights into bidders' strategic behavior under different auction designs, can aid in selecting the placement type that minimizes financing costs while encouraging broad participation.

This paper analyzes whether a specific issuance design—a two-stage placement using a supplementary non-competitive auction (top-up) after the main competitive auction—can enhance bidders' performance and improve outcomes in Treasury auctions. Top-ups are non-competitive placements where admitted participants have the right (but not the obligation) to buy additional quantities of Government securities at a price settled on the date of the main competitive auction. Bidders' allocations in the top-up are typically a function of the shares won in the main auction.

For bidders, the top-up offers immediate profit opportunities if market prices rise post-auction. Non-competitive subscriptions have indeed proven to be a strong incentive for bidders [Gemloc Advisory Services, 2010]. Some authors have compared the right to buy securities in the top-up to a European call option where the strike price is equal to the price settled on the main auction date [Coluzzi, 2007; Cardozo, 2010, 2013].

For issuers, top-up auctions are expected to improve participation and performance in the main auction by incentivizing more aggressive bidding and attracting investors who might otherwise be reluctant to participate[1]. In addition, through top-ups, the Treasury has the flexibility to increase the amounts issued at each auction without committing to larger amounts in advance, which might be challenging to place.

[1] Speaking about the introduction of top-up auctions in the placement procedure, Ms. Jo Whelan, Deputy-Chief Executive of the U.K. Debt Management Office, observed: "what we have tried to do … is to introduce a mechanism to incentivize bidders at auctions by allowing them the option to take up to 10 percent of their allocation at the clearing price on the same day but a few hours later … We need have, if you like, eager bidders at the auction and the top-up facility is one way of trying to achieve that". See House of Commons Treasury Committee [2010].

Instead, the possibility to adjust the issued amount is influenced by prevailing market conditions. If secondary market prices are increasing, operators will find it advantageous to participate in the top-ups, resulting in an increased issued amount. Conversely, if market conditions deteriorate in the hours following the competitive auction, operators will not exercise their right to buy and the issued amount will remain unchanged [IMF, 2003]. Top-ups are a common feature in primary dealership systems [European Primary Dealers Association, 2020; Gemloc Advisory Services, 2010; Pacini, 2007]. In these cases, the access to top-ups is restricted to Primary Dealers (PDs) as a special privilege for their market-making role[2].

This paper analyzes the impact of top-up auctions on bidders' behavior in the main competitive auction. It first discusses the key features of the top-up auction mechanism, highlighting elements that may influence bidding behavior in the main auction. The empirical analysis utilizes bidding data from Italian Treasury auctions for twelve-month bills. Exploiting the introduction of top-ups reserved for PDs in February 2009 as a natural experiment, a Difference-in-Differences approach is employed to assess the impact of this policy change on bidding aggressivity, defined as increases in quantity and price bids. The results indicate that, despite potentially counteracting incentives, the introduction of top-ups led to more aggressive bidding in the Italian Treasury bill market.

This paper makes several important contributions to the auction literature. First, it offers the first microdata analysis of bidding behavior in Italian Treasury auctions. This granular perspective provides a nuanced understanding of bidder strategies, crucial given Italy's substantial borrowing needs (third largest as a percentage of GDP among OECD countries [OECD, 2024]). Understanding and optimizing this auction system, including its incentives and obligations for admitted operators, is essential for efficient pricing and successful auction coverage.

Second, while previous research has explored top-up auctions, this study provides a more comprehensive analysis by examining the interplay of quantity and price effects under varying payment rules. This detailed approach clarifies the specific mechanisms through which top-up auctions may influence bidding.

Third, the findings suggest that top-up auctions can be a valuable tool for debt managers, potentially encouraging more aggressive bidding and reducing borrowing costs. By improving auction coverage, these auctions can also enhance market stability and investor confidence, particularly during periods of market stress, as demonstrated by the analysis of Italian Treasury bill auctions during the global financial crisis. This has direct implications for debt management and sustainability.

Fourth, this research contributes to the understanding of under-bidding dynamics—also defined as "bid shading"—in common value auctions. By examining the impact of top-up auctions on bid shading, the study demonstrates how specific auction design characteristics can mitigate this behavior These findings contribute to the ongoing discussion on optimal auction design for government securities, expanding the toolkit available to debt managers by highlighting the potential benefits of top-up auctions.

Finally, the paper provides a thorough examination of the Italian Treasury auction system, including the types of securities offered, the auction format, and, importantly, the role of primary dealers. This detailed analysis provides a basis for deriving actionable policy recommendations.

[2] The top-up auctions analyzed in this paper must not be confused with the practice of reopening the auction of a debt instrument already outstanding and traded on the secondary market [See Scalia, 1998].

The rest of the paper is structured as follows. Section II provides a review of the literature on optimal Treasury auction design and situates the contribution of this paper within the existing body of knowledge. Section III describes the framework for share auctions with top-ups and provides an illustrative example. Section IV offers the economic intuition of how the introduction of top-up auctions may impact bidding behavior inside the main auction. Section V describes the auction mechanism for Italian Treasury bills. Section VI discusses data set, estimation method and results. Lastly, Section VII summarizes the main findings and suggests further research paths.

II. Related Literature

There is a long-standing debate regarding the auction design that a sovereign should use to issue debt instruments. Most of the debate has focused on the comparative performance of two formats: discriminatory and uniform.

While the discriminatory (also called pay-as-bid or multiple-price) auction is the traditional and, until now, most common auction format for the placement of Treasury securities [Bartolini and Cottarelli, 1997; Brenner *et al*., 2009; Sareen, 2004], the merits of this type of auction have been questioned starting with the Sixties, when Milton Friedman argued that the U.S. Treasury could reduce the cost of financing the debt by switching to the uniform price auction format [Friedman, 1960].

In both discriminatory and uniform auctions, individual bidders submit collections of bids (demand schedules) and the securities are awarded in the order of descending price until supply is exhausted. However, uniform auctions differ from discriminatory in that the winning competitive bidders pay the same price, equal to the lowest winning bid, rather than their bid price. The argument in favor of this format is that, reducing the winner's curse relative to discriminatory auctions, uniform auctions would lessen bidders' incentive to hide their true valuations and would lead them to bid truthfully[3]. In addition, being strategically simpler, this format would reduce bid preparation costs and encourage more bidders to participate. Consequently, the uniform price mechanism should result in lesser collusion and higher revenues for the Treasury.

The theoretical literature after Friedman advanced arguments both in favor and against uniform auctions. Several economists supported this format on the basis of the comparison with single-unit auction models: they viewed the uniform price auction as a multiunit extension of the second-price-sealed-bid auction where bidders are induced to bid sincerely [Bikhchandani and Huang, 1992; Milgrom, 1989]. However, models by Wilson [1979] and Back and Zender [1993], which explicitly incorporate bidders' demand functions in the models, reached the opposite conclusion. These authors showed that uniform auction are

[3] Treasury auctions models are frequently considered *common value* models, where the value of the good for sale is the same to everybody but unknown at the time of bidding. In these models the winners are the bidders who made the highest guesses on the common value. This means that, conditionally on winning, the estimate is upward biased (winner's curse). This creates an incentive for bidders to place price bids inferior to what they believe is the common value (practice known as bid shading). In uniform auctions where all winners pay the clearing price, bidders should be relatively unconcerned with the winner's curse and have less incentives to shade their bids.

susceptible to arbitrary large underpricing, as a result of the market power which arises endogenously in equilibrium, and that discriminatory auctions can have a better revenue-raising performance[4].

More recent literature has shown that the results based on the single auction cannot be generalized to auctions where bidders desire more than one unit. The intuition that this comparison was deceitful aroused already in Vickrey [1961], but it is only at the end of the Nineties that Ausubel and Crampton [1998] showed "under general circumstances, that a bidder who desires more than one unit in a uniform price auction has an incentive to shade her bid". The authors concluded that a theoretical ranking of formats may be impossible, and that the superiority of an auction mechanism can only be determined empirically on a case-by-case basis.

Research on auctioning systems gained significant traction in the 1990s, spurred by the U.S. Treasury's "Treasury experiment[5]." Early studies focused on the revenue-generating capabilities of discriminatory and uniform auction formats, comparing auction prices to benchmarks like when-issued[6] or secondary market prices. These studies often found evidence of underpricing, particularly in discriminatory auctions[7]. However, empirical studies conducted in the 2000s [Alvarez and Mazon, 2019; Cardozo, 2010; OECD, 2018; Pacini, 2007] revealed overpricing in both auction formats, especially in European Treasury auctions[8,9].

[4] Back and Zender [2000] noticed that equilibria with bad outcomes from the seller's point of view can be supported in a uniform-price auction because bidders are concerned with a single point on their demand curves, the one corresponding to the stop-out price. The rest of a bidder's demand curve is left unrestricted and can be used to inhibit competition from other bidders. In a discriminatory auction, this is not the case. Each price bid by any bidder (above the stop-out price) will be paid by that bidder. This means each bidder has a direct interest in his entire demand curve. The use of a discriminatory auction effectively acts as a restriction on the set of strategies that may be played in equilibria."

[5] In November 1992 the U.S. Treasury, that had been using the discriminatory auction format for the issuance of bills since 1929 and for the issuance of all the other bonds and notes since the Seventies, started to run uniform-price auctions for the placement of 2-year and 5-year notes as an experiment. This change was prompted by Salomon Brothers' violations of the restrictions on the maximum amount of a security that a single firm can purchase in an auction. The Treasury's purpose in conducting uniform-price auctions was to determine whether the uniform-price auction technique could reduce the Treasury's financing costs compared with multiple-price auctions, by encouraging more aggressive bidding by participants, and whether it could broaden participation and reduce concentration of securities on original issue. Although the experiment yielded non-conclusive results, in 1998 the Treasury finally switched to the uniform price auction format for all issues.

[6] Since prices of securities auctioned by different methods frequently cannot be directly compared, many empirical works conduct the comparison on the auction mark-up, computed as difference between the price in auction and the price in the "when-issued market", where the price in auction is the lowest winning price bid in uniform price auction or the average winning price in discriminatory auctions while the price in the "when-issued market" refers to the average transaction price in "when-issued market" in the time period from shortly before the auction up until the time of the auction. The "when-issued market" is a market for forward contracts where transactions on securities are made "conditionally" because securities have been authorized, but not yet issued.

[7] See Nyborg and Sundaresen [1996], Malvey and Archibald [1998], Goldreich [2007] on the U.S. experiment, Umlauf [1993] examining Mexican T-bill auctions, and Tenorio [1993] who studied Zambia's weekly foreign exchange auctions.

[8] This phenomenon is at odds with the standard multi-auction theory based on common value and private information. In this setting the issuer should expect revenues inferior to the expected value of the securities being auctioned (common value), since bidders can extract informational rents from their private information. However, overpricing may be compatible with models based on private value and private information, as the bidders' private values of the auctioned security may be superior to the value prevailing in the secondary market. Overpricing can also be justified by some factors external to the auction mechanism per se, such as the interplay between the when-issued market and the auction. For example, Bikhchandani et al. [2000] argue that overpricing is the cost of revealing positive information too early by trading in when-issued markets before the auction.

[9] While potentially beneficial for issuers by lowering borrowing costs, this overpricing raises concerns about market manipulation and potential long-term consequences, such as discouraging investor participation, particularly among smaller investors. For a descriptive analysis of the causes and risks of overpricing see Pacini [2009].

