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Discriminatory versus uniform auctions: Evidence from JGB market

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Discriminatory versus uniform auctions:

Evidence from JGB market*

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Abstract

In 2007, the Japanese government changed the format of auctions for 30-year Japanese government bonds (JGB) from uniform to discriminatory. We examine data before and after this change to assess whether this has lowered the borrowing costs of the Japanese government, in the largest government bond market in the world. As Ausubel et al. (2014) described, the general revenue ranking of uniform and discriminatory auctions is an empirical question. Our empirical result shows that this policy change lowered borrowing costs. We also show that a discriminatory auction lowers the borrowing costs when the value of the bidders to JGB tends to be symmetric, which is consistent with the prediction of Ausubel et al. (2014).

JEL codes: C57; D82; G18; G28

Keywords: Discriminatory auction; Uniform auction; Markup; When-issued markets; Japanese government bond; government costs

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ノンテクニカル・サマリー（Non Technical Summary in Japanese）

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我が国では国債の発行のため、入札（オークション）を実施している。年間で 100 兆円を超える国債が発行されていること等を背景に、発行体である日本政府は資金調達コストを低く抑えながら国債の消化を促すかが重要となる。各国で用いられている入札方式には複数の種類があるが、主に、各社が応札した額がそのまま落札価格となる「コンベンショナル方式（discriminatory auction）」と、高い価格から落札していき発行額に達した最低価格を一律の落札価格とする「ダッチ方式（uniform auction）」が用いられている。我が国では物価連動国債と 40 年国債を除き、コンベンショナル方式が活用されているが、米国などを除き、多くの国でもコンベンショナル方式が用いられている（各国の概要は石田・服部（2020）を参照されたい）。

2020 年にポール・ミルグロム教授とロバート・ウィルソン教授が「オークション理論」でノーベル経済学賞を受賞したことからもわかるとおり、経済学ではオークションについて膨大な研究が蓄積されている。国債市場については、国債の発行規模が巨大であること等を背景に、どのような入札の方式を用いることが発行当局の資金調達コストを引き下げるかどうかについても様々な研究がなされている。もっとも、近年最も重要な研究な理論研究の一つである Ausubel et al. (2014)では、理論研究においてどのような方式が発行体にとって望ましいかについて結論付けることは困難であるとしている。その意味では、オークション方式の優劣は実証上の問題とも考えられ、国債の入札の実証研究は重要性を高めている。

国債の入札については、特に米国がコンベンショナル方式からダッチ方式に変更して以降、各国のデータを用いた実証が活発に行われてきた。もっとも、その内容をみると、ダッチ方式の方が良いという結論を出している研究がある一方で（Nyborg and Sundaresan 1996, Malvey and Archibald 1998 など）、コンベンショナル方式が良いとする研究結果（Marszalec 2017, Mariño and Marszalec 2020 など）、さらに、そもそも両者であまり違いがないという論文（Barbosa et al. 2021）も存在する。このように、実証分析では現時点ではどちらの方式が優れているか結論をつけにくい状況にあることから、我が国への示唆を得るためには我が国のデータを用いた検証が必要といえる。

本稿では、2007 年に 30 年債の発行方式がダッチ方式からコンベンショナル方式に変更されたことに着目し、この政策変更が入札結果に与える影響を分析する。具体的には、本稿では入札方式が変更した前後において、国債の入札結果が有意に変化したかどうかを検証するものであり、米国のデータを用いた Nyborg and Sundaresan（1996）や中国のデータを用いた Barbosa et al.（2021）などと同様、既に確立した手法を用いている。

我が国では、入札前に行われる国債の予約取引（WI 取引）があるが、WI のデータを一貫して取得できる点も、我が国をケースとして用いる強みといえる。米国の主要な先行研究である Nyborg

and Sundaresan（1996）では、入札方式の結果を受けにくい WI とのスプレッド（本稿では「マークアップ」と呼ぶ）をとる手法が用いられている。WI はフォワード取引の一種であるが、これを入札対象の国債に対する需要と解釈すれば、マークアップには入札方式の差異に起因する影響が含まれているはずである。本稿では、マークアップを利用して、入札の変更がなされた 2007 年の前後 3 年のデータを比較して、マークアップが統計的にみて有意に変化したかを検証している。

本稿の主な発見は、30 年債入札がダッチ方式からコンベンショナル方式に変更されたことで、マークアップが統計的に有意に低下したことである。これは、コンベンショナル方式に変更したことで、入札利回りが低下（価格は上昇）し資金調達コストが低下した可能性を示唆する結果である。発行当局の資金調達コストを引き下げたという点で当時の政策変更をサポートする結果と解釈することもできる。

本稿では、上記の結果がロバストであることを様々な検証を通じて確認している。例えば、2007 年のオークションの変更に際し、流動性や発行量が影響を与えている可能性もある。そのため、本稿では国債市場の流動性や発行量、その他の変数も追加をしており、上述の結果がロバストであることを確認している。また、もし 30 年入札の結果が 30 年国債の調達コストに影響を与えているのであれば、入札の変更がない 5 年から 20 年債の結果には影響をあたえていないはずである。筆者らはこの検証をプラセボテストとみなし 5－20 年債の入札において同様の検証を行っているが、これらの入札結果には影響を及ぼしていないという結果を得ている。この結果は、30 年債のマークアップ低下は、オークション方式の変更に起因するというストーリーと一貫性がある結果である。

本稿では Ausubel et al. (2014)で提唱されている「入札参加者の入札財に対する価値が対称的（symmetric）であれば、コンベンショナル方式のほうが望ましい」という仮説についても、検証を行っている。日本の WI データでは、取引の最高価格と最低価格の差を入手することができるため、この利回り差を、非対称性を示す代理変数として用いることで、仮説を検証することができる。本稿はこの仮説と整合的な結論も得ている。その意味で、Ausubel et al. (2014)の仮説を実証する初めての研究という点でも、学術的貢献・新規性がある。

なお、本稿は 2007 年の 30 年債の制度変更を利用した検証であり、現在の金融環境とは異なる可能性がある点には注意が必要である。本稿は入札方式の評価において、筆者が知る限り、我が国のデータを用いた初めての実証研究であり、実際の評価に当たっては複数の分析が必要になろう。特に、我が国では量的質的緩和などの影響があるため、多面的な評価が必要である点に注意が必要である。

参考文献

石田良・服部孝洋（2020）「日本国債入門―ダッチ方式とコンベンショナル方式を中心とした入札（オークション）制度と学術研究の紹介―」PRI Discussion Paper Series (No.20A-06)

1. Introduction

In a government bond auction, the auction is announced, bids are submitted, the government determines the market-clearing price and accepts all bids that exceed the clearing price. In a discriminatory auction (units at different prices), bidders pay what they bid, while in a uniform auction (units at the same price), bidders pay the market-clearing price for the accepted bids. According to Brenner et al. (2009), many governments conduct discriminatory bond auctions while some, such as the US and Switzerland, conduct uniform auctions.[1] A seminal paper by Ausubel et al. (2014) finds that the general revenue ranking of uniform and discriminatory auctions is ambiguous. In their conclusion, they emphasize that "determining the better pricing rule is, therefore, an empirical question" (p. 1391), suggesting that more empirical research is vital for evaluating this auction mechanism. They also indicate that the switch by the US Treasury from a discriminatory to a uniform auction is one experiment that can provide such empirical evidence.

In this paper, we discuss this empirical question in the context of the Japanese government bond (JGB) market. Japan started issuing 30-year JGBs in 1999. Initially, it conducted uniform auctions, but decided to switch the auction format from uniform to discriminatory in April 2007. The government also conducts discriminatory auctions for most 2-year to 20-year JGBs. Although many studies have investigated the switch in US Treasury auctions, to date, no study has investigated this switch in Japan's case, despite it being one of the largest government bond markets in the world.

