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Simen Rømo Skille, Vemund Wøien

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NTNU
Norwegian University of Science and Technology
Faculty of Economics and Management
Department of Industrial Economics and Technology Management

Simen Rømo Skille
Vemund Wøien

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Industrial Economics and Technology Management
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Supervisor: Peter Molnár

Norwegian University of Science and Technology
Department of Industrial Economics and Technology Management

Preface

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Abstract

This paper studies auction performance and bidder behaviour in the Norwegian Treasury auctions from 2003 to 2018, a period when the uniform price format has been utilised. Norwegian Treasury auctions differ from auctions in other countries by a low number of bidders participating (five on average) and that the issuing government does not suffer from budget deficits. We find an average underpricing of 0.11% of face value in the auctions, corresponding to a total amount of NOK 1,605 million over the period studied. Aggregate demand to supply ratios (coverage ratios) indicate healthy competition in the auctions. The dispersion of bids in an auction exhibits a positive relationship with underpricing, while coverage ratio exhibits a negative relationship. In addition to auction level analyses, we also study the behaviour of individual bidders and its impact on their success. Relatively to other countries, the bidders tend to bid for a larger amount, with higher discounts and more dispersion of bids. Despite the low number of bidders, we do not find any evidence of strategic behaviour, as bidders are not able to affect their monetary outcome in the auctions.

Sammendrag

Denne artikkelen studerer auksjonsytelse og budgiveres oppførsel i auksjoner av norske statspapirer mellom 2003 og 2018, en periode hvor papirene har blitt solgt i likprisauksjoner. Auksjoner av norske statspapirer skiller seg fra tilsvarende auksjoner i andre land på grunn av det lave antallet budgivere (5 i gjennomsnitt) samt at utstederen ikke lider av budsjettunderskudd. Vi finner en gjennomsnittlig underprising på 0.11% av pålydende, hvilket akkumulert tilsvarer 1 605 millioner norske kroner i løpet av perioden vi studerer. Kumulativ etterspørsel-til-tilbud rate (dekningsrate) indikerer et sunt nivå av konkurranse i auksjonene. Spredningen av bud i en auksjon utviser et positivt forhold til underprising, mens dekningsrate utviser et negativt forhold. I tillegg til å analysere på et auksjonsnivå, studerer vi også budgivernes oppførsel og dennes innvirkning på deres suksess. Relativt til andre markeder har budgiverne en tendens til å etterspørre et større volum med høyere rabatt og mer spredning i budene sine. På tross av få budgivere finner vi ingen bevis på strategisk oppførsel ettersom de ikke har mulighet til å påvirke sitt monetære utfall i auksjonene.

Contents

List of Tables

List of Figures

1. *Introduction*

In this paper, we study auction performance and bidder behaviour in Norwegian Treasury auctions between 2003 and 2018. This is a time period in which the securities were sold in uniform price auctions. The use of auctions to issue government debt securities is common practice in many countries. The two most popular auction formats are the discriminatory pricing model, i.e. a first-price sealed bid auction, and the uniform pricing model, i.e. a second-price sealed bid auction[1]. The Norwegian Treasury auctions follow the uniform price format but have previously followed the discriminatory pricing model. Throughout the world the auctioned quantities are often large, and this has led to attention concerning which auction format yields superior performance. Numerous studies have been done on revenue ranking of discriminatory versus uniform price auctions. Several studies have investigated the U.S. Treasury auctions, but studies of Treasury auctions in a great variety of countries, some of them in Scandinavia, have led to equally important contributions. An overview of the literature concerning Treasury auctions is given in chapter 2.

In this paper, we provide an overview of the Norwegian Treasury market. There exist no detailed overview that describes the primary and secondary markets of Norwegian Treasury securities. The Norwegian government has the highest credit ratings from established credit rating agencies, e.g. Fitch (AAA), Moody's (Aaa) and Standard & Poor's (AAA). This means that Norwegian Treasury securities represent a safe and attractive investment, especially during times of high uncertainty. Being able to understand the market is therefore relevant both to

[1]See Bartolini and Cottarelli (1997) for an overview of the auction formats adopted in 42 countries worldwide. Furthermore, Bagella et al. (2007) gives an updated review on auction format and institutional details to place government securities throughout the Eurozone.

domestic and foreign investors.

We also measure the performance of the auctions. During the time period we study, there has been issued in excess of NOK 1,400 Bn (ca. USD 140 Bn) worth of Treasuries. Measuring performance to assess the issuing process is therefore of great interest. When considering the scale of the issued volume, even small inefficiencies correspond to substantial losses for the government. Norway is in an unusual position as an effective oil-corrected budget deficit is covered by the Government Pension Fund Global[2]. This means that as opposed to other countries which need to borrow money to finance its operation, Norway does not. The absence of a need to borrow should intuitively lower underpricing in the auctions, as a borrower who is not dependent on the money has more power in negotiations. In addition, there is a low number of bidders in the auctions when compared to other countries. These attributes make the Norwegian market particularly interesting to study. We investigate which exogenous variables affect the auction performance. More specifically, we consider the effects of uncertainty, the number of bidders, the auction size and macroeconomic factors. In addition, we take a novel approach by investigating how bidding behaviour is related to bidder success. We do this by examining individual bidding behaviour as well as the overall bidding in the auctions. Based on this, we can also study the extent to which a bidder can influence her own outcome. Finally, we account for the outcome in the previous auction to test for patterns in success.