Adding complexity, more recent research has identified underpricing in U.S. Treasury auctions [Herb, 2025]. These contrasting results underscore the need for further investigation and a deeper understanding of the factors driving auction outcomes.

The inconclusive results relative to a revenue ranking of the uniform and discriminatory auctions has led the most recent theoretical and empirical literature on multiunit auctions to move in two different directions. On the one side, theoretical research has extended the analysis to the performances of other multiunit auction formats[10]. On the other side, it has examined how other features of the overall placement procedure, exogenous to the auction mechanism per se, can impact on pricing inside the auction[11].

My paper inserts itself in this recent literature by examining how the introduction of top-up auctions influences bidding behavior in the main auction through its impact on bid shading. To date, the auction literature has dedicated limited attention to top-up auctions due to the limited relevance of non-competitive bidding in certain empirical settings [Fevrier et al., 2002] and the complexities of modeling placement designs with top-ups. Despite this, several empirical and theoretical works have shed light on the role of top-ups.

Empirically, Coluzzi [2007] analyzed top-ups for Italian medium- to long-term bonds and found that the option implicitly granted in the top-up has a significant value. Coluzzi argued that aggressive bidding in the primary market was partially driven by the desire to gain rights to the top-up session. Similarly, Cardozo [2013] found that in the Colombian Treasury auction system, bonds with higher bidder participation in top-up auctions exhibited greater overpricing compared to the secondary market, suggesting that bidders incorporate the value of the top-up auction into their strategies.

Theoretically, Marszalec [2009] studied the Polish Treasury bill auction system and suggested that top-ups may influence main auction bidding through two opposing channels: a price effect (incentivizing under-bidding to depress the top-up price) and a quantity effect (incentivizing aggressive bidding to secure a larger share of the top-up supply). Marszalec [2017] later found that ignoring the top-up auction can introduce bias in valuation estimates. Marchettini [2019] developed the first equilibrium model for auction design with top-us and confirmed that the non-competitive session impacts main auction bidding through both price and quantity effects, with their relative importance depending on the top-up payment rule and the probability of a bid being marginal (i.e., the last to be served) in the main auction.

This paper expands the literature on top-up auctions by providing a comprehensive analysis of the impact of these non-competitive placements on bidding behavior in Italian Treasury auctions. The study also provides a more comprehensive analysis of top-up auctions by examining the interplay of quantity and price effects under varying payment rules. The paper also contributes to the understanding of bid shading dynamics in common value auctions, demonstrating how other features of the overall placement procedure, exogenous to the main auction format (i.e., discriminatory *versus* uniform), can mitigate this behavior.

[10] See for example Armantier and Sbai [2006] on the relative performance of different auction mechanisms, including the Spanish format.

[11] For example, Back and Zender [2000] show that the seller can reduce equilibrium under-pricing by choosing the supply ex post to maximize revenue, while Sareen [2011] and Pacini [2009] examine the consequences of a Primary Dealership system on the auction results.

III. THE FRAMEWORK FOR TREASURY AUCTIONS WITH TOP-UPS

III.1. The Auction Design

An auction mechanism with top-ups involves selling debt securities in two sessions (Figure 1). In t_0 the Treasury announces the specifics of the whole placement (i.e., offering amounts inside the main and top-up auctions, term and type of security, International Security Identification Number or ISIN[12], and issue, maturity, and settlement dates). The first round is a competitive auction (called "main" or "ordinary" or "base" auction). Bidders participating in the main auction (MA hereafter) must place their demand schedules, in the form of a collection of price-quantity bids, inside the bid-window $]t_0; t_{MA}[$, where t_{MA} is the "cut-off time" for the MA. In the MA securities are awarded in the order of descending price until supply is exhausted. The pricing rule (e.g., discriminatory pricing or uniform pricing) determines how much the winning bidders must pay. The results of the MA are communicated in t_{MA}.

The second round is a non-competitive placement (called "top-up" or "supplementary auction" or "secondary auction" or "reserved reopening auction" or "tap issue"), where participants have the right (but not the obligation) to buy additional securities. This right can be exercised at any time in the window $]t_{MA,} t_{TA}[$, with $t_{TA} > t_{MA}$. Differently from the competitive session, in the top-up auction (TA hereafter) prices and allocations are set at the time of the MA, and bidders' strategic choice consists only in the decision to participate or not in the TA. The settlement of the securities awarded both in the MA and TA auctions take places in $t_{SE} > t_{TA}$.

Besides these common features, top-ups specifications differ widely among countries:

- Depending upon the institutional setting, TAs can be performed systematically or at discretion of the Treasury[13].
- The access period when PDs can exercise the right to buy can vary between a few hours and a few days after the MA[14]. A longer access period increases the benefit for admitted bidders by raising the value of the option implicitly granted in the top-up auction.
- Participation in the TA can be restricted in various ways. Typically, only winning bidders from the first round are admitted to the TA. However, in most institutional settings, participation is further restricted to winning PDs in the MA or to the top-performing PDs. [European Primary Dealers Association, 2020; Pacini, 2009].

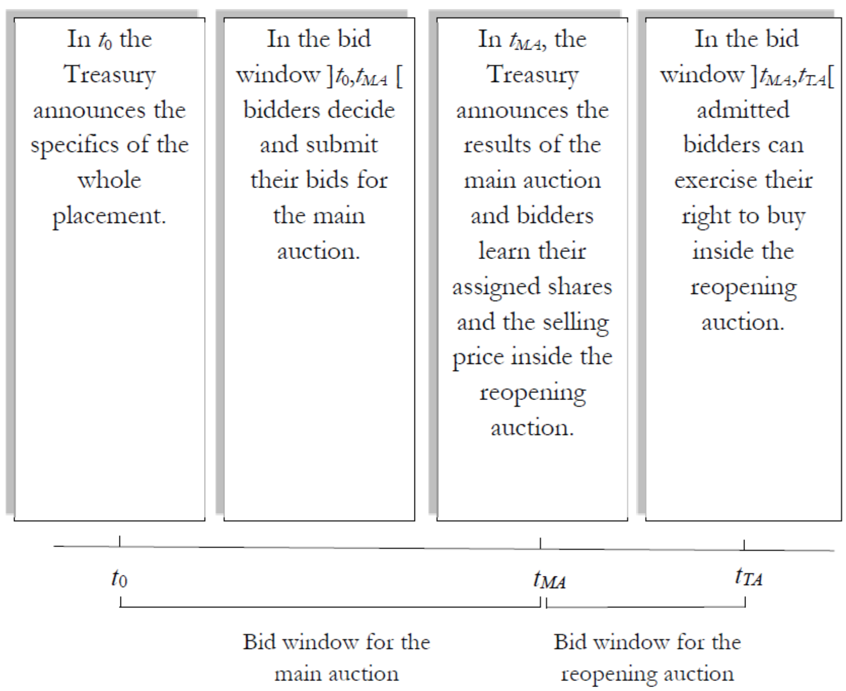
[12] The ISIN Code is a is a 12-character alphanumeric code that serves for uniform identification of a security. The ISIN code is issued by the National Numbering Agency (NNA)—a country-specific establishment—responsible for allocating ISINs for all the securities issued in the country. In Italy, Banca d'Italia is the NNA.

[13] Considering the cases of Italy, Colombia, and Poland (countries for which studies on TAs are available) we have the following: the Italian Government runs TAs for medium- and long-term bonds and for six- and twelve-month bills on a regular basis [Coluzzi, 2007]; the Colombian Government performs the TA only if the MA coverage ratio is at least 1.2 (see Cardozo [2010]); and the Polish Government runs top-up auctions for 52-week bills and 2-years bonds on a discretionary basis (see Marszalec [2009]).

[14] For instance, access period is: 3 hours in Brazil, 24 hours in Austria and Greece, 28.5 hours in Italy, 36 hours in Portugal, 2 days (4 days for the top 5 PDs) in Belgium, 3 days in Spain.

- Allocation rules for the TA phase differ across countries, but the TA allocation is typically a function of the share obtained in the MA[15].
- The TA price is the same for all admitted bidders and is determined in t_{MA}. It can be based on a price/index exogenous to the MA[16], or, more frequently, it is a function of the winning bids in the MA (Section III.2).
- The total amount of securities offered in the TA can be a fixed share of the amount supplied in the MA or can vary at the discretion of the Treasury[17].

Figure 1: Timeline of the placement procedure for an auction system with top-ups



Note: The auction design with top-ups involves the Treasury selling securities in two separate rounds. The first round is a competitive auction (main auction), where bidders specify the quantity and price pairs they are willing to purchase/spend for the auctioned securities. The second round is a non-competitive placement (top-up), where the allocation and price of the securities are pre-defined at the end of the first round. In the second round, admitted bidders have the right, but not the obligation, to purchase the securities at the pre-defined price.

[15] In the TA, each bidder has a preliminary allocation which is typically a function of the share obtained in the MA. However, the actual share may differ from this initial allocation, depending on other parameters. The preliminary allocation, as well as the rule to determine the actual allocation, may vary significantly among countries. For example, in Italy the preliminary allocation is a share of the top-up supply equal to the share obtained by the PD in the last three MAs relative to the total amount allocated to PDs in the same auctions. In Poland the preliminary allocation depends only on the share obtained in the last MA. In Colombia the Treasury offers three different amounts in the TA: the preliminary allocation for the first supply is proportional to what the bidders won in the MA, the preliminary allocations for the other two supplies are restricted to the PDs that are in the top positions of the PD program for the year.

[16] For instance, in Colombian Treasury auctions, the price that bidders must pay in the TA is the average secondary market price of the bond on the MA date, as calculated and published by the Colombian Securities and Stock Exchange. See Cardozo [2010, 2013].

[17] In Italy the amount offered in the TA is equal to 10 percent of the MA's issue for bills and 15 percent for medium-and long-term bonds (30 percent for the first tranche). In Colombia the supply for the TA is 80 percent of the MA supply if the coverage ratio of this auction is at least 2, 55 percent if the coverage ratio is between 1.2 and 2. In Poland the Treasury has discretion to offer up to 20 percent of the amount issued in the MA.

Based on its design, it is reasonable to assume that bidders admitted to the TA will exercise their right to buy only when they can profit from it, i.e., when the TA price is inferior to the price of the security in the secondary market at the time of the TA (V^{RA}). This hypothesis finds strong support in the empirical setting under analysis (Section VI.1), as in most of the TAs (80 percent) either all PDs exercise their right to buy in the TA session or none exercises it (Table 3).

III.2. Payment Rules in Top-ups

While the price of securities in the TA (P_{TA}) is typically the same for all admitted bidders, there are significant differences in how this price is determined across various institutional settings. Top-up payment rules can be divided in two groups.

(i) Rules that set P_{TA} based on a price/index exogenous to the auction mechanism.
(ii) Rules that set P_{TA} as a function of the bids in the MA.

Payment rules based on an exogenous price/index imply that the quantity and price bids in the MA will not influence the price in the TA. As a result, the TA price remains independent of the bidders' strategic behavior. For example, in Colombia, P_{TA} is set equal to the average secondary market price on the day of the MA (V^{MA}).

On the other hand, *payment rules that set P_{TA} as a function of the of the quantities and prices offered in the MA* imply that the TA price is influenced by bidders' strategic behavior within the MA. In these cases, the price paid in the TA typically depends on the format of the MA.