Irrespective of the auction mechanism, market participants can purchase the auctioned bond before the actual auction. This forward contract in the primary market is called when-issued (WI)

[1] Pycia and Woodward (2020) give a list of examples for auction shift.

in the JGB market. Following the literature, such as Simon (1994), Nyborg and Sundaresan (1996), Malvey and Archibald (1998), and Goldreich (2007), we examine the effect of auction formats on the funding cost by comparing the results in terms of the auction outcomes and WI yields. The strength of the Japanese data is the accessibility of WI data with a wide coverage of brokerage companies.[2] Many papers have already compared discriminatory and uniform auctions, but the WI data are not always available for most countries, except the US. In accordance with Simon (1994) and Nyborg and Sundaresan (1996), we measure the markups, defined as the spread between the highest winning yield at auctions over the WI yield, and examine whether the markups of the auction rate over the WI rate statistically decrease after the government switches from uniform to discriminatory auctions. [3] We find that the markups are lower in the discriminatory auctions, suggesting that the Japanese government can reduce its cost of debt by changing its auction format. Thus, our results show that the discriminatory auction lowers the cost of borrowing for the Japanese government.

Furthermore, we also investigate the important proposition by Ausubel et al. (2014) who state:

[2] The literature such as Lou et al. (2013) and Klingler and Sundaresan (2020) discusses the auction underpricing. In our paper, we take a spread of the auction result over WI. WI is priced, reflecting the expectation of the auction result by market participants; therefore, taking the spread of the auctioned yield with WI enables us to control the systematic underpricing or biases, stemming from JGB action since investors price WI reflecting these potential auction biases.

[3] The previous studies, such as Simon (1994) and Nyborg and Sundaresan (1996), discuss whether the auction shift lowers (increases) the government funding cost (revenue) using the markups computed as the spread of the winning yield at auctions over WI. For example, Nyborg and Sundaresan (1996) point out that "The difference between the 'true value' of the security and the auction average is frequently regarded as a measure of the winner's curse" (p.73), and they use markups to examine whether the uniform auction provides a higher revenue than the discriminatory one.

"in settings with symmetric bidders, the pay-as-bid auction often outperforms" (p. 1366).[4] As far as we know, no literature empirically investigates this important prediction. To address this issue, we use the proxy of the symmetric bidders in JGB auctions to test the prediction of Ausubel et al. (2014). Our data contain the highest and lowest WI prices among bidders in JGB auctions. The WI data is the observable bidder's value before the auction, which reflects how symmetric the value of the bidders in the JGB auction are. By utilizing this proxy, we empirically show that the markups are lower in a discriminatory auction when the value of the bidders tends to be symmetric. This empirical result supports the prediction of Ausubel et al. (2014).

We perform additional tests to confirm that our results are robust. First, we control not only the information about the auction (bid-cover ratios, issuance amount) but also the market condition (market liquidity, volatility, etc.).[5] In particular, since the Japanese government officially announced that it had changed the auction system when the 30-year bond market had matured, we include liquidity and the issue amount as proxies for the market maturity of the 30-year JGB. Second, in our main analysis, we examine the sample period from April 2004 to March 2010, covering the period before and after the policy change for the 30-year JGBs. Since the Japanese government switched the format for 30-year JGBs from uniform to discriminatory auctions in April 2007, the sample period from April 2004 to March 2010 compares three-year uniform with three-year discriminatory auction results. For robustness, we use the data from April 2004 to April 2020, which covers data to the present.

We also conduct the placebo experiment by using the markup of 5-year, 10-year, and 20-year

[4] Hortaçsu et al. (2018) note that bids in US Treasury auction are typically "flat".

[5] Beetsma et al. (2018) discuss that more successful auctions of euro area public debt, as captured by higher bid-to-cover ratios, lead to lower secondary-market yields.

JGBs. The Japanese government has continued to conduct the discriminatory auction for 5-year, 10-year, and 20-year JGBs during the sample periods, therefore a change to the auction format of 30-year JGB should not affect the markup of these JGB variables.[6] By creating a dummy variable, we regress the markup of these JGBs to the 30-year auction dummy and show that the shift of 30-year JGB from uniform to discriminatory does not significantly affect the market of the other JGBs. This result complements our empirical evidence of supporting the discriminatory auction.

We conduct a further robustness check. To provide additional evidence, we conduct difference-in-differences analyses to detect how the auction shift of 30-year JGB affects the markup. Using the 30-year JGB as a treatment group and the 5-, 10- and 20-year JGBs as control groups, we can increase the number of observations for the estimation. Our result confirms that the auction shift significantly lowers the markup. Furthermore, our main analysis relies on WI data since the existing literature using US data takes advantage of WI data for evaluating auction shifts.[7] We also confirm that the auctioned yield of 30-year JGB has become significantly lowered after the auction shift in the comparison of the other auctioned JGBs (5-, 10-, and 20-year JGBs).

Literature review*:* The theoretical literature is inconclusive in discussing which format, uniform or discriminatory, reduces borrowing costs for issuing bonds. Historically, Friedman (1960) argues that the uniform auction is better than the discriminatory auction.[8] The extant

[6] The Ministry of Finance, Japan started to issue 40-year JGB from 2007.

[7] For example, Barbosa et al. (2021) use the China's auction and evaluate the auction shift using change of the winning yield instead of WI. This is because the data for WI market are not available in China's market.

[8] In this paper, we focus on uniform and discriminatory auctions but there are other formats. For example, Abbink et al. (2006) discuss the Spanish type auction, which is a hybrid of the uniform and discriminatory auctions.

empirical literature comparing the uniform auction and the discriminatory one also reflects mixed results.[9] Some studies, such as Simon (1994), Marszalec (2017), and Mariño and Marszalec (2020), support the discriminatory auction. List and Lucking-Reily (2000), Kagel and Levin (2001), and Engelbrecht-Wiggans et al. (2006), who conduct field and experimental studies, imply there is less demand under the uniform auction. In contrast, Tenorio (1993), Umlauf (1993), Malvey and Archibald (1998) and Goldreich (2007) support the value of the uniform auction. Moreover, several papers, such as Nyborg and Sundaresan (1996), Hortaçsu and McAdams (2010), Bonaldi et al. (2015), and Barbosa et al. (2021), report insignificant differences between these auctions.

The closest literature to our paper includes Simon (1994), Nyborg and Sundaresan (1996), Malvey and Archibald (1998), and Goldreich (2007), who explore the implications for the markups of the winning yield at auctions over the WI yield. Although these papers highlight the US case, our paper focuses on Japan's policy change from uniform to discriminatory auctions for only a specific bond: the 30-year bond. There are empirical studies that discuss the auctions related to the JGB, such as Hamao and Jegadeesh (1998), Tsuruoka (2018), and Inaba (2019), but no paper investigates the change in the JGB auction from uniform to discriminatory, as far as we know.

Ausubel et al. (2014) assert that the revenue ranking of uniform and discriminatory auctions is an empirical question. In this respect, using the case of the Japanese market, our results provide empirical evidence that the discriminatory rule improves the performance of the auction through lower financing costs for the government. Furthermore, our empirical results also confirm the

[9] Empirical research on auction types has also been conducted in different industries, such as the electricity market, for example, in Bower and Bunn (2001).

policy implication in Ausubel et al. (2014) that the discriminatory auction often performs better than the uniform auction in auctions with symmetric bidders, although literature has not investigated this yet. By using the WI data among bidders, we show that the symmetric value of the bidders reduces the borrowing cost of the government under discriminatory auction. As such, our results provide empirical evidence that supports the theoretical implications in Ausubel et al. (2014).

Our paper is also related to Pycia and Woodward (2020). This paper discusses noncompetitive auctions in Poland, China, France, Mexico, and the Philippines and mentions that if the share of a noncompetitive auction is higher, either format (discriminatory or uniform) can be revenue dominant, but if the share is lower, both formats are equivalent, or the discriminatory format is revenue dominant. In 30-year JGB, the share of noncompetitive action amounts to approximately 17%, and the ratio of the standard deviation over the mean is approximately 11%, which is the second-highest number among these countries. This prediction is consistent with our finding that the switch from uniform to discriminatory lowers the funding cost of the government.

The remainder of this paper is organized as follows. Section 2 explains fundamental information about the JGB market and the WI market. Section 3 describes how to analyze the switch of the 30-year bond's auction format . Section 4 reports our empirical results including our robustness check and Section 5 concludes.