We find an average underpricing of 0.11% of face value in the auctions, corresponding to a total amount of NOK 1,605 million over the period studied. The underpricing is higher than in other countries, which is curious given Norway's uncommon position where it does not need to borrow money. Although we study auctions with a low number of bidders, aggregate demand to supply ratios (coverage ratios) are in line with findings from other countries and indicate high competition. Several variables impact auction performance, most considerably the volatility in bond returns and the key policy rate. We find that bid dispersion exhibits a positive relationship with underpricing, while the coverage ratio exhibits a negative relationship. When examining bidder behaviour, it is clear that the bidders tend to bid for greater demand with higher discounts and more dispersion when compared to other countries. Furthermore, we find

[2]GPFG, "Statens Pensjonsfond Utland" formally or "Oljefondet" informally.

that the return a bidder obtains is mainly determined by the overall bidding in the auction and that the individual bidder has negligible power. This is not an obvious outcome, since the low number of participants in the Norwegian Treasury auctions could lead to strategic behavior. For the share of auction supply a bidder is awarded (share awarded), she is to a great extent the master of her own faith and her bidding behaviour is more important than the overall bidding in the auction. As for the fraction of her bids that receives allotment (award ratio), the bidder's behaviour and the overall bidding both affect the outcome concurrently.

The rest of the paper is organised as follows: Chapter 2 provides an overview of the existing literature, and chapter 3 provides a detailed description of the Norwegian Treasury markets. Chapter 4 describes the data, while chapter 5 describes the variables used in the study. In chapter 6, the results from the analyses are presented, before we conclude in chapter 7.

2. *Literature Review*

Even though we do not study revenue ranking in this paper, this has been the main motivation for much of the existing literature on Treasury auctions. Proceeding, we first give a brief overview of the development and categories of the existing theoretical and empirical literature and comment on why the findings in the revenue ranking debate are ambiguous. We then review the empirical literature that has been most relevant to our study in more detail.

The research of Treasury auctions accelerated after Goldstein (1962) argued that the U.S. Treasury could increase its revenue by issuing government securities in uniform price auctions instead of following the discriminatory price format used at the time. This led to contributions on auction theory from e.g. Wilson (1979), Milgrom and Weber (1982) and Milgrom (1989), who argue that uniform auctions alleviate the winner's curse and therefore generate more revenue to the issuer. During the 1990s and the beginning of the 21st century there was an increase in empirical studies of natural experiments comparing auction outcome with a when-issued[1] or secondary market. These studies were often combined with a theoretical contribution or a review of existing auction theory. Cammack (1991) studies the impact of volatility on bidder behaviour in auctions of U.S. Treasury bills, and Friedman (1991) argues in favour of uniform auctions by stating that the Treasury could save a substantial amount by switching to uniform price auctions. Jegadeesh (1993) finds material underpricing in the auctions of U.S. 2-year Treasury notes and that auction profits are systematically related to the total fraction of winning bids tendered by banks and dealers. Hypotheses regarding auction theory are tested empirically on bidding data from Treasury bill auctions in Portugal by Gordy (1999), which

[1] An example is the when-issued forward markets trading securities that are authorised but not yet issued.

finds that bidders submit more bids to hedge the winner's curse. The empirical findings of underpricing from Umlauf (1993), Nyborg and Sundaresan (1996) and Goldreich (2007) argue in favour of the uniform price auction format, and this is particularly interesting because of their sample of data. Nyborg and Sundaresan (1996) and Goldreich (2007) utilise a dataset containing both uniform and discriminatory auctions in the U.S., and Umlauf (1993) studies a similar data sample from the Mexican Treasury auctions[2]. Besides, several studies concerning auctions of other objects have also argued in favour of uniform pricing. Examples include the Feldman and Reinhart (1996) study of the International Monetary Fund's gold auctions during 1976–80, as well as the Tenorio (1993) study of Zambia's 1985–87 foreign exchange auctions.

There is an overweight of the natural experiment studies that argue in favour of uniform price auctions. However, which auction format that is revenue superior is not unanimous within this category of papers. As Goldreich (2007) points out, Nyborg and Sundaresan (1996) are hampered by only having limited data from one of several main dealers in the U.S. when-issued market. He argues that because of this, the findings are not necessarily representative for the market as a whole. Goldreich (2007) also points out that the findings of Umlauf (1993) probably is affected by the readily apparent collusion in the Mexican Treasury auctions. Based on this, he argues that the results can not be used as an argument to generalise that uniform price auctions are revenue superior. Furthermore, Hamao and Jegadeesh (1998) study the discriminatory auctions of Japanese bonds and find no evidence of underpricing. Pacini (2009) looks at a sample of auctions from 12 European Monetary Union countries[3] and finds overpricing in 97% of the auctions, irrespective of the auction format adopted. He argues that the overpricing is due to a bundling of the responsibilities and privileges of primary dealers[4]: By obtaining good scores when reviewed, primary dealers can secure syndication mandates and other lucrative assignments. Thus, they might be willing to overpay in the auctions in order to reap later and greater benefits. In order to test this hypothesis, Coluzzi (2011) prices the primary dealer privileges in Italian Treasury auctions as a call option and finds it to have a positive and

[2]The U.S. Treasury experimented with uniform auctions in early 1992, a time when their regular practice was to use discriminatory auctions. The Mexican Treasury did the same in 1990.

[3]Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain.

[4]See Arnone and Iden (2003) for a comprehensive description of the role of primary dealers in a variety of countries across the world.

significant value. This is further backed up by studies on Austria by Elsinger and Zulehner (2007), Germany by Rocholl (2005) and Spain by Alvarez and Mazón (2019) whom all find overpricing in the Treasury auctions studied.

Another category of empirical papers is a smaller set of studies using a different method of comparison to review the auction outcome. In these studies, counterfactual analyses are carried out using structural models to estimate the bidder's marginal values of the auctioned object. The valuations are based on the observed bids combined with certain theoretical assumptions regarding bidder behaviour[5]. By subtracting what the bidder ends up paying from their estimated valuation, the bidder surplus can be approximated. By accumulating the bidder surpluses, one can find the total surplus in the auction and use this as a measure of auction performance. Adopting this methodology, Hortaçsu and McAdams (2010) study the Turkish Treasury auctions and find evidence that the discriminatory format is revenue superior to the uniform model. This finding is further backed up by studies in the French market by Février et al. (2004), the Korean market by Kang and Puller (2008) and the Polish market by Marszalec (2017), whom all find discriminatory pricing to outperform the uniform price model. However, Castellanos and Oviedo (2008) build on the methodology from Février et al. (2004), and find uniform pricing to yield higher revenue than discriminatory auctions in the Mexican market.