- In auction designs that adopt a uniform payment rule in the MA, P_{TA} is usually set equal to the MA clearing price P^C, also called stop-out price. The stop-out price refers to the lowest price accepted by the Treasury for the securities being auctioned. This price is determined through the auction process, where bidders submit competitive bids specifying the price at which they are willing to purchase specific quantities of the auctioned securities. Securities are then awarded in the order of descending price until the supply is exhausted. In this setting, when the auction is fully subscribed, the clearing price is the highest price among those submitted by bidders that ensures the cumulative demand up to that price is equal to or greater than the supply. When the auction is undersubscribed, the clearing price corresponds to the lowest price submitted by bidders. The clearing price is defined as:

$$P^C = max\left(min_{\substack{i=1,\dots,N \\ m=1,\dots,M^i}} p_i^m, argmax_{\left\{p_j^k,\ j\in(1,\cdots,\mathrm{N}),\ k\in(1,\cdots,M^j)\right\}} \sum_{i=1}^{N}\sum_{m=1}^{M^i} \mathbb{1}(p_i^m >= p_j^k)\, q_i^m \geq Q^{MA} \right), \quad (1)$$

  where the quantity-price pair (q_i^m, p_i^m) defines the m-*th* bid b_i^m presented by bidder i, with q_i^m being the quantity requested by the bidder at the requested price p_i^m (with $p_i^m > p_i^{m+1}$), M^i is the number of bids presented by bidder i, N is the number of bidders and Q^{MA} is the total quantity of debt securities supplied by the Treasury in the MA. Finally, $\mathbb{1}(A)$ is the indicator function of the event A. From (1) it is possible to derive that, when the TA price is set equal to the clearing price P^C only the MA marginal bids (i.e., the lowest bids to be served for each bidder) impact the top-up price[18].

[18] For any bidder i the marginal bid is defined as the bid b_i^m: $p_i^m \geq P^C > p_i^{m+1}$.

- In auction designs that adopt a discriminatory (or pay-as-bid) payment rule in the MA, P_{TA} is typically set equal to the MA average winning price P^{AW}. In this auction design, bidders pay each winning bid at the price p_i^m they offer for that bid. The average winning price corresponds to the weighted average price at which winning bidders acquire the auctioned securities. This is calculated by multiplying each winning bid's price by the quantity of securities associated with that bid, summing these products across all winning bids, and then dividing by the total quantity of securities allocated. The average winning price is defined as:

$$P^{AW} = \frac{\sum_{i=1}^{N}\sum_{m=1}^{M^i} \mathbb{1}(p_i^m > P^C)\, p_i^m \cdot q_i^m + min\Big(Q^{MA} - \sum_{i=1}^{N}\sum_{m=1}^{M^i} \mathbb{1}(p_i^m > P^C)\, q_i^m ,\ \sum_{i=1}^{N}\sum_{m=1}^{M^i} \mathbb{1}(p_i^m = P^C)\, q_i^m \Big) \cdot P^C}{min\big(Q^{MA}, \sum_{i=1}^{N}\sum_{m=1}^{M^i} \mathbb{1}(p_i^m >= P^C)\, q_i^m\big)}, \quad (2)$$

Formula (2) accounts both for the possibility of oversubscribed and undersubscribed auctions and accounts for the possibility of rationing. Rationing occurs when the sum of bidders' requested quantities at prices equal to or exceeding the clearing price exceeds the total supply Q^{MA}. In such instances, the quantities requested at the clearing price are not served in full. Conversely, in undersubscribed auctions, the total quantity requested by bidders at prices equal to or exceeding the clearing price is less than the total supply Q^{MA}.

From (2) it is possible to derive that, when the TA price is set equal to average winning price, the quantities and prices of any winning bid contribute to determine P_{TA}.

IV. CONSIDERATIONS ON THE IMPACT OF TOP-UPS ON BIDDING INSIDE THE MAIN AUCTION

After illustrating the design of an auction mechanism with top-ups, this section will delve deeper into how the introduction of post-auction non-competitive placements may impact bidders' strategic behavior within the MA.

Recent literature [Marszalec, 2009 and 2017; Marchettini, 2019] suggests that the introduction of the TA may affect the incentive to engage in "bid shading" (i.e., "under-bidding") in the MA. Bid shading refers to the practice where bidders intentionally submit bids lower than the value they believe the auctioned good is worth. This issue is particularly relevant in Treasury auctions, which are often considered common value models. In these models, the value of the good for sale is the same for everyone and is equal to the price in the secondary market at the time of settlement of the securities, though it is unknown at the time of bidding. Since the winners are those who make the highest guesses on the common value, the estimates of the common value by winning bidders are upward biased, leading to the "winner's curse." This creates an incentive for bidders to place bids lower than what they believe the common value to be.

As argued by Marszalec [2009], the introduction of the top-up auction may change this incentive through a quantity and a price effect.

i. The quantity effect reflects the impact of shading q_i^m and p_i^m on agent i's TA allocation. This effect represents an incentive to bid more aggressively because shading the bid may reduce the TA allocation. Specifically, shading the quantity bid would result in winning a smaller share of the MA supply, while shading the price may lead to the requested MA quantity not being allocated. Since the TA allocation is a function of the share of the MA supply won by each bidder, both outcomes would be negative for the bidder resulting in gaining a smaller share of the TA supply.

ii. The price effect reflects the impact of shading q_i^m and p_i^m on the TA price. This effect represents an incentive to bid less aggressively because shading the bid may reduce the TA price. Specifically, since the TA price may be a function of the quantity and price bids submitted in the MA, shading these bids may result in a lower TA price, providing a benefit for the bidder.

How important the first effect is relative to the second one depends on two factors: the TA payment rule and the probability that the bid will be marginal in the MA, i.e., the last to be served for bidder i (Marchettini, 2019). The TA payment rule influences the extent to which bidders' strategies inside the MA impact the TA price, which in turn impacts on the price effect. The strength of the quantity and price effect is then further influenced by the marginal versus infra-marginal state of the bid, as explained below and synthesized in Table 1 and Figure 2.

- When the top-up price is based on a price or index exogenous to the auction mechanism, it does not depend on bidders' strategic behavior in the MA. In this context, it is reasonable to expect that, when operators submit their bids in the MA, they consider only the impact of their MA bids on the TA allocation. Consequently, only the quantity effect is at play in this case, while the price effect is null. Furthermore, the quantity effect is stronger in marginal bids because in these bids shading the MA price may imply the requested bid not being allocated, which would reduce the TA allocation.
- Under payment rules that set the TA price as a function of the quantities and prices offered in the MA, both quantity and price effects are present. As before, the quantity effect is present in any bid and stronger for marginal bids. The price effect, instead, manifests differently depending on the specific TA payment rule.
    - In auction designs that set the TA price equal to the clearing price, P^C, the incentive to increase bid shading is expected to manifest only in states where the *m-th* bid is marginal in the MA because only in those states shading the bid impacts the clearing price P^C [see formula (1)].
    - In auction designs that set the TA price equal to the average winning price in the MA, P^{AW}, any winning bid contributes to determine the TA price [see formula (2)]. Therefore, for any bid where $p_i^m \geq P^C$, shading the price p_i^m results in a decline in the TA price. In this case, the incentive for bidders to shade the bid is expected to be stronger in bids in higher steps of the bidders' stepwise demand function, because these are the most expensive bids.

It should be noted that at the time when bidders present their demand schedules in the MA, P^{AW} and P^C are not known. Bidders will base their strategies on their expectation of which bids will be served, and, among those served, which bids are more likely to be marginal[19].

[19] In addition to the "direct" effects highlighted in this section, associated with the impact of shading the bid b_i^m on the TA allocation and price, the equilibrium model for the placement design with topups reveals additional "indirect" effects associated with the impact of shading the bid b_i^m on the likelihood that it will be marginal, and on the value of the option implicitly granted in the TA [Marchettini, 2019].

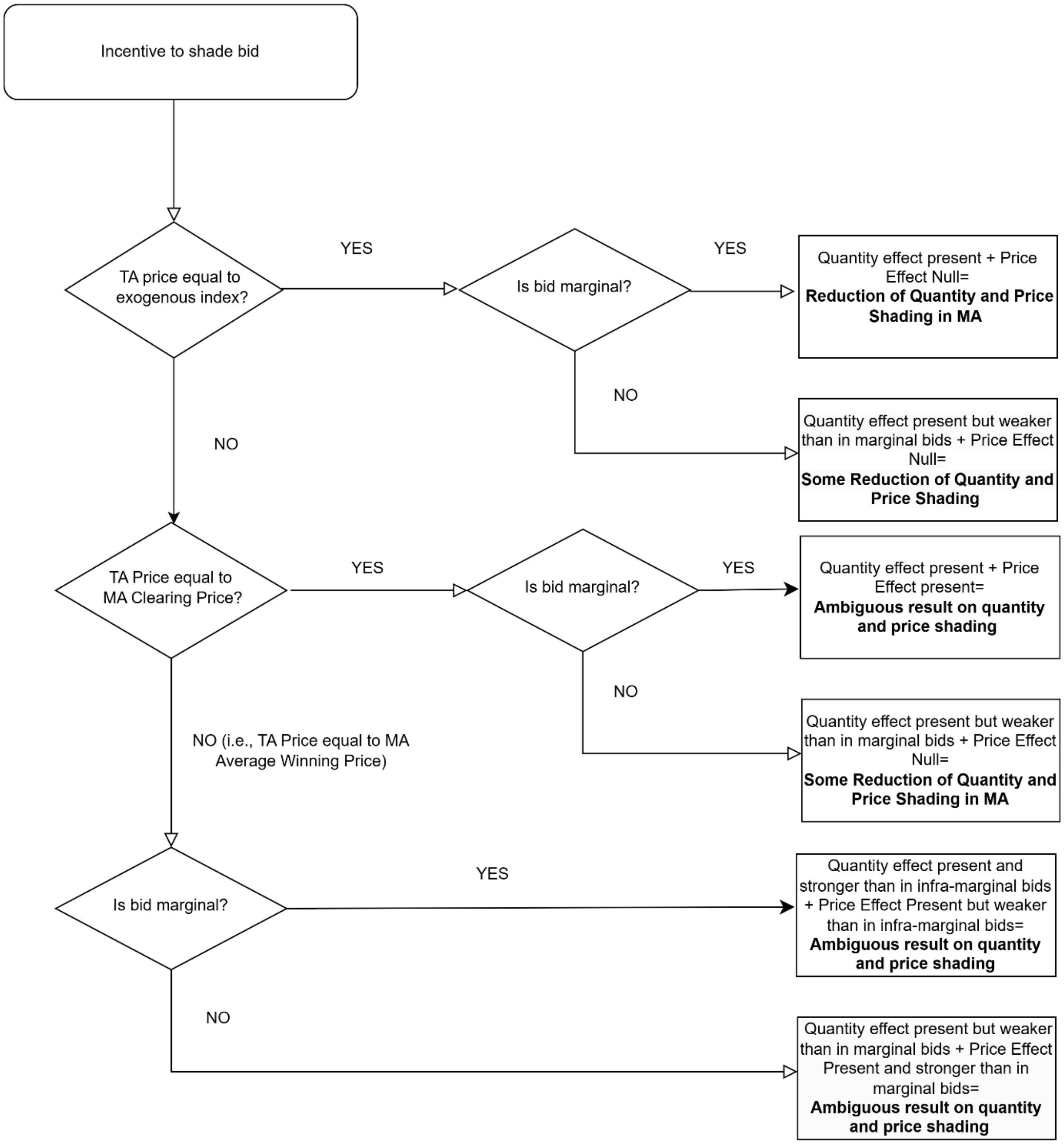
Based on these considerations, it is possible to have some priors on the overall net impact of the TA on bidding inside the MA, which allows ranking the TA payment rules in terms of their capacity to incentivize more aggressive bidding (Table 1).