2. The JGB market

2.1 The JGB market overview[10]

[10] The information and description in this section are based on the annual Debt Management Report, written by

In Japan, the Ministry of Finance (MOF) announces the JGB Issuance Plan at the end of each year. The plan is determined in line with the government budget. In the past few decades, the issuance has been huge. For instance, the initial JGB Issuance Plan for FY 2020, announced in December 2019, indicated an issuance amount of approximately 1.4 trillion dollars. In addition to the initial issuance, the JGB issuance may change due to a supplementary budget need. In response to the COVID-19 crisis, for example, the MOF altered the JGB Issuance Plan for FY 2020 four times: on April 7, April 20, May 27, and December 15, 2020. After these alterations, the MOF increased the issuance by 1.062 trillion dollars above the initial amount.[11] The annual increases in JGBs have led to an enormous amount of outstanding securities, reaching approximately 11.3 trillion dollars in December 2020.[12]

Due to this need to issue a huge amount of government bonds, the JGB market accounts for a large portion of the government bond market worldwide. Figure 1 shows the time series of outstanding government marketable securities from 1990 to 2009. In the 1990s, the US was the largest government bond market worldwide. After 1999, however, the amount of outstanding JGBs has risen rapidly and the JGB market surpassed the US as the largest market. This is an important reason underscoring our focus on the JGB market and the need to examine policy alterations in the government bond auction format at this point in time.

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the MOF.

[11] We calculated the issue amount in USD based on an exchange rate of 103.20 yen per dollar on January 1, 2021. For details on the issuance plans, see https://www.mof.go.jp/english/jgbs/debt_management/plan/index.htm（Ministry of Finance, Japan, date: October 11 2021）

[12] Kameda (2014) analyzes the relationship between budget deficits and interest rates using JGB data.

The MOF in Japan has issued various kinds of bonds including the Treasury discount bill (2-month, 3-month, 6-month, and 1-year), fixed-rate bonds (2-year, 5-year, 10-year, 20-year, 30-year, and 40-year), 15-year floating rate notes (FRNs), and 10-year Treasury inflation-protected securities (TIPS). Similar to the Treasury in the US, the MOF in Japan has used the scheme of primary dealers since October 2004 to ensure the smooth issuance of JGBs and improve liquidity in the market. Currently, there are 21 primary dealers, including financial securities and banks.[13] While primary dealers have some specific obligations, such as bidding and purchasing responsibilities, they can participate in some special auctions, such as buyback auctions and liquidity enhancement auctions.[14][15] In the JGB primary market, however, other financial institutions that are not primary dealers can participate in the JGB auctions, which helps prevent the short squeeze caused by too few participants at the auction.[16] Additionally, since March 2001,

[13] For details about the primary dealers see the press release published by the Ministry of Finance, Japan. https://www.mof.go.jp/about_mof/councils/meeting_of_jgbsp/160713pd.pdf（Ministry of Finance, Japan, date: October 11 2021）

[14] For details about obligations and rights of primary dealers in Japan see the website released by the Ministry of Finance, Japan. https://www.mof.go.jp/english/jgbs/debt_management/pd/index.html（Ministry of Finance, Japan, date: October 11 2021）

[15] Hattori (2019) examines the effect of the liquidity enhancement auctions in the JGB market. Díaz et al. (2006) discuss Spanish Treasury bond market liquidity.

[16] In January 2020, there were 233 financial institutions participating in the JGB auctions. For details about the participants see the press release published by the Ministry of Finance, Japan. https://www.mof.go.jp/english/jgbs/topics/bond/List_of_auction_partcipants.pdf（Ministry of Finance, Japan, date: October 11 2021）

the Japan MOF has offered tap issues, where it auctions government securities issued previously to improve market liquidity. The securities auctioned as tap issues have the same interest rates and maturity dates as the original securities, except the issue dates. The Japan MOF usually announces plans for tap issues in the previous fiscal year. Recently, the MOF has been offering tap issues with from one to four issues annually in super long-term securities.

2.2 The JGB market Auction format[17]

The Japanese government conducts a competitive auction for issuing public debt. According to Brenner et al. (2009), most countries use the discriminatory auction while some use the uniform auction. In Japan's auctions, both mechanisms are used. The Japan MOF generally uses the discriminatory format for most auctions. However, 40-year bonds and 10-year TIPS are issued through uniform auctions. Table 1 presents issued government securities and auction formats in Japan and other countries (the US, UK, Germany, and France). In Europe, many countries use the discriminatory auction rather than the uniform auction. Although the UK also uses both auction formats as well, all government securities except for TIPS are issued through discriminatory auctions. Germany and France use discriminatory auctions for all their government bond auctions. The US, however, uses the uniform auction for all government bond auctions.

The discriminatory auction differs from the uniform format in that the winning bidders pay their winning bid price. In both formats, participants in the auctions are supposed to submit multiple competitive bids that specify yield and quantity. The clearing price is determined at the

[17] The information and description in this section is based on the annual Debt Management Report, written by the MOF.

point at which the aggregate demand function intersects the supply curve of the securities.[18] The auctioneer allocates the securities to the highest competitive bidder and works down through the submitted bids until the bid price reaches the clearing price at the auction. Under the discriminatory auction, winning bidders pay their bid price for all securities they are allocated. In the uniform auction, however, each winning bidder pays the same price equal to the market-clearing price for allocated securities, regardless of their bid price.

2.3 The when-issued (WI) market

The description of when-issued market in Japan

The WI transaction occurs during the period between the auction announcement date and the issue date of the securities. The WI transactions before the auction date began in February 2004 in Japan as a means to issue JGBs smoothly. In the WI market, dealers and investors can buy and sell auctioned securities prior to the auction date. In other words, WI trading can be considered forward contracting for buying an auctioned bond. Participants in the WI market trade on a yield basis.[19] After the auction date of the securities, trading in the market occurs on a price basis. Figure 2 shows WI transactions of the JGB market.

Since potential bidders at the auction will trade them in the WI market, WI yields will reflect the demand for the auctioned securities. Hence, the WI market contributes to providing dealers and investors with valuable information on the auctioned securities, such as yield and price, prior

[18] The supply curve is inelastic at a quantity because the amount of sold securities is announced in advance and does not depend on the auction result.

[19] The 15-year FRNs are traded on a spread (discount margin) basis because we cannot define their compound yields due to floating interest rates.

to the auctions. Nyborg and Sundaresan (1996) examine auction data in the US and claim that the price discovery function of the WI market might alleviate the winner's curse and short squeeze because the market provides information on the auctioned securities and reduces uncertainty on the securities before the auctions.

Previous literature examines the effect of switching auction formats on auctioned yields by utilizing the markup between the auctioned yield and the WI yield. The use of the WI yield as a common reference for the auction result is justified because the WI index, as mentioned above, reflects the demand for the auctioned securities and can be considered to be the expected auction prices. The use of the WI variables is also justified in our case as the WI trading format remained unchanged before and after the JGB auction format switched from uniform to discriminatory in Japan. Moreover, the WI variables are determined prior to the auction and not affected by the format of the JGB auction; therefore, the markup should include a premium for the risk of the winner's curse or bid shading. For example, if the auction is conducted in the discriminatory format and there is uncertainty in the market prior to the auction, the effect of the winner's curse may increase and reduce the demand for the auctioned securities, expanding the markup. In contrast, under symmetric information among market participants, the markup should also include the effect of demand reduction under the uniform auction, expanding the markup. Finally, a direct comparison of winning yields at auctions is inappropriate for this study because they are affected by other variables that vary from auction to auction. Therefore, we need to use the WI yield or spread as a common reference index and calculate the markup.

The advantage of the data availability

In the JGB market, we can obtain WI data before and after the auction changed from uniform

to discriminatory auctions. Table 2 shows features of WI data used at the previous studies which investigate the effect of the auction format on auction results. While Simon (1994) uses data from a daily report, Nyborg and Sundaresan (1996) and Goldreich (2007) use WI tick data provided by interdealer brokers in the US. Although these tick data seem to be better than daily data such as WI JGB data, their tick data does not cover the whole market since the information is provided by only some parts of interdealer brokers. For example, Goldreich (2007) uses data from the GovPX, a company that provides real time data and historical tick data based on information offered by major US brokers. Fleming and Mizrach (2009) states, however, GovPX have covered only two-thirds of the whole market since one major broker has not provided information to the company. In addition, data that Nyborg and Sundaresan (1996) use is provided by only one interdealer broker.