Given the varying results, both within and across the methods of comparison, one can not draw a firm conclusion regarding revenue superiority from the existing literature. One consequence of this ambiguity is that although the U.S. Treasury changed its issuing regime from discriminatory to uniform pricing, France has conducted the opposite move (Pacini, 2009). Due to the vagueness of evidence, alternative explanations for the choice of auction format rather than revenue superiority have also been offered. For example, Brenner et al. (2009) survey sovereign issuers and find that market-oriented economies and those practising common law tend to use a uniform method. Economies who are less market-oriented and practice civil law, on the other hand, tend to use discriminatory price auctions.

As described, the existing literature has had a strong theoretical focus. However, there are

[5] E.g. Interdependent vs. private vs. common valuation, information structure, symmetry and risk-profile of bidders, auction setup and institutional details.

examples of papers that have a more applied approach to studying Treasury auctions as well. For example, Cammack (1991) finds that the underpricing is positively related to the dispersion of bids in the U.S. Treasury auctions, and Nyborg et al. (2002) documents that the volatility in returns of the auctioned securities is a driver of underpricing. Hortaçsu and Kastl (2012) study the Canadian Treasury auctions to investigate the information advantage of larger bidders. Rydqvist and Wu (2016) also study Canadian Treasury auctions and find that the auction performance varies with pre-auction inventory of securities. Alvarez and Mazón (2016) investigates how bidding behaviour in Spanish bond auctions is affected by secondary market price volatility, while Hortaçsu et al. (2018) use structural models to find significant differences between bidder groups[6] in U.S. auctions. In this paper, we provide a purely empirical approach to auction performance and bidder behaviour without relying on limiting assumptions of theoretical and structural models. The only assumption we make is that the secondary market is a neutral benchmark to determine the fair value of the securities being auctioned.

The measures of underpricing from most of the mentioned natural experiment studies are less relevant to us because they have available a forward market for the auctioned securities. However, there are several studies without a forward market available. Bjønnes (2001) studies Norwegian Treasury bill auctions between 1993 and 1998, which was a period where the auctions followed a discriminatory pricing model. Nyborg et al. (2002) studies the Swedish Treasury auctions between 1990 and 1994. The study considers both Treasury bill and bond auctions, which followed a discriminatory pricing model. Nyborg et al. (2005) studies the Finnish Treasury bond auctions in the period between 1992 and 1999, which followed a uniform price model. It is noteworthy that the Treasury in Finland has discretionary power in that the volume to be issued in the auction is not decided until after the bids are submitted. As the markets studied in these papers are the most comparable ones to the Norwegian market, we will turn to these studies throughout our paper for a comparison of methodology and results.

[6]Primary dealers, direct bidders and indirect bidders.

3. *Norwegian Treasury Auctions*

The Norwegian Central Bank (Norges Bank) has been responsible for the management of government debt since 2015 per a mandate from the Ministry of Finance. The task is carried out by the Government Debt Management. The objective is to meet the government's borrowing requirements at the lowest possible cost while taking risk exposure into account. As of the first quarter of 2019, the size of Norway's government debt was NOK 483 Bn, divided between NOK 422 Bn worth of government bonds and NOK 61 Bn worth of Treasury bills[1]. This corresponds to approximately USD 48, 42 and 6 Bn respectively as 1 USD $\cong$ 10 NOK. During 2018, NOK 38 Bn worth of bonds was issued through 15 auctions, in addition to the successful syndication of NOK 12 Bn worth of the new 10-year bond NGB 04/2028. During the same time, 16 Treasury bill auctions were held for a total of NOK 66 Bn[2]. There is a requirement that less than 25% of the outstanding bonds can mature in a single year. This objective is facilitated by issuing more frequent but smaller bonds[2].

In most countries, the main reason for the government to issue debt is to finance a budget deficit and to raise the reserves of foreign exchange[3]. In Norway, an effective oil corrected budget deficit is covered by transfers from the Government Pension Fund Global. Even though a deficit does not trigger a need to borrow money, there are still reasons to issue debt. Examples include financing equity issuance and capital injections to state lending institutions[4], to cover the repayment of existing debt that matures, ensuring sufficient levels of cash reserves, and

[1]Norges Bank. "Government Debt Management 1st Quarter 2019 Report" (p. 7).
[2]Norges Bank. "Government Debt Management 2018 Annual Report" (p. 4).
[3]Norges Bank. "Government Debt Management 2018 Annual Report" (p. 5).
[4]E.g. Norwegian State Educational Loan Fund ("Statens lånekase for utdanning") and Norwegian State Housing Bank ("Husbanken").

making sure the government budget is liquidity neutral.

3.1 Primary Market Issuance

In this section, we describe the Norwegian Treasury auctions. We use the terms *bid* and *tender* interchangeably. The debt portfolio of the Norwegian government is comprised of Treasury bills, government bonds and interest rate swaps. Government bonds and Treasury bills are issued to the market through uniform price auctions or syndication. The former method is the focus of our study as it has been used in all but two instances[5]. The total supply to be issued is disclosed in the announcement of the auction, and the amount is not to be changed after the bids are submitted. Norges Bank is supposed to automatically cancel the auction if the demand is lower than the offered volume. This has never happened. Any bid submitted in the auctions is a volume demanded at a particular price, denoted as a percentage of the security's face value. After all bids have been received, they are sorted by descending price (ascending yield). The equilibrium price is the price where the offered supply equals the demand, and this is the price that all bidders receiving allotment must pay. This means that all bids with an offered price higher than the equilibrium price will be allotted the full quantity demanded. If there is more residual demand than residual supply at the equilibrium price, the bids at this price are allotted quantity on a pro rata basis. Only primary dealers (discussed in section 3.2) are allowed to submit bids in the auctions. Other parties may submit their tenders via a primary dealer. The primary dealers then submit the tenders received to the Oslo Stock Exchange's trading system together with their own bids. The tenders can only be submitted in lots of NOK 1 million, with stated prices having two decimal points for securities with residual maturity of more than 12 months and four decimal points for those with residual maturity of 12 months or less.