Table 1: Priors on the net impact of the top-up on bidding behavior inside the main auction

		Quantity Effect (incentive to bid more aggressively)	Price Effect (incentive to bid less aggressively)	Overall Impact on Bidding	Ranking in terms of bidding aggressivity
TA Payment Rule	*Exogenous Price/Index*	Present in all bids, stronger in marginal bids	Null	More aggressive bidding	1
	Clearing price Pc	Present in all bids, stronger in marginal bids	Present in marginal bids	Ambiguous	2
	Average winning price P^{AW}	Present in all bids, stronger in marginal bids	Present in all bids stronger in infra-marginal bids	Ambiguous	3

Note: The table illustrates the anticipated impact of the TA on bidding behavior within the MA, based on the TA payment rule and the expected status of the bid (inframarginal vs. marginal). The TA payment rule influences whether bidder behavior inside the MA affects the TA price and consequently whether we should expect a “price effect,” leading to less aggressive bidding. The status of the bid determines the magnitude of the “quantity” and “price effects”.

Figure 2: Expected impact of the top-up on bid shading inside the main auction



Note: The flowchart illustrates the anticipated impact of the TA on bidding behavior inside the MA, depending on the TA payment rule and the status of the bid (marginal versus inframarginal) inside the MA. The quantity effect, that creates incentives to reduce bid shading, is expected to be independent on the TA payment rule and to be stronger the higher is the probability that the bid is marginal. The price effect, that creates incentives to increase bid shading, is expected to be stronger the more the TA price depends on bidder strategic behavior inside the main auction.

V. THE AUCTION FRAMEWORK FOR ITALIAN TREASURY BILLS

V.1. The Auction Mechanism

The Italian government issues bills (called *Buoni Ordinari del Tesoro—BOTs*) with three standard maturities: three-, six-, and twelve-months. The bills are all sold via a discriminatory auction mechanism. Six- and twelve-month BOTs are issued at regular intervals: the twelve-month BOTs are issued in the second week of every month, while the six-month BOTs are auctioned in the fourth week. In contrast, three-month BOTs, along with BOTs with atypical maturities, are issued periodically to fund the short-term cash needs of the Treasury. The auctions are conducted by Bank of Italy and only authorized dealers can participate (see Section V.2). TAs reserved to PDs (called *Specialists in Government Securities*) are envisaged only for six- and, starting with February 2009, twelve-months BOTs. In the TA the amount supplied by the Treasury is the 10 percent of the face value offered in the MA. The auction mechanism described in this section pertains to the system in effect during the observation period from January 2007 to April 2010, during which RAs for twelve-month bills were introduced.

The auction process begins a few days before the scheduled auction, when the Treasury announces the details of the upcoming issue, including the amount to be auctioned. After the auction is announced, but before it takes place, investors begin trading the yet-to-be issued security in what is called the *when-issued-market*. Transactions in this market are agreements to exchange securities and funds on the day the new security is settled. The when-issued market allows new Treasury issues to be efficiently distributed to investors and provides useful information to potential bidders about the prices the Treasury may receive at the upcoming auction.

After the announcement day, auction bids may be submitted to the Bank of Italy. Each bid specifies the quantity of the security sought and a price. All entities admitted to the primary market may submit a maximum of three bids for their own accounts or on behalf of their customers. All the bids are entered through a network-based system, an electronic platform for processing auction bids, based on the National Interbanking Network. Bidders may amend their bids as frequently as desired, with only the last bid submitted before the deadline considered valid. The deadline for submitting bids is 11:00 a.m. (GMT) of the auction date (cut-off time).

Quantity bids indicate the amount of Treasury bills a bidder wants to purchase—expressed in terms of the face value of the securities—for a certain price. For example, a bidder might submit a quantity bid for 10 million Euros worth of Treasury bills for a price *p*. The minimum quantity a bidder can request is 1.5 million Euros, whereas the maximum admissible requested amount is equal to the quantity offered by the Treasury in the auction. Price bids specify the price the bidder is willing to pay for the requested quantity. Prices are expressed as percentages of the face value[20]. For example, a price bid might be 99 percent of the face value. Prices must be specified with 10 basis point precision (i.e., the minimum increment is 0.1 percent).

As illustrated in Section III, the first bid to be accepted is that with the highest price and then all the others are allocated in descending order until the cumulated amount of accepted quantity bids reaches the amount tendered by the Treasury. Given that the auction is discriminatory, every accepted bid is settled at the requested price. If the total requested quantity is greater than the amount offered, the bids made at the lowest accepted price will be rationed and allocated pro-quota. The auction takes place just after the deadline for submitting bids and its result are promptly announced through the main financial information providers.

During the period of observation, the allocation mechanism underwent some modifications. As mentioned before, an important change, investigated in this paper, was the introduction of TAs reserved to PDs for twelve-month BOTs in February 2009. In addition, starting with April 2009, in conformity with international practice, bids need to be expressed as yield-quantity pairs rather than price-quantity pairs.

V.2. Bidders

Banks and investment firms that intend to participate in the Italian Treasury auctions must satisfy certain legal, technical, and operational requirements[21] and must sign an agreement with the Bank of Italy. While all the registered firms are allowed to participate in the auctions, activity inside the auction has been increasingly dominated by PDs. This category of operators, introduced in 1994, is selected among the operators operating in the Italian-regulated on-screen secondary market (*Mercato Telematico dei titoli di Stato* – MTS)[22], with a view to enhancing the demand of Italian government bonds at auctions, increasing liquidity of the secondary market, and assisting the Treasury with advice on debt management policy issues. PDs are selected by the Department of the Treasury (DoT) in accordance with Ministerial Decree no. 219 of May 13th 1999[23] to guarantee a high level of efficiency and transparency in the Italian Government securities primary and secondary markets.

[20] This type of pricing, common for Treasury bills, is referred as issuance "at discount". This practice implies that bills are sold at a price lower than their face value. When the bill matures, the investor receives the face value. The difference between the purchase price and the face value represents the interest earned by the investor. The conversion from prices to yields can be calculated using the following formula:

$$Yield = (100 - p)/p \times 360/t,$$

where: p is the price of the BOT (expressed as a percentage of the face value), t is the time to maturity in days, and 360 is used because Italian BOTs use the day count convention of 360 days per year.

[21] Operators must be authorized to exercise at least one of the activities indicated in Article 1.5 of the Legislative Decree 58 of 24 February 1998 (the "Consolidated Law on Financial Intermediation"). In addition, for the purposes of participating in tenders, the intermediary must be able to send and receive messages on the National Interbank Network, while, for the purposes of settling the items assigned in the auction, the intermediary must be a participant in Monte Titoli S.p.A. system or must appoint an intermediary (the "settlement agent") and have the latter complete the form accepting the engagement. Finally, to verify the correct management of the messages on the Network, each intermediary intending to participate in tenders must perform tests with the Bank of Italy.

[22] This is a regulated market pursuant to Section 66 of the Legislative Decree N.58, 24/2/1998, and operated by MTS S.p.A. under the supervision of Bank of Italy and CONSOB.

[23] The ministerial Decree n. 219 of May 13th 1999 was replaced by the Decree n. 216 of December 22nd 2009 in effect since April 3rd 2010.

To obtain a PD status, a bidding institution must apply for a license from the DoT and satisfy certain requirements. The status of PD implies several obligations and privileges. The most important obligation (necessary condition for retaining the status of PD) is attaining the minimum annual primary market share of 3 percent of the bonds issued by the Ministry of the Economy and Finance on the primary market[24]. Over the years, obligations have become increasingly more stringent, and include qualitative aspects—such as, the use at each auction of all three available bids—as well as quantitative criteria aimed at discouraging bidding behaviors that result to be distortive of auction outcomes. In addition to the primary market requirements, PDs must contribute to the efficiency of the secondary market and must satisfy organizational requirements relative to minimum capital and organizational structure. By monitoring PDs' compliance with the requirements, the Treasury can precisely analyze and assess their activity in the various segments where they are required to operate. This assessment process includes assigning points to each PD and creating a ranking at the end of the year, with the top five positions publicly disclosed.

PDs' privileges include the exclusive access to reserved TAs following the auctions of medium-long-term bonds and of six- and twelve-month BOTs, to the debt exchanges and repurchase auctions and to the selection as lead managers of syndicated issues, and, as a rule, as counterparties to transactions in derivatives. Regarding access to TAs, each PD is entitled to receive a share of the TA supply proportional to the amount they were allocated in the last three MAs, relative to the total amount allocated to all PDs in those same auctions. The price for the TA is the same for all admitted bidders: it is set at the weighted average price of the last main auction for discriminatory bill auctions or at the clearing price of the last main auction for uniform-price bond auctions.

VI. Testing the Impact of Top-ups on Bidding Behavior in Italian Treasury Bill Auctions

VI.1 Data

The dataset contains information on 331 competitive auctions of Italian Treasury bills and covers the period January 2007-April 2010. The sample includes 29 three-month, 40 six-month, and 40 twelve-month BOT auctions, as well as 23 auctions of bills with atypical maturity (See Table 2). The bid-to-cover ratio averages 1.5 for six- and twelve-month BOT auctions, and 2 for three-month BOT auctions, as well as for auctions with atypical maturities. Notably, the ratio exceeds 1 in all competitive placements within the sample, indicating that no auctions have been under-subscribed. The dataset includes all bids associated with these auctions.

On average, PDs submit three bids while non-PDs submit two. In most of the cases, PDs submit more than one bid (above 95 percent of the cases for all maturities), non-PDs, instead, submit one bid in half of the

[24] Individual market shares are calculated by the Treasury as a weighted average of the bidders' allocations along the year. Each maturity has a different weight in contributing to the 3 percent requirement, with weights being higher the longer is the residual maturity of the security. For example, the weight for 3-months bills is 0.25, while the weight for 30-years bonds is 13. This system of weights is motivated by the Treasury's desire to extend the debt maturity profile.

cases (57 percent). The thrust of this finding is that PDs employ more sophisticated bidding strategies and typically submit a full demand schedule, unlike non-PDs, that preferably submit only one or two bids. This difference is also motivated by the qualitative requirements that PDs must meet during the auction process (see Section V.2). The distribution of dealers participating in the auctions is rather stable across auctions and is dominated by the participation of PDs.

Table 2: Italian Treasury bill auctions: summary statistics of competitive placements (January 2007-April 2010)

	3-Month		6-Month		12-Month		Atypical	
Number of Auctions	*Count*	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*
Total	29		40		40		23	
Totally Served	29	100	40	100	40	100	23	100
Partially Served	0	0	0	0	0	0	0	0
Bid-to-Cover Ratio	*Mean*	*Std.*	*Mean*	*Std.*	*Mean*	*Std.*	*Mean*	*Std.*
	2	0.36	1.4	0.19	1.6	0.29	1.9	0.37
Number of Bidders	*Mean*	*Std.*	*Mean*	*Std.*	*Mean*	*Std.*	*Mean*	*Std.*
PDs	21.8	2.1	21.5	1.4	21.3	1.5	21.5	1.2
Non-PDs	8.5	1.8	8.1	2.1	8.2	2	5.9	1.5
Number of Bids	*Mean*	*Std.*	*Mean*	*Std.*	*Mean*	*Std.*	*Mean*	*Std.*
PDs	3	0.3	3	0.2	2.9	0.4	2.9	0.4
Non-PDs	1.9	0.9	2	1	1.8	1	1.5	0.8

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Note: The table indicates that Italian Treasury bill auctions were consistently fully subscribed throughout the observation period. The distribution of participating operators is skewed towards PDs, with little variation across maturities and over time. PDs demonstrate more sophisticated bidding behavior, as evidenced by their typical utilization of all the three bids allowed by the Italian Treasury.