Although many empirical papers have investigated the auction format, WI data is not available for most countries. As we described in the introduction, Barbosa et al. (2021), who focus on auctions in the Chinese government bond market, have a relatively similar motivation to our analysis, although WI data is not available in the Chinese market. Because of the data restriction, Barbosa et al. (2021) use the "normalized auction yield rate" constructed as the weighted average winning rate at the auction minus the corresponding market bond yield one day before the auction, and exploit the effect of the experiment on the normalized yield. For Japan, on the other hand, we have access to WI data that covers most interdealer brokers in Japan for a long period. The Japanese Securities Dealers Association (JSDA) receives data from 18 major security companies in Japan and has offered it every business day on its homepage since August 2002. In this data, WI yield data have also been available since February 2004, when WI transactions started. Moreover, we emphasize our WI data covers the highest and lowest price, which reflects the symmetry of the bidder's opinion toward the JGB market and makes it possible to examine the

hypothesis cast by Ausubel et al. (2014).

3. Analysis on the switch of the 30-year JGB auction format.

3.1 History of the JGB auction switch

As we have described, the Japanese government mainly uses discriminatory auctions for issuance of JGBs. However, the government has changed the auction format from the uniform auction to the discriminatory auction. The government used a uniform auction when it started to issue 30-year bonds in 1999 but, in April 2007, the government switched from uniform to a discriminatory auction format, after considering the opinions of JGB market participants.[20] However, some JGBs are still issued through uniform auctions. For instance, the government has continued to issue 40-year bonds by uniform auctions since Japan's MOF started to issue such securities in November 2007. In addition, 10-year TIPS have been issued mainly through uniform auctions except in three cases.[21] In the appendix, we explain the government scheme which allows them to exchange opinions with market participants and the background of the auction format change for 30-year JGBs.

3.2 Data

[20] For details regarding opinions from market participants, see the minutes of the Meeting of the JGB Market Special Participants (17th round) released by the Ministry of Finance, Japan.
https://warp.ndl.go.jp/info:ndljp/pid/1022127/www.mof.go.jp/english/bonds/minutes/17th070907.pdf
（Ministry of Finance, Japan, date: 11 October 2021）

[21] In auctions for 10-year TIPS, the Japan MOF used the discriminatory format for auctions on August 2007, February 2008, and August 2008. We exclude TIPs because WI data are not available.

We obtain auction data from the Japan MOF website. The MOF releases auction results including an issuance amount, quantity of bids, the quantity of accepted bids, price, and yield, such as the lowest price, the winning yield, and the spread at the auction (for 15-year FRNs). [22]

The WI data are from the "Reference Statistical Prices [Yields] for OTC Bond Transactions" posted by the JSDA. As we described in the section 2, the JSDA collects bond prices and coupons daily from 18 main securities firms and provides securities-level data on its website. The statistics are based on the quotations reflecting the execution prices on over-the-counter (OTC) securities transactions and posted every business day. Data are based on quotations at 3:00 PM on the day. [23] We obtain the other data, such as bond volatilities and bid ask spread, from Bloomberg.

Based on previous literature, such as Simon (1994), Nyborg and Sundaresan (1996), Marlvey and Archibald (1998), and Goldreich (2007), we use as a dependent variable the markup that is the winning yield at auctions minus the WI yield. In our study, we use the highest winning yield at the auction (winning yield) to calculate the markup. As mentioned, the WI variables are not affected by whether the auction is conducted as uniform or discriminatory. Hence, we can consider that the markup includes a risk premium at the JGB auctions. If the switch of the auction format from uniform to discriminatory reduces the markup, the switch would lower the MOF borrowing costs.

Our focus is on the 30-year bonds auctions where the MOF switched the auction format from uniform to discriminatory. In addition, since the WI transaction data are available only after

[22] Average price and yield are available if the auction format is discriminatory. However, yield is not available if the securities are FRNs. The highest yield is not available if the securities are FRNs.

[23] For details, see "System for Dissemination of Reference Statistical Prices (Yields) for OTC Bond Transactions," Japanese Securities Dealers Association, http://www.jsda.or.jp/en/statistics/bonds/prices/files/baisanntiseidogaiyou.pdf (Japanese Securities Dealers Association, date: 11 December 2021)

March 2004 in Japan and the MOF changed the auction format at 30-year bonds in April 2007, we first focus on an approximate six-year.[24] This period includes only 12 uniform auctions due to the availability of WI data; therefore, we have to use a small sample. Figure 3 diagrams our empirical study.

3.3 Methodology

Our objective is to examine whether the switch from uniform to discriminatory auctions lowers the borrowing costs of the government. Following Simon (1994) and Goldreich (2007), we regress the markups on the dummy variable for auction technique and the control variables as follows:

$$Markup_t = \alpha + \beta AuctionDummy_t + \gamma Controls_t + \epsilon_t \quad (1)$$

where $Markup_t$ is the markup defined as the highest winning yield at auctions minus the WI yield at time t. $AuctionDummy_t$ is a dummy variable that equals one if the auction is conducted through the discriminatory format at time t and zero if the auction is conducted through the uniform format. A negative coefficient β indicates that the switch from the uniform to the discriminatory auction lowers the borrowing costs for the MOF.

$Controls_t$ represent the control variables that include bond volatility and bid to cover ratio. We compute the volatility as a standard deviation of the 30-year JGB. Because Simon (1994) calculates volatilities from the observations at three business days prior to the auction date, we

[24] The MOF did not conduct a 30-year bond auction in March 2004.

also compute a standard deviation using three business days. The bid to cover ratio is defined as the amount of the bids received in the auction divided by the amount sold.

Some previous research has focused on auction choice and endogeneity. For example, Gupta et al. (2020) examined India's two-stage auction design and controlled for the endogeneity of auction choice by switching regression models. However, unlike other governments previously examined in the literature, the Japanese government only changed the auction format once, and after the transition in April 2007, they did not change it in response to any market circumstances. Therefore, we basically assume that the auction format is predetermined by the spread of WI and the auctioned yield.

Ausubel et al. (2014) assert that "in settings with symmetric bidders, the pay-as-bid auction often outperforms" (p. 1366). First, they show that discriminatory auction dominates uniform auction under symmetric valuations and the flat demand for the auctioned good among investors.[25] Second, they also show that discriminatory outperforms uniform under symmetric information settings with decreasing linear marginal utility. For testing the effect of symmetric valuations on the performance of the auction formats, we conduct the estimation as follows:

$$Markup_t = \alpha + \beta Auction_t + \gamma Auction_t \cdot Symmetric_t + \delta Controls_t + \epsilon_t \qquad (2)$$

where $Symmetric_t$ is a proxy of the symmetric value of the bidder. As the proxy of the symmetric value of the bidder to the JGB auction, we use the spread between the highest WI price and the

[25] Ausubel et al. (2014) investigate the symmetric valuation among the bidder, but the other literature pursue the different aspect of asymmetry in mutl-unit auctions. For example, Sade et al. (2006) argue asymmetry in bidders' capacity constraints plays an important role in inhibiting collusion and promoting competitive outcomes in multiunit auctions.

lowest one (WI price gap), which reflects the observable value of most broker-dealers before the government conducts the auction. Our conjecture is that γ is positive because when the bidder's value tends to be symmetric, the outcome of the discretionary should be better (the markup tends to be lower under the discriminatory auction).

4. Empirical results

4.1 The estimation based on Equation (1)

The regression results are presented in Table 3. This reflects data on 30-year bonds in the period of the first six years, from April 2004 to March 2010. Column (1) provides the result of the regression of markup on the auction dummy and shows that the coefficient of the auction dummy is negative and statistically significant at the 5% level. This implies that markups of the winning yield over WI yields are 1.78 basis points lower at the discriminatory auction than the uniform auction.

Columns (2), (3), and (4) show the results of regressions with the control variables. In Column (2), bond volatility is included to control the effect of uncertainty about the value of the securities on bidders' behaviors. In Column (3), we add the bid to cover ratio at the auction, which captures the extent of competition at the auction. In Column (4), we include the auction dummy, volatility, and bid to cover ratio. Although these specifications indicate lower significance than column (1), they show that the coefficient of the auction dummy is negative and statistically significant at the 10%. In terms of the control variables, the coefficients of the bid to cover ratio and the bond volatility are not statistically significant.

These findings suggest that the switch from the uniform auction to the discriminatory auction for the 30-year JGBs lowers the borrowing costs for the MOF. Since the winning yields do not

increase but rather lower due to the shift to the discriminatory auction, the revenue the MOF receives from the auctions increase due to the change in auction format.

4.2 The estimation based on Equation. (2)

Table 4 shows the results when we conduct the regression based on Equation (2). As in the previous results, we use the data in the first 6 years (from April 2004 to March 2010) and estimate four specifications: specification (1), without any other control variables, and specifications (2) - (4) with control variables.