The 12-month zero-coupon Treasury bills are first issued on the International Monetary Market (IMM) dates, which are the third Wednesday in March, June, September and December. The standard supply in these auctions is NOK 6 Bn. Auctions held on other dates than IMM dates

[5]The first is the previously mentioned syndication issuance in 2018. The second is a NOK 15 Bn syndication of the new 10-year government bond NGB 09/2029 in the first quarter of 2019 (Norges Bank. "Government Debt Management 1st Quarter 2019 Report", p. 2). For further detail on syndication, see Appendix A.1.

will reopen existing Treasury debt and issue additional volume in these. In the two subsequent bill auctions after an IMM date, the bill which had precisely 6 months residual maturity on the IMM date will be reopened. In the third auction following an IMM date, the bill with six months residual maturity on the next IMM date will be reopened. When the bills are reopened, issuance volumes are usually NOK 2–3 Bn[6]. In addition, Norges Bank normally seeks to issue one new 10-year bond per year to maintain a yield curve of up to 10 years in line with its mandate. Outstanding bonds are also normally reopened with additional volume of NOK 2–3 Bn[7].

3.2 Primary Dealer System

Norges Bank makes use of a system where it enters into bilateral primary dealer agreements with several counterparties that are members of Oslo Stock Exchange. There are separate agreements for government bonds and Treasury bills. The system is a part of the strategy to achieve the lowest possible borrowing cost. The primary dealer agreement works in the following way: As a primary dealer, the banks or other financial institutions have the sole right, but also an obligation, to participate in the auctions. Additionally, they are required to quote volumes and prices in the secondary market to ensure liquidity. This is elaborated upon in section 4.2. The agreements are entered into on a yearly basis, and as per 2019 Danske Bank, DNB, Nordea and Skandinaviska Enskilda Banken (SEB) are the primary dealers in both government bonds and Treasury bills.

From Norges Bank's point of view, the primary dealers serve three roles. First, they facilitate that the Government Debt Management can issue planned volumes of government papers. Second, the mandatory price quoting on Oslo Stock Exchange reassures investors of the existence of a liquid market for the securities. Third, the agreement ensures that the Government Debt Management has an arena to interact with counterparties in possession of market knowledge and large contact networks of investors.

[6]Norges Bank. "Strategy and borrowing programme 2019" (p. 13).
[7]Norges Bank. "Strategy and borrowing programme 2019" (p. 9).

As the primary dealers in several countries communicate an increasing cost of the obligations that follow with the agreement, Norges Bank decided at the end of 2016 to introduce a remuneration scheme for the primary dealers in Norwegian government securities. The reasoning is that the scheme will contribute to obtaining the lowest possible borrowing cost by maintaining an attractive primary dealer system. The remuneration consists of two separate components: a base remuneration that is paid to every primary dealer (both in government bonds and Treasury bills) and a performance-based component determined by an assessment carried out by the Government Debt Management. The ceiling for aggregate remuneration to all primary dealers was NOK 10 million for the calendar year 2018 and resulted in a NOK 6 million payout, down from NOK 7 million in 2017. The payout consisted of NOK 1 million base remuneration divided equally between the dealers and NOK 5 million in performance-based remuneration divided in an undisclosed manner[8]. In 2017, the year the remuneration scheme was introduced, the performance-based remuneration was NOK 6 million.

In addition to the remuneration scheme, the primary dealers have at least two apparent advantages from their roles. Firstly, all other market participants interested in taking part in the auction need to submit their bids to one of the primary dealers. This means that a primary dealer will be able to see the market interest in the security to be issued through holding parts of the order book. Hence, they obtain an information advantage as they plan their bidding strategy. Secondly, they may be able to make money from a bid-ask spread in the secondary market, i.e. if they can win securities in the auction and then turn around to the secondary market and sell them at a markup.

[8]Norges Bank. "Government Debt Management 2018 Annual Report" (p. 10).

4. *Data*

4.1 Bid Data

The dataset is provided by Norges Bank and consists of the complete set of individual bids and awards in Treasury bill and government bond auctions. The data comprises the 15-year period from September 2003 to September 2018. This period only contains auctions with the primary dealer system implemented for both bill and bond auctions. The implementation of a primary dealer system in Treasury bill auctions was effective in August 2003, while a similar agreement was introduced in bond auctions in 1995[1]. All auction participants are uniquely identified but anonymised. In other words, we see the whole history of bids for bidder 1, but we do not know who bidder 1 is. For each auction, we have information about all bids submitted, i.e. prices and quantities offered. We also know whether a bid was allocated volume or not. Norges Bank does not know which bids are submitted on behalf of the primary dealers themselves and which are submitted on behalf of other market participants.

The dataset contains a total of 21,632 bids (9,786 bids in bill auctions and 11,846 bids in bond auctions) distributed over 374 auctions (201 and 173 bill and bond auctions respectively). This corresponds to an average of 49 bids in bill auctions and 68 bids in bond auctions. There are no auctions with missing data for the entire period. There are 1,842 bid schedules[2] submitted in the auctions (1024 and 818 in bill and bond auctions respectively). On average, this corresponds to 5.1 and 4.7 bid schedules submitted in bill and bond auctions. The maximum and minimum

[1] From 2006, this system meant that primary dealers were given an exclusive, but mandatory right to participate in the auctions. Both primary dealers and other participants were allowed from August 2003 to 2006.

[2] A bid schedule is the set of bids submitted by a single bidder in a single auction.