The dataset also contains information on 55 top-up auctions, of which 40 associated with six-month and 15 with twelve-month placements. In most of the top-ups (80 percent of the cases) either all admitted PDs exercised their right to buy or none exercised it (Table 3).

Table 3: Italian Treasury bill auctions: participation in top-ups (January 2007-April 2010)

	6-Month		12-Month	
	Count	*%*	*Count*	*%*
Full Exercise	16	40.0	11	73.3
No Exercise	17	42.5	1	6.7
Partial	7	17.5	3	20.0

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Note: The table shows that 80 percent of the TAs were either fully subscribed or not subscribed at all during the observation period. This pattern is consistent with the hypothesis that TAs function similarly to a call option, where the right to purchase is typically exercised exclusively when the secondary market price is below the TA price (that acts as the strike price).

VI.2. Estimation Method and Results

The analysis in this section uses a reduced form approach to evaluate the impact of the introduction of TAs for 12 months bill in Italian Treasury auctions.

As argued in Section IV, introducing the TA with a payment rule that sets the TA price equal to the MA average winning price is expected to generate incentives that act in opposite directions on bid shading in the MA (Figure 2 and Table 1). This section will evaluate which incentive is dominant in the context of the Italian institutional setting. The analysis is limited to three-bid demand schedules, as these allow for examining bidders' differential strategic behavior in infra-marginal versus marginal bids.

The estimation method is a Difference-in-Difference (DiD) approach, which is typically used to estimate the impact of a specific intervention or treatment (in our case the introduction of top-up auctions) by comparing the changes in outcomes over time between a population that is exposed to the intervention (in our case PDs) and a population that is not (in our case non-PDs). This approach suits well the Italian Treasury bill auction dataset, given that the introduction of the TA reserved to PDs for twelve-month bills in February 2009 offers a "natural experiment" environment to evaluate the effects of TAs on bidders' quantity and price bids inside the MA.

The DiD regression relies on the assumption that in absence of treatment, the unobserved differences between treatment and control groups would remain constant overtime (*parallel trends assumption*). Violation of this assumption means that other factors, not the treatment, could be driving the differences in outcomes between the treated and control groups, leading to biased estimates. This concern is particularly relevant in the analysis described in this section because pooling together results from several different auctions naturally induces unobserved heterogeneity due to changes in financial market conditions that may impact on bidding behavior. This issue is further exacerbated by the fact that the observation period (January 2007–April 2010) coincides with a period of high volatility in the Italian Treasury market, which is linked to the unfolding of the Global Financial Crisis and the onset of the European sovereign debt crisis.

Based on these considerations, it is relevant to control for factors external to the introduction of the TA that may influence bidders' behavior and then test whether the parallel trend assumption holds. First, to minimize unobserved heterogeneity, the paper controls for fluctuations in market conditions that could affect the common value of auctioned bills and, consequently, price bids. This is achieved by dividing price bids by the average winning price in each auction, creating what the paper refers to as 'normalized price bids.' Additionally, to control for the impact of higher financing needs for the Treasury, reflected in increased securities offered in auctions over the observation period[25], which could impact on the absolute value of quantity bids, quantity bids are divided by the total offered amount in each auction, resulting in what is defined as 'normalized quantity bids.'

The parallel trend assumption is tested by visually inspecting average normalized quantity and price bids (January 2007-January 2009). Charts in Figure 3 suggest a potential violation of this assumption for the first

[25] The average amount offered by the Treasury in twelve-month bill monthly auctions increased from Euro 6.4 billion in 2007 to 7.4 billion in 2010.

and second quantity bids and the third price bid, as the difference between PDs and non-PDs appears to increase over time.

To assess whether the differences in trends before the introduction of the TA is statistically significant, regressions are estimated using only pre-treatment data (January 2007-January 2009).

$$\begin{aligned}\bar{q}_{i,t}^{m} &= \alpha_0^m + \alpha_1^m \cdot Time + \alpha_2^m \cdot D_{PD,i,t} + \alpha_3^m \cdot (Time \cdot D_{PD,i,t}) \\ \bar{p}_{i,t}^{m} &= \beta_0^m + \beta_1^m \cdot Time + \beta_2^m \cdot D_{PD,i,t} + \beta_3^m \cdot (Time \cdot D_{PD,i,t})\end{aligned} \tag{3}$$

where $\bar{q}_{i,t}^{m}$ and $\bar{p}_{i,t}^{m}$ are, respectively, bidder i's normalized quantity and price bids at time t—with $i \in \{1, \cdots, N\}$ and $m \in \{1,2,3\}$—, $Time$ is a linear time trend, $D_{PD,i,t}$ is a state dummy indicating whether bidder i is a PD at time t, and $Time \cdot D_{PD,i,t}$ is an interaction term of the time trend and state dummy. This regression aims to test the null hypothesis that the parallel trend assumption holds for both quantity and price bids. This corresponds to testing $\mathrm{H}_0 : \alpha_3^m = 0$ and $\beta_3^m = 0,\ m \in \{1,2,3\}$. The results of this regression reject the parallel trend assumption for all quantity bids and for the second and third price bids (Table 4)[26].

As the parallel trends assumption is violated, the standard DiD specification may yield biased estimates. Therefore, it is necessary to adjust the model to account for a secular trend that exacerbates the differences between PD and non-PD bids over time, as well as to consider factors unrelated to the introduction of the TA that could explain variations in quantity and price bids before and after the treatment. To address this, the following "augmented" DiD regressions for standardized quantities and prices is estimated over the full observation period (January 2007-April 2010):

$$\begin{aligned}\bar{q}_{i,t}^{m} &= \gamma_0^m + \gamma_1^m \cdot D_T + \gamma_2^m \cdot D_{PD,i,t} + \gamma_3^m \cdot (D_T \cdot D_{PD,i,t}) + \gamma_4^m \cdot Time + \gamma_5^m \cdot (Time \cdot D_{PD,i,t}) + \gamma_6^m \boldsymbol{C}_t \\ \bar{p}_{i,t}^{m} &= \delta_0^m + \delta_1^m \cdot D_T + \delta_2^m \cdot D_{PD,i,t} + \delta_3^m \cdot (D_T \cdot D_{PD,i,t}) + \delta_4^m \cdot Time + \delta_5^m \cdot (Time \cdot D_{PD,i,t}) + \delta_6^m \boldsymbol{C}_t\end{aligned} \tag{4}$$

where D_{Tt} is a time dummy equal to 0 before February 2009 (when the TA was introduced) and to 1 otherwise, $\boldsymbol{C}_t$ is a vector of controls, and all other variables are the same as in regressions (3).

The first four terms in (4) corresponds to the "standard" baseline DiD specification. In this specification, the time dummy controls for biases that can derive from any factors or events that change after the treatment period and influence the outcome variable (quantity and price bids) for all units in the study, regardless of whether they are in the treatment (PD) or control (non-PD) group. The state dummy removes biases in post-intervention period comparisons between PDs and non-PDs that could be the result of permanent constant differences between those groups. The interaction of the state and time dummy is the DiD term, which identifies the impact of TA on quantity and price bids. The corresponding meaning of the coefficients in this regression is as follows: γ_0^m and δ_0^m are the average bid m's quantity and price, γ_1^m and δ_1^m represent the average change in bid m's quantity and price after the introduction of the TA (February 2009), common to both PDs and non-PDs; γ_2^m and δ_2^m capture the average constant difference in the quantity and price bids

[26] These results are consistent with the increasingly significant role of PDs in the Italian primary market over time. This evolution has been driven by progressively stricter requirements to maintain the primary dealer status set by the Italian Treasury (see Section V.2). The framework has demonstrated its resilience during major international crises [IMF, 2003], with no disruptions observed in the primary market. In 2012, Maria Cannata, Director General of the Italian Treasury, Public Debt, stated: … "*The creation of the figure of the Specialist in government securities, who committed to subscribing to significant portions of government securities at auction, allowed for the successful consolidation of the Italian public debt over time. By the end of 2010, the average life of government securities reached a historic high (7.20 years), and the financial duration was nearly 5 years (4.91 years, to be precise)*" [Dipartimento del Tesoro, 2012].

between PDs and non-PDs before the introduction of the TA; and γ_3^m and δ_3^m represent the difference in the changes over time to be attributed to the introduction of the TA.

The additional terms in Equation (4) account for potential confounding factors. Specifically, these terms control for:

- Common Time Trend: A linear time trend common to both PDs and non-PDs, captured by the *Time* variable. This accounts for secular changes in bids common to both control and treatment group.
- Differential Time Trends: The possibility of diverging linear trends in bids between PDs and non-PDs, captured by the interaction term between the time trend and the state variable ($Time \cdot D_{PD,i,t}$). This accounts for pre-existing differences in bidding behavior between the two groups.
- Market Dynamics: The influence of broader market conditions on bids, independent of the policy change. This is achieved by including a vector $\boldsymbol{C}_t$ of control variables, such as the Italian-German bond spread, which reflects the change in risks associated with lending to the Italian government, and the VIX, which serves as proxy for market volatility.

By incorporating these controls, the analysis aims to isolate the specific impact of the policy change (TA introduction) on bidding behavior, while accounting for other potential sources of variation in quantity and price bids.

Tables 5 and 6 present the results of the analysis for twelve-month quantity and price bids, respectively. The first column in both tables displays the baseline DiD estimates. The second and third columns show results from augmented DiD specifications, where:

- Augmented Specification (1) includes the time trend and its interaction with the state dummy.
- Augmented Specification (2) includes the time trend, its interaction with the state dummy, and two control variables that proxy for market conditions (i.e, the spread between Italian and German bonds and the VIX to proxy market volatility).

In all specifications, the coefficient of interest is the DiD term, which captures the impact of the TA on PDs' bidding behavior.

For quantity bids, it is noticeable that in the augmented DiD specifications the estimated coefficient of the DiD term drops by 30-40 percent compared to the baseline specification. Additionally, the DiD coefficient for the first bid loses statistical significance. This outcome is to be expected and reflects the fact that part of the differences in quantity bids observed in the PD and non-PD groups post-treatment are explained by a secular trend — not included in the baseline specification —present already before the TA was introduced. Although the estimated DiD coefficient of the second and third quantity-bids fall compared to the baseline estimate, they remain positive and significant, thus supporting the theory that the introduction of the TA has had a statistically significant impact on bidding behavior.

For price bids, it is noticeable that the estimated coefficient of the DiD term of the third bid becomes (weakly) significant and negative in the augmented specifications while it is insignificant in the baseline specification. The impact of the TA on the first and second price bids is insignificant under all specifications.

While the evidence so far suggests that the introduction of the TA is associated with an increase in PDs' second and third quantity bids and a decrease in the third price bid, interpreting the estimates as causal requires that the parallel trend assumption is satisfied. Even when accounting for the time trend, its interaction with the treatment variable, and various controls, it is possible that unobserved factors continue to influence the observed increase in the post-treatment period. To address this concern, a robustness check is conducted by estimating the DiD regressions specified in Equation (4) for quantity and price bids using data from six-month bill auctions. It is important to note that this analysis serves solely as a robustness check and not as an evaluation of a separate treatment effect. The primary focus remains on assessing the impact of the February 2009 policy change on twelve-month Treasury bills, which were the only securities affected by the introduction of the TA.