First, all the specifications show that coefficients of discriminatory auction dummy are significantly negative as with the case of Equation (1), which implies that the effect of the auction format switch is robust. They also show a lower significance level than the results under Equation (1). Second, we find that the coefficients of the interaction between discriminatory auction dummy and WI price gap are positive and statistically significant at the 1% level. This result implies that an asymmetricity among auction bidders makes discriminatory auction inefficient in terms of revenue, which is consistent with the argument by Ausubel et al. (2014). In addition, the results on Equation (2) indicate relatively higher R-squared, which implies that these specifications are better in terms of fitness of the models for the data.

4.3 **Robustness check**

(i) Longer period

We conduct regressions with an expanded period: the period to date (April 2004 to a recent auction, April 2020). Although we use the same specifications discussed in Section 3, we add a time-trend as a control variable as in Simon (1994), because the yield in the JGB market reflects a

decreasing time trend in the long run, especially after QQE (the 30-year yield was almost 0% in 2016).

Table 5 provides the regression results in the period to date (April 2004 to April 2020). First, we conduct the regression using Equation (1). In Columns (1), we regress the markup on the auction dummy and time-trend in the period. The coefficients of the auction dummy are negative and statistically significant at the 10% level. In Columns (2), we add control variables (volatility and bid to cover). Even if we control these variables, the coefficients of the auction dummy are negative and significant. Overall, as in the baseline regression, these results indicate that the change of auction format from uniform to discriminatory reduces the markup by approximately 1.4 basis point to 1.6 basis points and contributes to an increase in the MOF's revenue.

Next, we regress under Equation (2) in the expanded period and check the heterogeneity of the effect of the auction switch with respect to asymmetricity of the JGBs valuation. Column (3) and (4) show the results. As with the previous regressions, we use the two kinds of specifications, and find that both specifications in the expanded period show that the coefficients of the discriminatory auction dummy are significantly negative, which indicates the robustness of our finding described so far. With respect to the interaction term between the auction dummy and WI price gap, we confirm that both specifications indicate a positive coefficient, and they are statistically significant at the 5% or lower level, which is also consistent with the baseline result and the argument by Ausubel et al. (2014).

For control variables, we have some references. The coefficients of the time-trend variable are positive in all columns and statistically significant in all the specifications. With respect to bond volatility, both coefficients are positive, which is consistent with previous studies. The results imply that uncertainty in the JGB market after 2010 causes bidders to demand higher yields.

(ii) Control for the amount and liquidity in the 30-year JGB market

Considering that the MOF switched the auction format because of the improvement of the 30-year JGB market, we controlled for the amount issued at each auction and liquidity (bid-ask spread) as a robustness check.[26] Table 6 shows the results with the two cases of the period: (i) from April 2004 to March 2010 (columns (1) and (2)) and (ii) from April 2004 to April 2020 (columns (3) and (4)). Period (i) corresponds to the baseline case, and period (ii) corresponds to the expanded period. All the specifications show that the coefficients of the auction dummy are negative and significant at the 10% or lower levels. In addition, the coefficients of the interaction term are positive and statistically significant as with our previous results. With respect to the two additional control variables, bid-ask spread and log of issue amount, none of the specifications had significant coefficients. These findings imply that our result is robust even when we control for the proxy variables concerning improvement of the market.

(iii) The placebo experiment (using 5- to 20-year JGBs)

Since the Japanese government changed the auction format of 30-year JGB, this shift significantly reduced the markup of 30-year JGB. From a different point of view, the auction dummy should not affect the markup of other JGBs. From April 2004 to the present, the Japanese government has continued to conduct the discriminatory auction for 5, 10 and 20-year JGBs: therefore, to regress the markup of these bonds on the auction dummy should be interpreted as the

[26] In terms of the amount issued, we use a logarithm of the issuance amount in the auction in the same way as Barbosa et al. (2021). Although we also regress by using the exact value of the issuance amount rather than the logarithm, we find that the results are same as the case of the regression using the logarithm.

placebo experiment to provide more convincing evidence of the auction shift.

In this placebo experiment, we use the two periods: (i) from April 2004 to March 2010 and (ii) from April 2004 to April 2020 based on Equation (1). Additionally, we also use all the control variables, including issuance amount and bid ask spread. Table 7 shows the estimation result when we use the data of 5, 10 and 20-year JGB. This table shows that the auction dummy has no significant effect on the markup, which supports our key findings.

(iv) The Difference-in-Differences

For a further robustness check, we conduct the difference-in-differences analysis using data from 5-, 10-, 20- and 30-year JGBs. In this study, we can use not only the markup based on WI as a dependent variable but also the winning yield. Because the MOF issues JGB on a monthly and quarterly basis, we can investigate how the winning yield of 30-year JGB changes after the auction change by comparing the auction results of 5-, 10-, 20- and 30-year JGBs. The existing research on US data relies on WI data to evaluate auction shifts. However, some literature uses the winning yield without the WI price (see Barbosa et al. (2021)); therefore, our empirical result should even be convincing if we can confirm the robust result with the winning yield without the WI price. Following Du et al. (2018), we conduct regression based on the following models:

$$Markup_{it} = \alpha_i + \beta_1\, 30\, JGB_i \cdot Post\ Apr\ 2007_t + \gamma_1\, 30\, JGB_i + \gamma_2\, Post\ Apr\ 2007_t + \delta Controls_{it} + \epsilon_{it} \quad (3)$$

$$Markup_{it} = \alpha_i + \beta_1 30\, JGB_i \cdot Post\ Apr\ 2007_t + \beta_2 30\, JGB_i \cdot Post\ Apr\ 2007_t \cdot Symmetric_{it} + \gamma_1\, 30\, JGB_i + \gamma_2\, Post\ Apr\ 2007_t + \delta Controls_{it} + \epsilon_{it} \quad (4)$$

where $30\,JGB_i$ is a dummy variable that takes value one if the bond is 30-year JGBs and zero otherwise, and $Post\ Apr\ 2007_t$ is a dummy variable that takes value one if the auction is conducted after the treatment (after April 2007) and zero otherwise. i denotes the types of bonds (5-, 10-, 20- and 30-year JGBs), and our model includes fixed effects.[27] As with the case of previous specifications, we conjecture that β_1 should be negative and β_2 should be positive. We also use the winning yield as a dependent variable in this estimation to check whether our result depends on WI data.

The results are shown at Table 8. Columns (1) to (4) are the regression where we use markup as a dependent variable. Columns (1) and (2) are based on Equation (3), and Columns (3) and (4) are based on Equation (4). All specifications except for Column (2) show that β_1 is negative and statistically significant at the 10% or lower level. For the symmetricity effect, Columns (3) and (4) show that β_2 is positive and statistically significant at the 1% level. These results show that the auction change reduced the markup by approximately 2 to 3 basis points and that the effect becomes small if the WI price gap is large. This makes our baseline results more robust.

When we use the winning yield as a dependent variable, the results are similar. Columns (5) to (8) show the results, Columns (5) and (6) are based on Equation (3), and Columns (7) and (8) are based on Equation (4). All specifications indicate that β_1 is negative and β_2 is positive, and these results are statistically significant at the 10% or lower level. Thus, this implies that our key findings are robust even if we use the winning yields rather than markups.

[27] We drop fixed effects for 30-year JGBs due to the multicollinearity with the 30 JGB dummy.

5. Conclusion

We study whether switching the auction format from uniform to discriminatory contributes to reduced borrowing costs by examining data on 30-year JGBs whose auction format changed in April 2007. We find that the markups, defined as the spread between the winning yield at auctions and WI yield, were lower in the discriminatory auction than the uniform one, suggesting that the Japanese government can reduce borrowing costs by switching the auction format from uniform to discriminatory. We also show that the effect of the auction switch has a heterogeneity with respect to asymmetric valuation among JGB's traders. This finding is consistent with the argument by Ausubel et al. (2014). Our result is robust when we conduct regressions in the case of a longer period or with additional control variables. In addition, our placebo experiment shows that in the auction of other JGBs, the auction dummy variable does not affect the auction results, which makes our baseline results more robust. Moreover, our difference-in-differences analysis using markup and winning yields as dependent variable indicates the consistent results with our baseline regression.