Table 4.1: Norwegian Treasury auctions, bid schedules and bidders per year, 2003–2018

	Auctions		Bid Schedules		Bidders	
Year	Bills	Bonds	Bills	Bonds	Bills	Bonds
2003	6	2	42	14	7	7
2004	16	5	86	41	5	8
2005	14	5	81	35	6	7
2006	14	7	77	42	6	6
2007	12	7	71	42	6	6
2008	11	7	65	42	6	6
2009	10	10	58	60	6	6
2010	11	7	64	42	6	6
2011	8	6	45	32	6	5
2012	16	17	77	68	5	4
2013	14	21	67	84	5	4
2014	13	20	64	80	5	4
2015	12	15	51	60	4	4
2016	16	17	64	68	4	4
2017	16	16	64	64	4	4
2018	12	11	48	44	4	4
Sum	201	173	1,024	818	*N.M.*	*N.M.*

Note: Bidders is the average number of auction participants during the relevant year. The sum for this metric is not meaningful to calculate.

number of bid schedules is 9 and 4 respectively for bill auctions, while the equivalent numbers are 11 and 4 for bond auctions. A total of 12 bidders submitted tenders in one or more bill auction during the period, while 18 bidders submitted tenders in at least one bond auction. There are substantial differences in the number of auctions in which the bidders have participated. Four bidders partook in close to all bill auctions (between 195 and 201), two bidders partook in 130 and 74 respectively, and the rest in between 1 and 7 auctions. For bond auctions, four of the bidders partook in all 173 auctions, two of the bidders in approximately 50 (up until ca. 2012) and the rest in 1 to 4 auctions. What is not clear from these statistics, however, is that the number of auction participants has been steadily decreasing throughout the period. See table 4.1 for an overview of the number of bidders over the years studied. Furthermore, the composition of auctions and bid schedules between years, security types and auction types can be seen in table 4.1 and 4.2.

Table 4.2: Norwegian Treasury auctions and bid schedules, reopenings and new issues, 2003–2018

	Auctions			Bid Schedules		
	New Issues	Reopenings	Sum	New Issues	Reopenings	Sum
Bills	61	140	201	328	696	1,024
Bonds	9	164	173	47	771	818
Sum	70	304	374	375	1,467	1,842

As mentioned, none of the auctions was undersubscribed. Like us, Bjønnes (2001) reports no undersubscribed auctions in his study of Norwegian Treasury bills between 1993 and 1998. By contrast, Nyborg et al. (2002) reports 35 incidents of undersubscription in Swedish Treasury auctions between 1990 and 1994. The Finnish Treasury determines the auction supply after receiving the bids, making undersubscription impossible in the study by Nyborg et al. (2005).

4.2 Secondary Market Data

The secondary market data is provided by Oslo Stock Exchange. The TITLON database is used to retrieve data from September 2003 until the end of June 2018. The database is available free of charge for academic purposes. Due to some missing data, input from the end of June to October 2018 has been provided by Oslo Stock Exchange directly. The dataset consists of daily entries of opening price, highest and lowest price traded, traded volume, and the best bid and best ask price at close for all bills and bonds it covers.

The government debt securities are traded in the secondary market with automatic order matching on Oslo Stock Exchange. This is both done directly between participants (over the counter) as well as in supplementary trading venues such as Bloomberg, Eurex Bonds and Tradeweb[3]. Per the Primary Dealer Agreement, the dealers are obliged to quote firm bid and ask prices on Oslo Stock Exchange's ordinary sub-market with automatic order matching. The agreements

[3] In the market with automatic order matching, primary dealers quote binding prices and volumes every trading day in accordance with the Primary Dealer Agreement. Members of Oslo Stock Exchange can trade at these prices and volumes directly in the trading system (Norges Bank. "Government Debt Management 2018 Annual Report", p. 13).

also put some restrictions on the quotes. For Treasury bills, there should be no more than 10 basis points spread between the bid and ask quotes. In addition, the primary dealers are obliged to have a minimum of NOK 75 million of visible orders placed per Treasury bill[4]. For government bonds, the spread should not exceed 10 basis points for bonds with residual maturity of up to 1 year, and no more than 5 basis points for those with residual maturity greater than or equal to 1 year. The minimum size of visible orders are NOK 75 million for bonds with residual maturity up to 2 years, NOK 55 million for those between 2 and 7 years, and NOK 45 million for those with residual maturity greater than or equal to 7 years[5]. After automatic matching, the primary dealers need to submit a new quote of price and volume within 3 minutes. This is a requirement both for Treasury bills and government bonds.

From mid-2016 some primary dealers started giving quotes for new-issues on the auction day, which can be considered as when-issued quotes. This is done voluntarily, as the Primary Dealer Agreement only requires quotes on the first day of trading. Given no holiday/weekend in between, the first day of trading is usually two days after the auction.

[4]Norges Bank. "Primary Dealer Agreement for Norwegian Treasury bills for calendar year 2019" (p. 2-3).
[5]Norges Bank. "Primary Dealer Agreement for Norwegian Government bonds for calendar year 2019" (p. 2-3).

5. *Definitions of Variables*

Two of the main goals in this paper is to evaluate the effect that several variables have on auction performance and the impact of bidder behaviour on bidder success. Most of this chapter explains how the variables we use to achieve this are defined and why we choose to define them that way. In section 5.1, we provide a detailed description of auction performance measures used in the literature and justify our choices. We utilise three auction performance variables; underpricing, auction level bid dispersion and coverage ratio. We also introduce explanatory variables for auction performance in this section. In section 5.2, we define bidder-specific variables, both relevant to their success and their behaviour.

5.1 Auction Level Analysis

In subsection 5.1.1 we define the auction performance indicators used in this study, while we in subsection 5.1.2 introduce the exogenous variables we expect to influence the auction performance.