This approach is justified as six-month bills function effectively as a control group. They are close substitutes for twelve-month bills but were not affected by the 2009 policy change, which exclusively targeted twelve-month bills[27]. A significant DiD estimate for twelve-month bills, in conjunction with an insignificant estimate for six-month bills, bolsters the argument that the observed effect for twelve-month bills is attributable to the policy change rather than other confounding factors. Therefore, the objective of this analysis is to test the null hypothesis that the data generating process of PDs' quantity bids in six-month bill auctions remained unchanged after February 2009. This equates to testing the insignificance of the DiD term coefficients for six-month quantity bids.

Similar to the twelve-month bill analysis, both the standard baseline DiD model and two augmented DiD regressions (including a time trend, its interaction with the state dummy, and the vector of controls) are estimated. The augmented specification is necessary because the parallel trend assumption is violated also in the case of the six-month bill auctions[28].

Table 7 presents the analysis results. The coefficients of the DiD term in the augmented specifications are not statistically significant for all quantity bids and for the third price bid. This confirms that the significant DiD coefficients in the twelve-month bill regression capture the introduction of the TA, as this is the only relevant difference between the auctions of the two types of bills during the observation period.

VI.3. Delving Deeper into the Results

The analysis in Section VI.2 has identified two main findings:

1. The introduction of TA has had a statistically significant positive impact on PDs' requested quantities. The effect of the TA on PDs’ quantity bids is more pronounced in the lower steps of bidders’ demand functions. This is evidenced by a higher DiD term coefficient for the third bid compared to the second bid (0.011 versus 0.008 or 0.009, depending on the specification), while the coefficient for the first bid is non-significant.
2. The introduction of TA has a weakly significant negative impact on PDs' third price bids, while the impact on the first and second price bid is non-significant.

These findings suggest that the “quantity effect” has been dominant in quantity bids, i.e., the TA has reduced PDs’ incentive to shade quantity bids to gain a larger share of the TA supply, while the price effect has been

[27] The TA was introduced in May 2002 for the six-month maturity, and no additional changes were implemented in February 2009.

[28] The estimates of α_3^m (with $m \in \{1,2,3\}$) in regressions (3) are statistically significant for all quantity bids and for the third price for six-month bills. While estimates of regression (3) are not presented for brevity, the significance of the differential time trend in bids between PDs and non-PDs is confirmed by the significant coefficients for the interaction term between the time trend and the state dummy in Table 7.

dominant in the third price bid. Quantity and price effects have offset each other in the first quantity bid and in the first and second price bids, i.e., PDs' incentive to increase price bid shading to reduce the TA price and the incentive to reduce price bid shading to win a larger share of the TA supply have neutralized each other.

To conclusively determine whether the quantity or price effect has been dominant in twelve-month bill auctions, the DiD regression is applied to the cumulated value of bids by running the following regression:

$$\bar{v}_i^3 = \phi_0 + \phi_1 \cdot D_T + \phi_2 \cdot D_{PD} + \phi_3 \cdot (D_T \cdot D_{PD}) + \phi_4 \cdot Time + \phi_5 \cdot (Time \cdot D_{PD}) \qquad (5)$$

where $\bar{v}_i^3 = \bar{q}_i^1 \cdot \bar{p}_i^1 + \bar{q}_i^2 \cdot \bar{p}_i^2 + \bar{q}_i^3 \cdot \bar{p}_i^3$ and all other variables are as in equation (4).

The results reported in Table 8 confirm that the quantity effect has been dominant, and that the introduction of TA has had a positive impact on PDs' overall bid value, as illustrated by a positive significant DiD term coefficient. This result suggests that even in an auction design with top-up that sets the TA price equal to the average winning price in the MA—which is expected to stimulate the least aggressive bidding among the designs with top-ups (see Table 1 and Figure 2)—the introduction of top-ups may incentivize a decrease in bid shading.

In the context of the Italian Treasury bill auctions, the impact of TA is not only statistically significant but also substantial. Specifically, the DiD term coefficients indicate that the introduction of TA led to an average increase in PDs' requested shares of 80-90 basis points for the second and 110 basis points for the third bid (Table 5). This translates to a 53 percent and 65 percent increase compared to the average normalized PDs' requested quantity bids before the introduction of TA. This result is reflected in an increased auction coverage ratio from 1.46 before the introduction of the TA to 1.68 after its introduction. While the TA is also associated with a minor decrease of 5 basis points in the third price bid (Table 16), this does not offset the significant increase in requested shares. Overall, the TA resulted in a 190 basis point increase in PDs' cumulative requested normalized values (Table 8).

This outcome is particularly remarkable in the context of an environment marked by high volatility, as acknowledged by the Italian Treasury. In 2012, Maria Cannata, Director General of the Italian Treasury, Public Debt, stated in a hearing before the Budget Committee of the Chamber of Deputies [Dipartimento del Tesoro, 2012]:

> "… *even in a context that, starting from the summer of 2007, with the outbreak of the subprime crisis, presented increasingly severe problems and difficulties, up until the end of 2010, the Italian Treasury has always managed to achieve commendable results, with an average issuance cost at historic lows (2.19% in 2009 and 2.10% in 2010), increasing average life and duration, and solid demand from institutional investors on a global scale* …"

Among the innovations that have proven crucial for this successful result Ms Cannata mentions the introduction of TAs for twelve-month bills:

> "*Previously, this option was available for all medium to long-term securities and only for the six-month BOT. Extending it to the annual BOT allows for better exploitation of additional unmet demand in the auction or that emerges the following day.*"

VII. CONCLUSIONS

This paper examined the impact of introducing secondary non-competitive placements (top-ups) on bidding behavior in Treasury auctions. Theoretical analysis suggested that top-ups influence bidding through two opposing channels: a quantity effect, which incentivizes more aggressive bidding to secure a larger share of the top-up supply, and a price effect, which may encourage less aggressive bidding to reduce the top-up price. The relative strength of these effects depends on the top-up payment rule and the expected status of the bid (marginal vs. infra-marginal). Notably, the weaker the link between the top-up price and bidders' strategies in the main auction, the stronger is expected to be the quantity effect, leading to greater bidding aggressiveness.

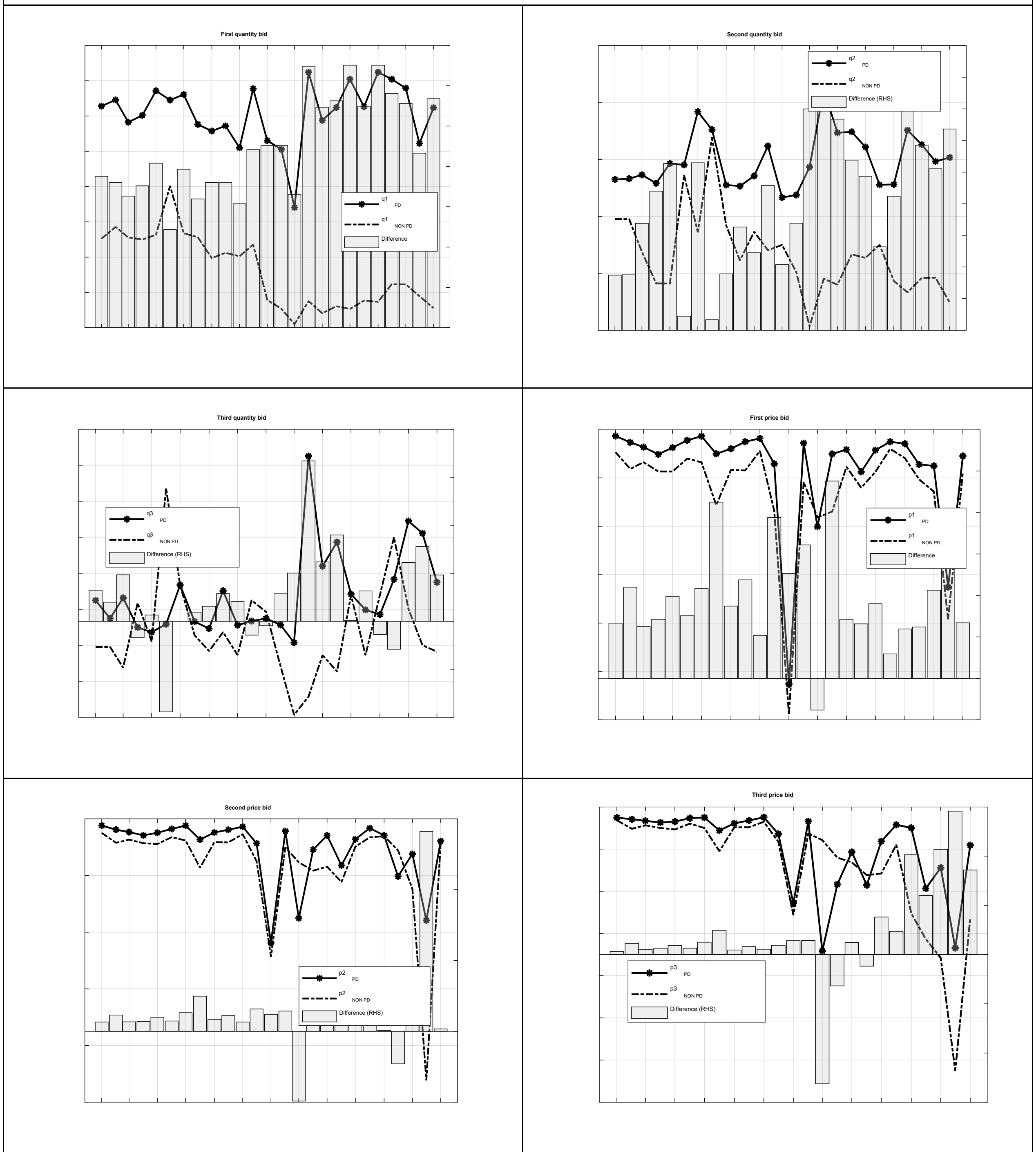
Using a Difference-in-Differences approach on Italian twelve-month Treasury bill auctions, this study found that despite the presence of counteracting incentives, the introduction of top-ups led to more aggressive bidding by Primary Dealers. The observed increase in bidding aggressiveness, especially for marginal bids, resulted in higher requested quantities and cumulative bid values. This is particularly significant given that the top-up price was linked to the average winning price—a payment rule expected to be least conducive to aggressive bidding, as it ties the top-up cost to all winning bids in the main auction. In addition, the introduction of top-ups coincided with a period of high volatility in Treasury markets.

These findings have several important policy implications for Debt Management Offices:

- Enhanced Auction Performance – Top-ups, even when their pricing is linked to main auction bids, can effectively improve auction coverage and mitigate bid shading.
- Flexibility in Auction Design – Debt Management Offices have room to tailor top-up mechanisms. Even under pricing rules that might be perceived as less favorable to bidders, top-ups can still encourage aggressive bidding, broadening the range of viable auction strategies.
- Increased Demand and Liquidity – By stimulating more aggressive bidding and expanding overall participation, top-ups can enhance demand for government securities, improve market liquidity, and ultimately reduce borrowing costs, contributing to a more stable debt market.

Future research could examine the impact of alternative top-up pricing rules that are less dependent on main auction bids, potentially amplifying bidding aggressiveness and leading to higher price bids. Additionally, further analysis could identify the Bayesian equilibrium model for top-up auctions (Marchettini, 2019) and employ a structural econometric approach to deepen the understanding of bidding dynamics.