As Ausubel et al. (2014) emphasize, determining the better pricing rule is an empirical question. We discuss the revenue ranking in the uniform auction and the discriminatory auction by considering Japan's case, one of the largest government securities' markets in the world. Our contribution is to the ranking of the auction formats empirically and to show that discriminatory auction dominates uniform auction in large and matured government securities markets with symmetric valuation for the securities among investors and traders.

Since our paper is the first empirical paper that uses the Japanese data, therefore further analysis is need for an actual application. Our analysis focuses on a one-shot change in 30-year JGB in 2007. Especially, the BOJ has conducted an unprecedented monetary easing called QQE

right now. Our empirical results can provide the justification of past policy change, but more empirical papers which utilize JGB data should be required for obtaining the policy implication.

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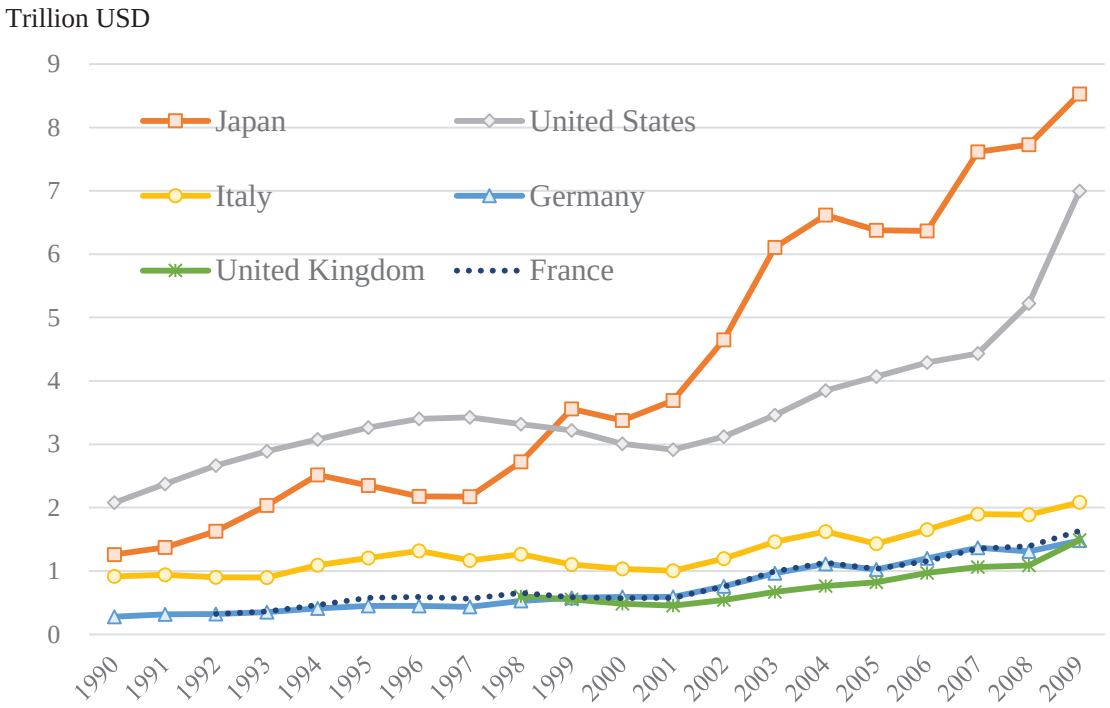
Figure 1. Time series of outstanding amounts of government marketable securities



Source: OECD Statistics
Note: The data show central government debts.

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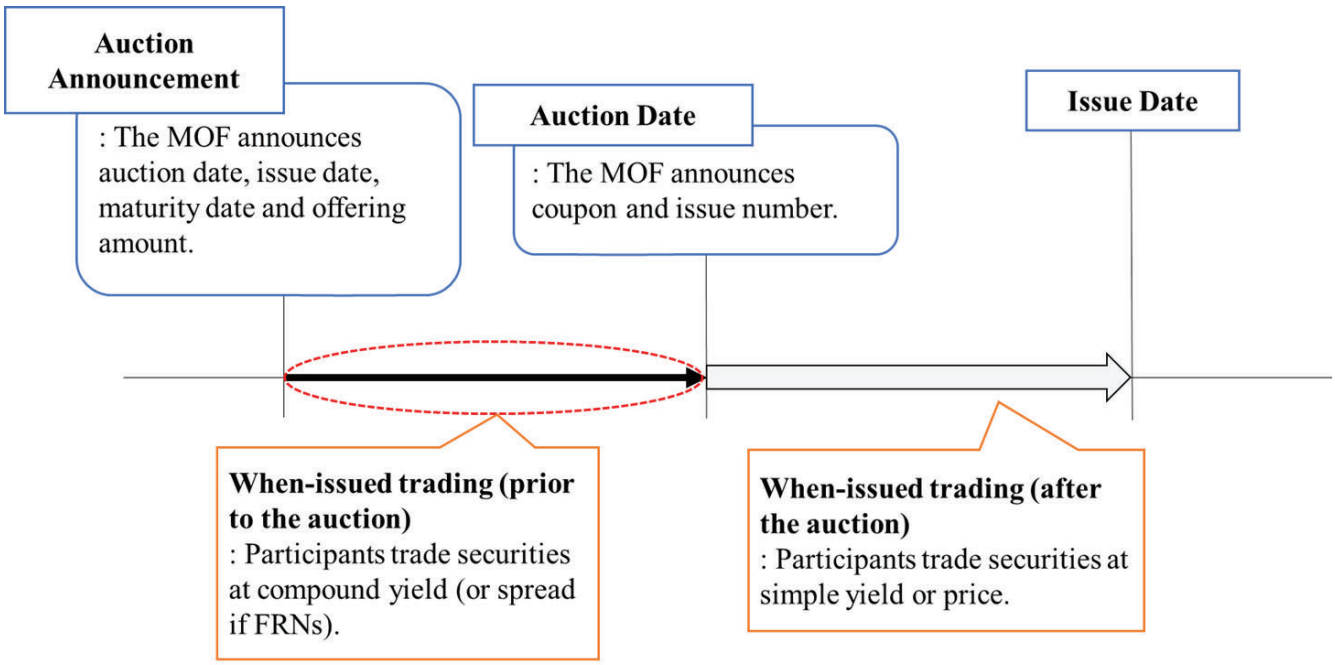
Figure 2. When-issued transaction



Source: "Debt Management Report 2019", Financial Bureau, Ministry of Finance, Japan.

Table 1. Government bond issuance in Japan and foreign countries

	Japan	United States	United Kingdom	Germany	France
Short-term	About 2-month 3-month 6-month 1-year	4-week 8-week 13-week 26-week 52-week Cash Management Bill	1-month 3-month 6-month 12-month	3-month 5-month 6-month 9-month 11-month 1-year	Less than or equal to 1-year
Medium-term	2-year 5-year	2-year 3-year 5-year 7-year	From 1 to 7-year	2-year 5-year 7-year	From 2 to 8-year
Long-term	10-year	10-year	From 7 to 15-year	10-year	From 8 to 50-year
Super Long-term	20-year 30-year 40-year	20-year 30-year	From 15 to 55-year	15-year 30-year	
Others	Treasury Inflation-Protected Securities (10-year)	Treasury Inflation-Protected Securities (5-year, 10-year, 30-year) Floating Rate Notes (2-year)	Treasury Inflation-Protected Securities (From 5 to 55-year)	Treasury Inflation-Protected Securities (5-year, 10-year, 30-year)	Treasury Inflation-Protected Securities (From 2 to 30-year)
Auction Format	Discriminatory Auction (except for 40-year and TIPS) Uniform Auction (40-year, TIPS)	Uniform Auction	Discriminatory Auction (except for TIPS) Uniform Auction (TIPS)	Discriminatory Auction	Discriminatory Auction