5.1.1 Auction Performance Indicators

We have chosen three measures of performance to evaluate the auctions. To determine *underpricing*, we measure the auction outcome against a benchmark representing the market price. The previous work on Treasury auctions covers a wide range of countries, and the availability of benchmark data varies between markets. Thus, several benchmarks are used in the existing

Table 5.1: Studies of underpricing in Scandinavian Treasury auctions

	Bjønnes (2001)	Nyborg et al. (2002)	Nyborg et al. (2005)
Data and Sample	Norway Bills (1993–98)	Sweden Bills and bonds (1990–94)	Finland Bonds (1992–99)
Measure of Underpricing	Secondary market price minus weighted average winning bid price	Secondary market price minus weighted average winning bid price	Secondary market price minus stop out price
Benchmark	Average of bid and ask quote	Bid quote	Bid quote minus dealer markup

Note: The data and sample row describes what time period and securities that was studied. The measure of underpricing row describes how the secondary market price is used to calculate underpricing. The benchmark row gives information on how the secondary market quotes is used to calculate the secondary market price.

literature. The benchmark is usually constructed from a when-issued market for the securities when this is available (examples include Cammack, 1991; Hamao and Jegadeesh, 1998 and Goldreich, 2007). However, this is not available in Norway, nor in the other Scandinavian countries. In the absence of a when-issued market, studies like Bjønnes (2001), Nyborg et al. (2002) and Nyborg et al. (2005) construct a benchmark from available secondary market quotes. Table 5.1 presents a summary of the methodologies used in these papers. The underpricing measures used by Bjønnes (2001) and Nyborg et al. (2002) are equal, while Nyborg et al. (2005) utilize a different measure due to the difference in auction price format.

Regarding the benchmark, Bjønnes (2001) argues that the best proxy in the Norwegian market is the average of the bid and ask quotes. Nyborg et al. (2002) argues that in Sweden, the best proxy for the secondary market is the bid quote. In Finland, Nyborg et al. (2005) argues that the estimation of underpricing will be done with the least amount of error if transactions' systematic deviation from the posted bid quote is taken into account. This does not correspond to the average of the bid and ask quote, neither to one of the quotes directly. Instead, as shown in the table, the transaction yield used is the bid quote minus the dealer markup. The dealer markup is defined as the average spread between the bid quote and the actual transaction sell yield.

We have chosen the bid-ask midpoint as the benchmark in this paper. There are three main reasons for doing so. First, industry practitioners advise that the midpoint is a representative proxy for the true secondary market price, i.e. where trades take place. This is substantiated by Bjønnes (2001), who states that using the midpoint was recommended to him by practitioners as well. In addition, we have conducted an empirical analysis of the spread between bid and ask quotes, and the quotes at which trades take place. This was done by calculating the residuals between the trade and the bid, mid and ask quotes individually for all trading days in the period. As both the average residual and the sum of absolute residuals are lowest for the midpoint, this is considered to be the closest proxy out of the three quotes. The analysis shows that this is consistently the case across all government debt securities traded in the secondary market throughout the period studied in this paper. In addition, it is worth pointing out that the data shows that this proxy is balanced between providing too positive and too negative estimates, i.e. it serves as the least biased estimator.

When a reopening auction takes place, bid and ask quotes from the secondary market are available for the auction day. In these cases (304 auctions), we can use the midpoint of the bid and ask quotes directly to calculate underpricing. For most of the period studied, no secondary market quotes are available on the auction day for new issues of bills or bonds[1]. In these cases, we use the quotes from the first trading day of the issued security. However, as the first trading day (i.e. the issue date) is typically two days after the auction day[2], we need to correct for time elapsed and possibly other events that have taken place in the meantime. The correction is conducted to ensure that a potential difference in terms between the auction and the secondary market is not due to external events. Such events could be a change in interest rates or geopolitical situations. The correction is carried out in different ways for bills and bonds. For new issues of bills (61 auctions), we construct an implied secondary market price on the auction day. We do this by using the yield of one reference bill with a shorter duration and the yield of one reference bond with a longer duration than the auctioned bill. The yields are used to calculate the implied secondary market yield for the auctioned bill on the auction day:

[1]From mid-2016 some primary dealers started posting market quotes on the auction day. For the auctions where this is the case, we use the posted quotes from the auction day.

[2]Unless there is a weekend or holiday between the auction and the issuance.

$$y_t = y_{t+\tau} - (y^r_{t+\tau} - y^r_t) \tag{5.1}$$

where y_t is the estimated secondary market yield on the auction day and $y_{t+\tau}$ is the observed secondary market yield (midpoint of the bid and ask quotes) on the first day with active trading in the auctioned security. $y^r_{t+\tau}$ and y^r_t are the duration-weighted averages of observed secondary market yields of the two reference securities. Using the implied yield obtained from equation 5.1 we can calculate the implied secondary market price on the auction day. This is then used as a proxy for the market value of the issued bill, and by subtracting the price obtained in the auction, we get the underpricing. This is similar to what is done in e.g. Hamao and Jegadeesh (1998) and Bjønnes (2001).

For new issues of bonds we are not able to use the same method, as no reference bond with longer duration exists[3]. In our dataset, we have 9 new issues of bonds. We conduct an empirical analysis of the 10 first trading days of a new issued bond. The results show that in all 9 cases, at least one bond already trading in the market mimics the yield changes of the auctioned bond very well[4]. By mimicking well, we mean that the relationship between the yield levels of the bonds is close to constant. Thus, we use the relationship between the yield of the best mimicking bond on the auction day relative to the first trading day as a correction factor for new issues of bonds. This is used to calculate implied secondary market yield for the issued bond on the auction day:

$$\frac{y_t}{y_{t+\tau}} = \frac{y^r_t}{y^r_{t+\tau}} \iff y_t = \frac{y^r_t}{y^r_{t+\tau}} \cdot y_{t+\tau} \tag{5.2}$$

The notation in equation (5.2) is equivalent to the notation in equation (5.1). The correction factor analysis is further elaborated upon in Appendix A.2. Using the implied secondary market

[3] In 2004–12, all new issues had time to maturity of 11 years. From 2014 they had time to maturity of 10 years.

[4] In 8 out of 9 cases the bond with the closest time to maturity was the bond that most closely mimicked the yield changes.

yield, we can estimate the implied secondary market price on the auction day. Finally, we can calculate the underpricing as the difference between the auction price and the implied secondary market price on the auction day.