Figure 3: Pre-treatment trends in quantity and price bids of primary dealers (PD) and non-primary dealers (non-PDs)



Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Note: This figure provides a visual test for the parallel trend assumption, essential for unbiased DiD estimates. The assumption requires that the difference between the treatment and non-treatment groups (in our analysis, PDs and non-PDs) remains constant during the pre-treatment period. The figure suggests that this assumption may not hold for all quantity bids and the third price bid, as the difference between PD and non-PD bids shows an increasing trend.

Table 4: Test for parallel trend assumption in pre-treatment period for quantity and price bids in twelve-months Italian Treasury bill auctions

Quantity and Price Bids	Interaction Term Coefficient and Significance
$\bar{q}_i^1$ — First Quantity Bid	2.65E-05*** (0.000)
$\bar{q}_i^2$ — Second Quantity Bid	1.28E-05*** (0.000)
$\bar{q}_i^3$ — Third Quantity Bid	1.73E-05** (0.000)
$\bar{p}_i^1$ — First Price Bid	-4.72E-09 (0.000)
$\bar{p}_i^2$— Second Price Bid	3.05E-07 (0.000)
$\bar{p}_i^3$ — Third Price Bid	1.23E-06** (0.000)

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Newey-West standard errors in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1% level, respectively.

Note: The sample covers 600 observations (each observation corresponds to a demand schedule of/ three bids, with each bid corresponding to a quantity-price pair) over the period January 2007-January 2009 (pre-treatment period). This table presents the results of a test for the parallel trend assumption in a standard Difference-in-Differences (DiD) model. The test focuses on the coefficient of the interaction term between the time trend variable and the treatment dummy in equations (3). Under the null hypothesis, the interaction term should have a coefficient of zero, indicating that there are no differential trends between the treatment and control groups prior to the intervention. Rejecting the null hypothesis would suggest that the parallel trend assumption does not hold, which could bias the estimates of the treatment effect. The reported coefficients, standard errors, and p-values provide evidence that the parallel trend assumption is rejected for all quantity bids and for the third price bid.

Table 5: DiD estimates of the impact of top-ups on quantity bids in Italian twelve-months Treasury bill auctions

	Baseline Specification	Augmented Specification (1)	Augmented Specification (2)
	$\bar{q}_i^1$ — First Quantity Bid		
DiD Term	0.010*** (0.002)	-6.62E-04 (0.003)	-7.20E-04 (0.003)
TIME Dummy	-0.005*** (0.001)	0.004*** (0.001)	0.00* (0.002)
PD Dummy	0.023*** (0.001)	0.002*** (0.001)	0.015*** (0.002)
Trend	Not included	-2.20E-05*** (0.000)	-2.16E-05*** (0.000)
Interaction Trend PD Dummy	Not included	2.43E-05*** (0.000)	2.44E-05*** (0.000)
Spread	Not included	Not included	2.43E-04 (0.005)
VIX	Not included	Not included	-1.75E-05 (0.000)
C	0.008*** (0.001)	0.014*** (0.001)	0.015*** (0.002)
	$\bar{q}_i^2$ — Second Quantity Bid		
DiD Term	0.013*** (0.002)	0.008*** (0.002)	0.009*** (0.003)
TIME Dummy	-0.005*** (0.001)	-0.001 (0.002)	-2.89E-04 (0.002)
PD Dummy	0.009*** (0.001)	0.005*** (0.002)	0.005*** (0.002)
Trend	Not included	-7.74E-06* (0.000)	-1.07E-05* (0.000)
Interaction Trend PD Dummy	Not included	1.08E-05*** (0.000)	1.09E-05*** (0.000)
Spread	Not included	Not included	0.001 (0.003)
VIX	Not included	Not included	2.34E-05 (0.000)
C	0.007*** (0.001)	0.009*** (0.001)	0.009*** (0.001)
	$\bar{q}_i^3$ — Third Quantity Bid		
DiD Term	0.017*** (0.002)	0.011*** (0.004)	0.011*** (0.004)
TIME Dummy	-0.008*** (0.001)	-0.008*** (0.002)	-0.004 (0.003)
PD Dummy	0.006*** (0.001)	0.002 (0.002)	0.001 (0.002)
Trend	Not included	-1.71E-06 (0.000)	-1.54E-05** (0.000)
Interaction Trend PD Dummy	Not included	1.36E-05** (0.000)	1.40E-05** (0.000)
Spread	Not included	Not included	0.006 (0.004)
VIX/	Not included	Not included	4.31E-05 (0.000)
C	0.012*** (0.001)	0.012*** (0.002)	0.012*** (0.002)

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Newey-West standard errors in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1% level, respectively.

Note: This table presents Difference-in-Differences (DiD) regressions based on Equation (4), analyzing the impact of the February 2009 policy change on normalized quantity bids. Using 920 observations from January 2007 to April 2010, three models are estimated: a standard DiD model; a DiD model including a linear time trend and its interaction with a PD vs. non-PD state variable [Augmented Specification (1)]; and Augmented Specification (1) including also controls for market stress [Augmented Specification (2)]. The key coefficient is the DiD term, indicating the policy's impact. Results show a significant impact on the second and third quantity bids, but no significant effect on the first quantity bid.

Table 6: DiD estimates of the impact of top-ups on price bids in Italian twelve-months Treasury bill auctions

	Baseline Specification	Augmented Specification (1)	Augmented Specification (2)
	$\bar{p}_i^1$ — First Price Bid		
DiD Term	4.64E-05 (0.000)	1.09E-04 (0.000)	1.09E-04 (0.000)
TIME Dummy	-5.58E-05 (0.000)	-1.55E-04*** (0.000)	-1.43E-04 (0.000)
PD Dummy	1.08E-04*** (0.000)	1.51E-04*** (0.000)	1.50E-04*** (0.000)
Trend	Not included	2.22E-07** (0.000)	1.50E-07 (0.000)
Interaction Trend PD Dummy	Not included	-1.42E-07 (0.000)	-1.37E-07 (0.000)
Spread	Not included	Not included	5.15E-05* (0.000)
VIX	Not included	Not included	-4.20E-07 (0.000)
C	1.000*** (0.000)	1.000*** (0.000)	1.000*** (0.000)
	$\bar{p}_i^2$ — Second Price Bid		
DiD Term	1.78E-04 (0.000)	-6.48E-06 (0.000)	-2.02E-05 (0.000)
TIME Dummy	-1.57E-04 (0.000)	9.33E-05 (0.000)	3.71E-05 (0.000)
PD Dummy	1.54E-04*** (0.000)	2.63E-05 (0.000)	2.46E-05 (0.000)
Trend	Not included	-5.59E-07* (0.000)	-5.37E-07* (0.000)
Interaction Trend PD Dummy	Not included	4.16E-07 (0.000)	4.32E-07 (0000)
Spread	Not included	Not included	1.22E-04 (0.000)
VIX	Not included	Not included	-4.76E-06* (0.000)
C	1.000*** (0.000)	1.000*** (0.000)	1.000*** (0.000)
	$\bar{p}_i^3$ — Third Price Bid		
DiD Term	2.09E-04 (0.000)	-5.16E-04* (0.000)	-5.48E-04* (0.000)
TIME Dummy	-1.21E-04 (0.000)	9.67E-04*** (0.000)	7.79E-04*** (0.000)
PD Dummy	2.72E-04** (0.000)	-2.32E-04** (0.000)	-2.31E-0.4** (0.000)
Trend	Not included	-2.43E-06*** (0.000)	-2.00E-06*** (0.000)
Interaction Trend PD Dummy	Not included	1.64E-06*** (0.000)	1.66E-06*** (0.000)
Spread	Not included	Not included	-6.06E-06 (0.000)
VIX	Not included	Not included	-8.31E-06 (0.000)
C	1.000*** (0.000)	1.000*** (0.000)	1.000*** (0.000)

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Newey-West standard errors in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1% level, respectively.

Note: This table presents Difference-in-Differences (DiD) regressions based on Equation (4), analyzing the impact of the February 2009 policy change on normalized price bids. Using 920 observations from January 2007 to April 2010, three models are estimated: a standard DiD model; a DiD model including a linear time trend and its interaction with a PD vs. non-PD state variable [Augmented Specification (1)]; and Augmented Specification (1) including also controls for market stress [Augmented Specification (2)]. The key coefficient is the DiD term, indicating the policy's impact. Results show a weakly significant impact on the third price bid, but no significant effect on the first and second price bids.

Table 7: Robustness check: DiD estimates of the impact of top-ups on PDs' quantity and third price bids in Italian six-month Treasury bill auctions

	Baseline Specification	Augmented Specification (1)	Augmented Specification (2)
	$\bar{q}_i^1$ — First Quantity Bid		
DiD Term	0.004*** (0.001)	-0.004 (0.002)	-0.003 (0.002)
TIME Dummy	-0.004*** (0.001)	0.003*** (0.001)	0.004** (0.002)
PD Dummy	0.024*** (0.001)	0.019*** (0.002)	0.019*** (0.002)
Trend	Not included	-1.65E-05*** (0.000)	-1.88E-05*** (0.000)
Interaction Trend PD Dummy	Not included	1.66E-05*** (0.000)	1.66E-05*** (0.000)
Spread	Not included	Not included	0.001 (0.003)
VIX	Not included	Not included	8.71E-06 (0.000)
C	0.007*** (0.001)	0.012*** (0.002)	0.012*** (0.002)
	$\bar{q}_i^2$ — Second Quantity Bid		
DiD Term	0.007*** (0.001)	0.001 (0.002)	0.001 (0.003)
TIME Dummy	-0.002*** (0.001)	0.001 (0.001)	0.002 (0.002)
PD Dummy	0.010*** (0.001)	0.006*** (0.001)	0.006*** (0.001)
Trend	Not included	-6.89E-06*** (0.000)	-9.07E-06** (0.000)
Interaction Trend PD Dummy	Not included	1.24E-05*** (0.000)	1.23E-05*** (0.000)
Spread	Not included	Not included	-0.001 (0.004)
VIX	Not included	Not included	9.36E-05 (0.000)
C	0.005*** (0.000)	0.007*** (0.001)	0.006*** (0.001)
	$\bar{q}_i^3$ — Third Quantity Bid		
DiD Term	0.010*** (0.002)	0.003 (0.003)	0.004 (0.003)
TIME Dummy	-0.003** (0.001)	-0.001E-04 (0.002)	0.003 (0.003)
PD Dummy	0.005*** (0.001)	0.001 (0.002)	0.001 (0.002)
Trend	Not included	-3.49E-06 (0.000)	-1.75E-05** (0.000)
Interaction Trend PD Dummy	Not included	1.32E-05** (0.000)	1.33E-05** (0.000)
Spread	Not included	Not included	0.006 (0.004)
VIX/	Not included	Not included	8.65E-05 ((0.000)
C	0.010*** (0.000)	0.011*** (0.002)	0.010*** (0.002)
	$\bar{p}_i^3$ — Third Price Bid		
DiD Term	3.39E-04** (0.000)	-2.88E-04 (0.000)	-3.11E-04 (0.000)
TIME Dummy	-1.72E-04 (0.000)	8.11E-04*** (0.000)	6.38E-04*** (0.000)
PD Dummy	2.63E-04*** (0.000)	-1.62E-04** (0.000)	-1.61E-04** (0.000)
Trend	Not included	-2.12E-06*** (0.000)	-1.61E-06*** (0.000)
Interaction Trend PD Dummy	Not included	1.37E-06*** (0.000)	1.37E-06*** (0.000)
Spread	Not included	Not included	-1.60E-04 (0.000)
VIX/	Not included	Not included	-4.76E-06 ((0.000)
C	1.000*** (0.000)	1.000*** (0.000)	1.000*** (0.000)

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Newey-West standard errors in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1% level, respectively.