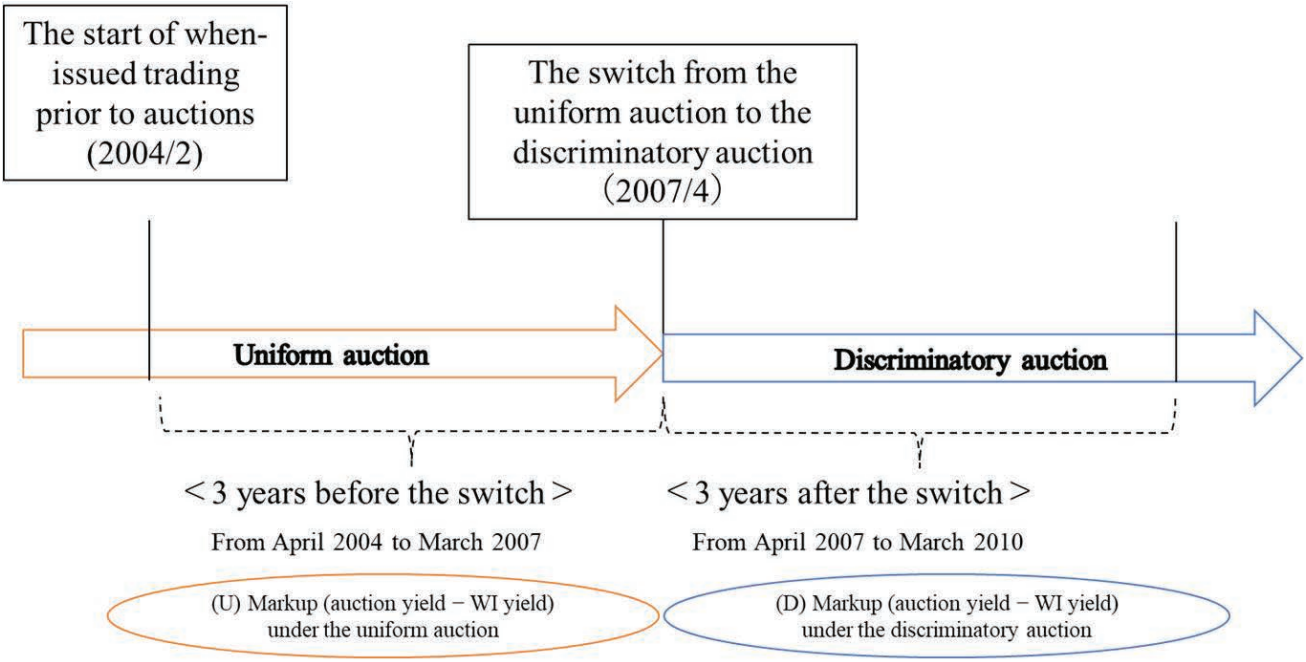
Source: “Debt Management Report 2020”, Financial Bureau, Ministry of Finance, Japan.
Note: Cash management bills are issued for a need for short-term finance.

Table 2. Features of WI data at the previous studies

Literature	Source	Details
Goldreich (2007)	GovPX	GovPX provides real-time WI data and historical tick data based on market information from interdealer brokers. Offered data includes bid and offer prices, quantity, trade prices, and its volumes. In the 2000s, GovPX received market information from major interdealer brokers except for one, and therefore GovPX's information covered about two-thirds of the whole market (Fleming and Mizrach, 2009). Goldreich (2007) use WI price data from a half-hour before the auction time (1:00 PM) to a half-hour after the auction time.
Nyborg and Sundaresan (1996)	market data from Garban. Inc.	Garban. Inc. was one of the major interdealer brokers in the US Treasury market in the 1990s. Offered data includes volume, the number of transactions, and yields. Nyborg and Sundaresan (1996) examine the sample period from July 1992 to August 1993 and calculate markups by using WI transaction data, focusing on from 12:00 PM to 3:00 PM.
Simon (1994)	"Quotations on United States Government Securities"	This is a daily report published by the Federal Reserve Bank of New York. Simon (1994) use WI yield measured at the close of business on auction dates. Some of the WI yields are measured at the opening on the day after the treasury auction.

Note: This figure describes features of WI data used in previous studies that investigate the effect of the auction switch on auction results.

Figure 3. Image of our empirical study



If (D) is lower than (U), the switch contributes to reducing borrowing costs for the MOF.

Table 3. Results of OLS regression based on Equation (1) (First 6 years: Apr 2004 - Mar 2010)

	2004.4 - 2010.3			
	(1)	(2)	(3)	(4)
Auction dummy	-0.0178 **	-0.0216 *	-0.0232 *	-0.0248 *
	(0.0077)	(0.0111)	(0.0115)	(0.0131)
Volatility		-0.3183		-0.2256
		(0.3497)		(0.3400)
Bid to cover			0.0095	0.0076
			(0.0111)	(0.0111)
Constant	0.0043	0.0136	-0.0242	-0.0120
	(0.0038)	(0.0114)	(0.0338)	(0.0361)
R-squared	0.0684	0.0851	0.0899	0.0974
# Obs	28	28	28	28

Note: This table shows the regression result based on Equation (1). The period is from April 2004 to March 2010. The dependent variable is a markup, which is the spread of the winning yield at auctions over the WI rate at auction days. The auction dummy is a dummy variable that takes value one if the auction is a discriminatory price auction and zero if the auction is a uniform price auction. Volatility is the standard deviation of yields on the previously issued 30-year bonds over the three business days prior to each auction. Bid to cover is the ratio of the quantity of tenders to supply by the MOF in each auction. Newey-West standard errors are in parentheses, and note as follows: *, ** and *** stand for 10%, 5% and 1% significance, respectively.

Table 4. Results of OLS regression based on Equation (2) (First 6 years: Apr 2004 - Mar 2010)

	2004.4 - 2010.3			
	(1)	(2)	(3)	(4)
Auction dummy	-0.0347 **	-0.0377 **	-0.0422 ***	-0.0429 **
	(0.0128)	(0.0144)	(0.0151)	(0.0160)
Auction dummy × WI price gap	1.3233 ***	1.3055 ***	1.3730 ***	1.3598 ***
	(0.3964)	(0.3868)	(0.3987)	(0.4013)
Volatility		-0.2620		-0.1268
		(0.2777)		(0.2419)
Bid to cover			0.0120	0.0110
			(0.0107)	(0.0106)
Constant	0.0043	0.0119	-0.0317	-0.0247
	(0.0039)	(0.0096)	(0.0323)	(0.0330)
R-squared	0.2510	0.2622	0.2850	0.2873
# Obs	28	28	28	28

Note: This table shows the regression result based on Equation (2). The period is from April 2004 to March 2010. The dependent variable is a markup, which is the spread of the winning yield at auctions over the WI rate at auction days. The auction dummy is a dummy variable that takes value one if the auction is a discriminatory price auction and zero if the auction is a uniform price auction. The WI price gap is the spread of the highest WI price over the lowest WI price. Volatility is the standard deviation of yields on the previously issued 30-year bonds over the three business days prior to each auction. Bid to cover is the ratio of the quantity of tenders to supply by the MOF in each auction. Newey-West standard errors are in parentheses, and note as follows: *, ** and *** stand for 10%, 5% and 1% significance, respectively.

Table 5. Results of OLS regression based on Equations (1) and (2) (Apr 2004-Apr 2020)

	2004.4 - 2020.4			
	(1)	(2)	(3)	(4)
Auction dummy	-0.0158 *	-0.0144 *	-0.0299 ***	-0.0279 **
	(0.0085)	(0.0083)	(0.0114)	(0.0123)
Auction dummy × WI price gap			0.9479 ***	0.9007 **
			(0.3321)	(0.3611)
Trend	0.1474 **	0.1651 **	0.2632 ***	0.2714 ***
	(0.0730)	(0.0637)	(0.0961)	(0.0946)
Volatility		0.3010 *		0.2198
		(0.1598)		(0.1402)
Bid to cover		0.0011		0.0003
		(0.0036)		(0.0032)
Constant	-0.1450 *	-0.1751 ***	-0.2624 ***	-0.2779 ***
	(0.0741)	(0.0640)	(0.0974)	(0.0954)
R-squared	0.0425	0.0634	0.1240	0.1354
# Obs	137	137	137	137

Note: This table shows the regression result based on Equations (1) and (2). The period is from April 2004 to April 2020. The dependent variable is a markup, which is the spread of the winning yield at auctions over the WI rate at auction days. The auction dummy is a dummy variable that takes value one if the auction is a discriminatory price auction and zero if the auction is a uniform price auction. The WI price gap is the spread of the highest WI price over the lowest WI price. Trend is a time-trend. Volatility is the standard deviation of yields on the previously issued 30-year bonds over the three business days prior to each auction. Bid to cover is the ratio of the quantity of tenders to supply by the MOF in each auction. Newey-West standard errors are in parentheses, and note as follows: *, ** and *** stand for 10%, 5% and 1% significance, respectively.