The second performance measure we utilise is *auction dispersion*. This is calculated on a per-auction basis as the standard deviation of the quantity-weighted bids submitted. The auction dispersion in auction j with n submitted bids is defined as:

$$AuctionDispersion_j = \sqrt{\frac{\sum_{i=1}^{n} Q_i \cdot (P_i - \bar{P}_w)^2}{\sum_{i=1}^{n} Q_i}}, where \tag{5.3}$$

$$\bar{P}_w = \frac{\sum_{i=1}^{n} Q_i \cdot P_i}{\sum_{i=1}^{n} Q_i} \tag{5.4}$$

Here, Q_i is the volume and P_i is the price of bid i. $\bar{P}_w$ is the quantity weighted average bid price in the auction. If the bidders are uncertain or disagree about the true value of the auctioned security, this will lead to greater bid dispersion. As the auctions are of a uniform price format, the bidders should tender their true value if they are certain about the value of the auctioned security. Since the price of the security is practically capped from above, an increase in dispersion is not symmetric around the average bid. Thus, greater dispersion means that bidders tend to spread their bids downwards instead of concentrating them around the true value. This will naturally degrade the auction performance. Studies of individual bidder behaviour tend to examine intrabidder dispersion instead of total bid dispersion in an auction. In this first part of our analysis, we consider the performance of the auctions as a whole. Thus, we calculate all variables on an auction level as opposed to an individual bidder level. Examining bidder behaviour and individual bidder performance is done separately, and the metrics used in this second part of our study will be introduced in section 5.2.

The last performance measure is the *coverage ratio*, which is calculated as the ratio between the total auction demand and the auction supply. In an auction with n bidders, we write:

$$CoverageRatio_j = \frac{\sum_{i=1}^{n} Q_{ij}}{Q_j} \tag{5.5}$$

where $Q_{i,j}$ is the volume tendered by bidder i in auction j and Q_j is the auction supply in auction j. For example, if the aggregate demand equals NOK 10 Bn in a NOK 5 Bn auction, this corresponds to a coverage ratio of 2. A coverage ratio of less than 1 means that the auction is undersubscribed. As previously mentioned, this has not occurred during the period studied. Intuitively, a higher coverage ratio corresponds to greater competitive intensity and better auction performance. The reasoning is as follows: If an increase in coverage ratio only results in more bids below the equilibrium price, the auction outcome is no worse. If some of the additional bids are above the equilibrium price, the auction performance is enhanced. Therefore, auction performance should only increase with higher coverage ratio.

5.1.2 Exogenous Variables

In addition to measuring the performance of the auctions, we examine what the performance determinants are. To do so, we have gathered a set of exogenous variables and test whether they influence auction performance. In this subsection, we define and describe these variables.

To capture different kinds of financial stability, we have included multiple measures related to uncertainty. First, we have estimates of the standard deviations in returns of the auctioned security, obtained by estimating a GARCH(1,1)-model. This approach is similar to what is done in the papers studying Scandinavian auctions (Bjønnes, 2001; Nyborg et al., 2002 and Nyborg et al., 2005). See Appendix A.3 for additional details on the model estimation. Second, "new" is a multiplicative dummy which is equal to 1 when the auction is for a new issue, and 0 otherwise. Multiplied with volatility, the dummy will capture whether the impact of volatility is different for new issues. This is also done by Bjønnes (2001). Third, the VIX, formally known as the CBOE Volatility Index, measures the expected volatility as implied by S&P500 index options. We have included VIX as a regressor since it serves as a measure of the overall uncertainty in the global financial markets. Usually, the VIX is quoted as annualised standard deviation, but we have chosen to denominate it as daily standard deviation[5] for consistency with the other volatility measures used. Finally, we have constructed an index of credit default swaps (CDS) to measure overall uncertainty in competing debt markets. The index is constructed from the CDS spreads of 5-year government debt for the 5 largest Eurozone economies[6]. A larger spread can be interpreted in the following way: The seller of protection requires a higher premium because the default risk is higher. Thus, an increasing index value corresponds to increased uncertainty of defaults in the Eurozone.

In addition to the uncertainty measures, we have included the auction size and the number of bidders as explanatory variables. The auction size is simply the supplied quantity in the auction, and the number of bidders is the number of bidders that submitted at least one tender in the auction. The last explanatory variable is the Norwegian key policy rate. Due to the inverse relationship between bond yields and interest rates, the key policy rate is expected to affect the performance of the auctions. This is because the popularity of low-yielding government debt decreases with higher interest rates.

5.2 Bidder Level Analysis

In subsection 5.2.1, we motivate and define our bidder success measures. In subsection 5.2.2, we define the bidder behaviour measures we use in our analyses.

5.2.1 Bidder Success Measures

In order to describe the performance of the individual bidders, we have chosen to use three different metrics. First, consider the *return* of the bidders. This metric is calculated by looking at the underpricing a bidder receives, while also taking into account the volume the bidder was willing to commit in the same auction. We introduce this measure in an attempt to capture

[5]The calculation is done by assuming 252 trading days a year.
[6]Germany, United Kingdom, France, Italy and Spain

the profit bidders obtain in the auctions. Since the underpricing in the auction is equal for all, we add an element of volume to distinguish between the bidders. Simply multiplying the underpricing with the volume a bidder is awarded would favour large bidders, although they could have experienced disappointingly low awards in the auction. Thus, we create a return measure that captures total return relative to the other bidders irrespective of the bidder's size. The metric is calculated per bid schedule in the following manner:

$$Return_{i,j} = \frac{underpricing_j \cdot Q^*_{i,j}}{Q_{i,j}} \tag{5.6}$$

where $underpricing_j$ is the underpricing per NOK in auction j, $Q^*_{i,j}$ is the awarded volume to bidder i in auction j, and $Q_{i,j}$ is the cumulative tendered volume from bidder i in auction j.