Note: To verify the robustness of results for 12-month bills, regressions (4) was also applied to 6-month bill auctions, which were unaffected by the policy change. This analysis examined whether a statistically significant change in bidding behavior occurred in February 2009 for these unaffected auctions. Using a sample of 950 observations from January 2007 to April 2010, three DiD model specifications were estimated, as for twelve-month bills, including controls for time trends and market stress. Non-significant results for 6-month bills would confirm that the observed effects in 12-month bills are attributable to the policy intervention. As expected, the analyses controlling for the time trend [Augmented specifications (1) and (2)] found no significant change in bidding behavior for 6-month bills, supporting the robustness of the main findings.

Table 8: Estimates of the overall impact of top-ups on PDs' bids in Italian twelve-month Treasury bill auctions: DiD estimates applied to cumulated bid values

	Baseline Specification	Augmented Specification (1)	Augmented Specification (2)
DID Term	0.040*** (0.005)	0.018*** (0.007)	0.019*** (0.007)
TIME Dummy	-0.018*** (0.002)	-0.004 (0.004)	-1.30E-04 (0.005)
PD Dummy	0.037*** (0.003)	0.022*** (0.004)	0.022*** (0.004)
Trend	Not included	-3.15E-05*** (0.000)	-4.78E-05*** (0.000)
Interaction Trend PD Dummy	Not included	4.88E-05*** (0.000)	4.93E-05*** (0.000)
Spread	Not included	Not included	0.008 (0.010)
VIX	Not included	Not included	4.88E-05 (0.000)
C	0.026*** (0.002)	0.036*** (0.004)	0.035*** (0.004)

Source: Italian Ministry of Economy and Finance—Department of Treasury and author's calculations.

Newey-West standard errors in parenthesis. 0. *, ** and *** denote statistical significance at the 10, 5 and 1% level, respectively.

Notes: This table presents Difference-in-Differences (DiD) regressions based on Equation (5), analyzing the impact of the February 2009 policy change on normalized cumulated bid values. Using 920 observations from January 2007 to April 2010, three models are estimated: a standard DiD model; a DiD model including a linear time trend and its interaction with a PD vs. non-PD state variable [Augmented Specification (1)]; and Augmented Specification (1) including also controls for market stress [Augmented Specification (2)].The sample covers 920 observations (each observation corresponds to a demand schedule of three bids, with each bid corresponding to a quantity-price pair) over the period January 2007-April 2010.The key coefficient is the DiD term, indicating the policy's impact. Results provide evidence that the introduction of the TA had a statistically significant impact on the cumulated bid value.

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Annex: Illustrative Example of a Treasury Auction Design with Top-ups

A Treasury auction design with top-ups is a placement design involving selling securities in two rounds: the main auction and the top-up auction.

Main Auction (MA)

The first session is a competitive placement where the Treasury tenders €600 million of Treasury securities. Five dealers participate in the auction, three of which are primary dealers. Each dealer can submit up to a maximum of three bids, defined as quantity-price pairs, with quantities expressed in millions of Euros, measured in terms of the face value of the securities being auctioned, and prices measured as a percentage of the face value (Table A.1). For instance, in her first bid bidder 1 offers to purchase €80 million of Treasury bills at 97.7 percent of its face value, indicating the bidder's willingness to pay Euro 97.7 for every 100 Euro of the bond's face value[1].

Table A.9: Bids submitted by dealers in the main competitive auction.

Bidder (i=1, ..., 5)	Bid (b_i^m, m=1,...,M)	Primary Dealer Dummy (*1=Yes*)	Requested Quantity (q_i^m) *mln Euros*	Offered Price (p_i^m) *% of Face Value*
1	b_1^1	1	80	97.7
	b_1^2	1	100	96.3
	b_1^3	1	130	95.0
2	b_2^1	0	120	97.4
3	b_3^1	1	70	98.0
	b_3^2	1	30	96.0
4	b_1^4	0	50	98.3
5	b_5^1	1	100	97.6
	b_5^2	1	100	96.7
	b_5^3	1	120	95.4

Bids are fulfilled in descending order of price until the amount supplied by the Treasury is exhausted. In the example, the bid priced at 96.3 percent is the last to be accommodated, as it causes the total cumulative demand to reach €620 million, exceeding the Treasury's offered amount of €600 million (Table A.2). However, with only €80 million remaining after fulfilling higher-priced bids, this bid is rationed and only partially served. The bids with the three lowest prices do not receive any allocation. Table A.2 and Figure A.1 illustrate the auction results: bids priced above the clearing price are fulfilled, the bid priced at the clearing price is rationed, and bids below the clearing price are not fulfilled.

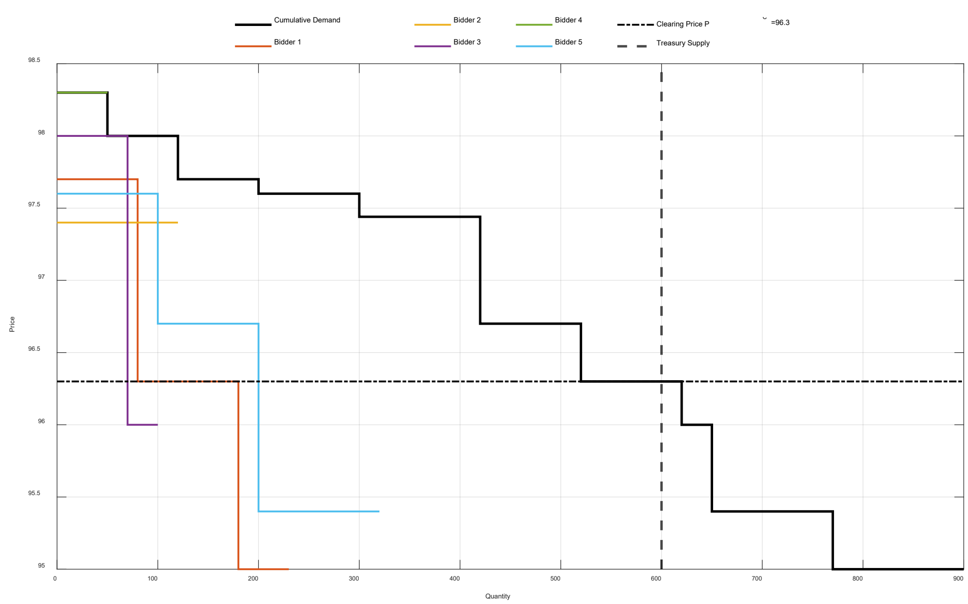
[1] The price of a Treasury security is inversely related to its yield. In the case of zero-coupon bonds, such as Treasury bills, yields are calculated as the difference between the face value and the purchase price, annualized over the maturity period:

$$Yield = \frac{Face\ Value - Price}{Price} \frac{365}{Days\ to\ Maturity}.$$

Table A.10: Bid allocations in the main competitive auction.

Bidder (i)	Bid (m)	Primary Dealer	Requested Quantity (q_i^m)	Offered Price (p_i^m)	Cumulative Quantity $(\sum_i \sum_m q_i^m)$	Allocated Quantity $min(Q^{MA} - \sum_i \sum_m q_i^m, q_i^m)$
4	1	0	50	98.3	50	50
3	1	1	70	98.0	120	70
1	1	1	80	97.7	200	80
5	1	1	100	97.6	300	100
2	1	0	120	97.44	420	120
5	2	1	100	96.7	520	100
1	2	1	100	96.3	620	80
3	2	1	30	96.0	650	—
5	3	1	120	95.4	770	—
1	3	1	130	95.0	900	—

Figure A.1.: Main auction's outcome



Note: The chart illustrates bidders' demand schedules. In real-life Treasury auctions, bidders' demand schedules are stepwise functions rather than continuous ones, as bidders can only submit a discrete number of bids (3 in the example). The offered prices p_i^m define the heights of the steps, while the requested quantities q_i^m determine the length of each step. The cumulative demand curve is derived by sorting individual bids by descending prices and aggregating quantities at each price starting from the highest offered price. The clearing price is determined at the intersection of the cumulative demand and the Treasury's supply. All bids above the clearing price are fully satisfied. Bids at the clearing price may be partially allocated if the quantity requested at that price exceeds the remaining available supply. Bids below the clearing price are not served.

At the end of the auction, the Treasury communicates the summary of the MA outcome. In addition to this summary, Table A.3 reports the average secondary market price of the auctioned securities on the day of the MA (V^{MA}), as this information can be relevant for the TA price, depending on the TA payment rule.

Table A.11: Summary of the main auction's results

Offered Amount (mln. Euros)	600
Requested Amount (mln. Euros)	900
Allocated Amount[1](mln. Euros)	600

Bid-to-Cover Ratio[2]	1.5
Stop-out Price[3]	96.3
Average Winning Price[4]	97.4
Average Secondary Market Price on the day of the MA (V^{MA})	97.2
[1] Cumulative sum of securities allocated to bidders. [2] Cumulative sum of securities requested by bidders, divided by the total offered amount. [3] Clearing price, corresponding to the price of the lowest winning bid [see formula (1)]. [4] Weighted average of winning prices [see formula (2)].	

Top-up

In the second session, the Treasury offers 20 percent of the amount auctioned in the MA, corresponding to €160 million (Q^{RA}). PDs that have submitted at least one winning bid in the MA have the right (but not the obligation) to buy additional securities in the TA. This session is a non-competitive placement, where allocations and prices are pre-determined and depend on the results of the MA and the TA payment rule. In the example, all primary dealers have access to the TA because they all submitted at least one winning bid. The preliminary TA allocation for each admitted bidder is assumed to correspond to the share of the total MA supply allocated to the bidder[2]. If the sum of the preliminary allocations is inferior to the amount offered in the TA, the remaining amount is allocated pro-quota (Table A.4).

Table A.12: Top-up Allocations if all admitted bidders exercise their right to buy

Bidder	Total Allocated Quantity in MA (Q_i)	Allocated Share of Total MA Supply ($s_i = Q_i / Q^{MA}$)	Preliminary TA allocation ($s_i \cdot Q^{TA}$)	Final TA allocation $q_i^{TA} = \left(s_i \cdot \sum_i Q_i / Q^{MA}\right)$
1	80	0.133	16	27.43
3	70	0.117	14	24
5	200	0.333	40	68.57

The TA price depends on the TA payment rule, as discussed in Section III.2 and illustrated in Table A.5.

Table A.13: Top-up price under different payment rules

Average Secondary Market Price on the MA day (*Payment rule based on a price/index exogenous to the auction mechanism*)	MA Stop-out Price (*Payment rule common when the MA adopts a uniform auction design*)	MA Average Winning Price (*Payment rule common when the MA adopts a discriminatory auction design*)
97.2	96.3	97.4

As mentioned in Section III.1, it is reasonable to assume that bidders admitted to the TA will exercise their right to buy only when the TA price is lower than the price of the security in the secondary market at the time of the TA (V^{TA}). This is because the option implicitly granted by the top-up auction has positive value only when the top-up price is lower than the secondary market price.

[2] This allocation rule is the simplest option (see footnote 10).

PUBLICATIONS

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