Table 6. Results of OLS regression (adding issuance amount and bid ask spread)

	2004.4 - 2010.3		2004.4 - 2020.4	
	(1)	(2)	(3)	(4)
Auction dummy	-0.0284 **	-0.0427 ***	-0.0158 *	-0.0286 **
	(0.0129)	(0.0143)	(0.0087)	(0.0125)
Auction dummy × WI price gap		1.3654 ***		0.8853 **
		(0.4562)		(0.3687)
Trend			0.1238 **	0.2395 ***
			(0.0605)	(0.0883)
Volatility	-0.1528	-0.1332	0.3251 **	0.2377 *
	(0.3754)	(0.2809)	(0.1583)	(0.1388)
Bid to cover	0.0080	0.0109	0.0022	0.0009
	(0.0112)	(0.0109)	(0.0037)	(0.0033)
Bid ask spread			0.1392	-0.0348
			(0.2694)	(0.2840)
Log of issue amount	0.0414	-0.0039	0.0197	0.0115
	(0.0301)	(0.0460)	(0.0192)	(0.0168)
Constant	-0.3696	0.0086	-0.3083 **	-0.3462 **
	(0.2670)	(0.3920)	(0.1494)	(0.1471)
R-squared	0.1051	0.2874	0.0700	0.1378
# Obs	28	28	137	137

Note: This table shows the regression result based on Equations (1) and (2). We use two periods: from April 2004 to March 2010 ((1) and (2)) and from April 2004 to April 2020 ((3) and (4)). The dependent variable is a markup, which is the spread of the winning yield at auctions over the WI rate at auction days. The auction dummy is a dummy variable that takes value one if the auction is a discriminatory price auction and zero if the auction is a uniform price auction. The WI price gap is the spread of the highest WI price over the lowest WI price. Trend is a time-trend. Volatility is the standard deviation of yields on the previously issued 30-year bonds over the three business days prior to each auction. Bid to cover is the ratio of the quantity of tenders to supply by the MOF in each auction. Bid ask spread is the quoted bid-ask spread of the previously issued 30-year bonds. The log of the issue amount is the logarithm of the issuance amount of each auction. We do not control the bid ask spread in the first six years because of multicollinearity. Newey-West standard errors are in parentheses, and note as follows: *, ** and *** stand for 10%, 5% and 1% significance, respectively.

Table 7. Results of OLS regression based on Equation (1): 5 to 20-year JGBs

	2004.4 - 2010.3			2004.4 - 2020.4		
	20-year	10-year	5-year	20-year	10-year	5-year
	(1)	(2)	(3)	(4)	(5)	(6)
Auction dummy	0.0064	0.0046	0.0050	0.0066	-0.0001	-0.0007
	(0.0112)	(0.0076)	(0.0095)	(0.0093)	(0.0074)	(0.0107)
Trend				-0.0018	0.2826 ***	0.1934 *
				(0.0474)	(0.0669)	(0.0996)
Volatility	-0.0365	-0.2179	0.5546	0.1580	0.2779 **	0.4577
	(0.3017)	(0.2022)	(0.5477)	(0.1675)	(0.1267)	(0.3308)
Bid to cover	-0.0083	-0.0173 **	-0.0009	-0.0057 *	-0.0124 ***	-0.0029
	(0.0065)	(0.0074)	(0.0051)	(0.0029)	(0.0038)	(0.0028)
Bid ask spread	-9.6416		13.4081 *	-0.2686	0.6742	1.0361 *
	(15.1396)		(7.9113)	(0.3555)	(0.4555)	(0.6154)
Log of issue amount	0.0043	-0.0423	-0.0559	0.0002	-0.0015	-0.0183
	(0.0258)	(0.0577)	(0.0447)	(0.0166)	(0.0242)	(0.0180)
Constant	0.1800	0.4743	0.2772	0.0174	-0.2571	-0.0350
	(0.4647)	(0.5639)	(0.5663)	(0.1749)	(0.2356)	(0.2589)
R-squared	0.0764	0.0989	0.0911	0.0554	0.1485	0.1275
# Obs	72	48	72	193	169	193

Note: This table shows the regression result based on Equation (1). We use two periods: from April 2004 to March 2010 ((1) - (3)) and from April 2004 to April 2020 ((4) - (6)). The dependent variable is a markup, which is the spread of the winning yield at auctions over the WI rate at auction days. The auction dummy is the same dummy variable as we use in the previous regressions, which the value one in the period when the auction on 30-year JGB is discriminatory (until March 2007) and zero in the period when the auction is uniform (after April 2007). Trend is a time-trend. Volatility is the standard deviation of yields on the previously issued bonds over the three business days prior to each auction. Bid to cover is the ratio of the quantity of tenders to supply by the MOF in each auction. Bid ask spread is the quoted bid-ask spread of the previously issued bonds. The log of the issue amount is the logarithm of the issuance amount of each auction. Newey-West standard errors are in parentheses and are noted as follows: *, ** and *** stand for 10%, 5% and 1% significance, respectively.

Table 8. Results of OLS regression: Difference-in-difference using 5- to 30-year JGBs

Dependent variable	Markup: Winning yield minus WI yield				Winning yield			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
30-JGB dummy × Post Apr 2007	-0.0217 *	-0.0174	-0.0386 ***	-0.0345 **	-0.1725 ***	-0.1246 *	-0.2190 ***	-0.1563 *
	(0.0121)	(0.0127)	(0.0147)	(0.0156)	(0.0605)	(0.0666)	(0.0745)	(0.0862)
30-JGB dummy × Post Apr 2007 × WI price gap			1.3233 ***	1.3184 ***			6.1052 **	6.4271 **
			(0.4217)	(0.4382)			(2.5460)	(2.6160)
30-JGB dummy	0.0031	-0.0017	0.0031	-0.0053	1.5434 ***	1.3516 ***	1.5278 ***	1.3362 ***
	(0.0059)	(0.0244)	(0.0059)	(0.0241)	(0.0480)	(0.1432)	(0.0491)	(0.1532)
Post Apr 2007	0.0039	0.0048	0.0039	0.0052	0.0041	0.0279	-0.0275	0.0017
	(0.0044)	(0.0058)	(0.0044)	(0.0058)	(0.0307)	(0.0353)	(0.0355)	(0.0405)
Volatility		0.1411		0.1443		4.7760 ***		4.7074 ***
		(0.3001)		(0.3004)		(0.9287)		(1.0224)
Bid to cover		-0.0057 *		-0.0055 *		-0.0008		-0.0465 *
		(0.0030)		(0.0029)		(0.0009)		(0.0265)
Bid ask spread		-4.3906		-4.5647		-20.2434		-15.2314
		(13.2927)		(13.3888)		(63.4696)		(86.7192)
Log of issue amount		-0.0022		-0.0050		-0.1293		-0.1235
		(0.0175)		(0.0173)		(0.1057)		(0.1142)
Constant	0.0013	0.1255	0.0013	0.1558	0.9224 ***	2.4901	0.9380 ***	2.4944
	(0.0040)	(0.3495)	(0.0040)	(0.3496)	(0.0406)	(1.7908)	(0.0419)	(2.2748)
R-squared	0.0314	0.0494	0.0599	0.0775	0.8576	0.8736	0.8669	0.8840
# Obs	222	222	222	222	247	247	222	222

Note: This table shows the regression result based on Equations (3) and (4). The sample period is from March 2004 to March 2010. We use two dependent variables: markup, which is the spread of the winning yield at auctions over the WI rate at auction days, and winning yield at auctions. The 30-JGB dummy is a variable that takes the value one if the bond is 30-year JGB and zero otherwise. Post Apr 2007 is a variable that takes the value one if the auction was conducted after April 2007 and zero otherwise. The WI price gap is the spread of the highest WI price over the lowest WI price. Volatility is the standard deviation of yields on the previously issued bonds over the three business days prior to each auction. Bid to cover is the ratio of the quantity of tenders to supply by the MOF in each auction. Bid ask spread is the quoted bid-ask spread of the previously issued 20-year bonds. The log of the issue amount is the logarithm of the issuance amount of each auction. We also include 10-year JGB dummy and 20-year JGB dummy to control the fixed effects. Robust standard errors are in parentheses and are noted as follows: *, ** and *** stand for 10%, 5% and 1% significance, respectively.