Second, we define *share awarded* as the relative volume awarded to a bidder in an auction, i.e.:

$$ShareAwarded_{i,j} = \frac{Q^*_{i,j}}{Q_j} \tag{5.7}$$

where $Q^*_{i,j}$ again is the volume awarded to bidder i in auction j and Q_j is the auction supply in auction j. This metric describes the relative success of the bidder in terms of being awarded volume in an auction when compared to the other participants. As a bidder on average tenders for more than half of the auction supply, it is reasonable to assume that they are interested in being allocated large volumes in the auctions.

Finally, consider *award ratio*. This metric describes the fraction of a particular bidder's tenders that is awarded in the auction. Mathematically, we write:

$$AwardRatio_{i,j} = \frac{Q^*_{i,j}}{Q_{i,j}} \tag{5.8}$$

where $Q^*_{i,j}$ is the volume awarded to bidder i in auction j and $Q_{i,j}$ is the volume tendered by bidder i in auction j.

5.2.2 Bidder Behaviour Measures

We focus our measures of a bid schedule along the bidders' choice variables: the demanded volume, the price level and the dispersion of bids. This is in accordance with the existing literature. *Share of supply* describes the appetite of a bidder and is calculated as the volume tendered by a bidder as a fraction of the supplied volume in the auction. Mathematically, we write:

$$ShareOfSupply_{i,j} = \frac{Q_{i,j}}{Q_j} \tag{5.9}$$

where $Q_{i,j}$ is the aggregate demand of bidder i in auction j and Q_j is the supply in auction j. This is often referred to as *"quantity demanded"* in the literature.

Following the same logic, we also calculate *share of demand*. This measure describes the appetite of a bidder relative to that of the other auction participants. It is calculated as the volume tendered by a bidder relative to the aggregate demand from all bidders in the auction, i.e.:

$$ShareOfDemand_{i,j} = \frac{Q_{i,j}}{\sum_{i=1}^{n} Q_{i,j}} \tag{5.10}$$

in an auction with n participating bidders.

For each demand schedule submitted in an auction, we calculate the quantity-weighted average bid, $\mu_{i,j}$. Bid shading is measured by the *discount*, which for bidder i in auction j is defined as:

$$Discount_{i,j} = P_{j,t} - \mu_{i,j} \tag{5.11}$$

where $P_{j,t}$ is the secondary market price at the end of the day of auction j. The measure describes the price level a tenderer submits bids at relatively to the post-auction market price. This means that it represents a normalised measure of the price level of bids submitted by bidder i in auction j.

Intrabidder dispersion is the quantity-weighted standard deviation of bidder *i's* n submitted bids in auction j:

$$IntrabidderDispersion_{i,j} = \sqrt{\frac{\sum_{k=1}^{n} Q_{i,j,k} \cdot (P_{i,j,k} - \mu_{i,j})^2}{Q_{i,j}}} \tag{5.12}$$

Where $Q_{i,j,k}$ and $P_{i,j,k}$ is bid *k's* volume and price, respectively. $Q_{i,j}$ is the total demand of bidder i in auction j. The difference between this measure and the previously defined *auction dispersion* (see equation (5.3) in subsection 5.1.1) is whether it is calculated for a single participant's bid schedule or for all bids in an auction.

Finally, we calculate the *bottom spread* of the bid schedule. As opposed to *intrabidder dispersion*, which takes the whole bid schedule into account, this measure is concerned only with the part of the schedule containing the lowest bids. The metric is calculated by looking at the difference between the overall quantity-weighted average bid, $\mu_{i,j}$, and the quantity-weighted average bid from the lowest 20% of the bids, $\mu_{i,j}^{20}$. For bidder i in auction j, this is calculated as:

$$BottomSpread_{i,j} = \mu_{i,j} - \mu_{i,j}^{20} \tag{5.13}$$

The motivation for including this measure in addition to *intrabidder dispersion* is to test how the dispersion of a bid schedule affects a bidder's success in greater detail. By including *bottom spread*, we can study whether the dispersion in the bottom of the schedule affects the outcome more than the dispersion in the overall schedule.

6. *Results*

This chapter is organised into two sections. We first carry out an auction level analysis in section 6.1. We provide an overview of the observed auction performance and study how exogenous variables affect it. In addition, we examine the relationship between the different performance indicators. Section 6.2 presents the bidder level analysis. In particular, we compare bidding behaviour with that in other countries and study the relationship between bidding behaviour and bidder success. Finally, we investigate how a bidder's auction outcome is related to her outcome in the previous auction.

6.1 Auction Level Analysis

In subsection 6.1.1, we present the observed auction performance. Some of the existing literature reports similar statistics, and we provide insights into the similarities and differences with other studies. The absence of a need to borrow money gives the Norwegian government a unique position as an issuer. It is therefore compelling to investigate the auction performance relative to other countries. Given the large volumes issued in the auctions, external conditions can potentially have immense effects for the Norwegian government in monetary terms. Thus, we examine the determinants of auction performance in subsection 6.1.2. We suggest a hypothesis about the relationships between the auction performance and exogenous variables, and present the relationships found. Finally, subsection 6.1.3 examines the relationships between the three performance variables to provide a holistic view of the overall auction performance.

Table 6.1: Descriptive statistics for auction level performance indicators

	Underpricing			Auction Dispersion			Coverage Ratio		
	Bills	Bonds	All	Bills	Bonds	All	Bills	Bonds	All
Mean	0.064	0.158	0.107	0.100	0.569	0.317	2.517	2.532	2.524
Median	0.035	0.102	0.055	0.071	0.488	0.206	2.416	2.367	2.397
Std. Dev	0.126	0.227	0.186	0.102	0.354	0.344	0.643	0.762	0.700
Max	1.484	1.575	1.575	0.705	3.033	3.033	4.770	5.398	5.398
Min	-0.037	-0.245	-0.245	0.008	0.056	0.008	1.161	1.125	1.125
Observations	199	172	371	199	172	371	199	172	371

Note: Underpricing, auction dispersion and coverage ratio are defined in subsection 5.1.1. The descriptive statistics for these three variables are given for three samples; bill auctions only, bond auctions only and all auctions together. The units of underpricing and auction dispersion is per cent of face value, while coverage ratio is unitless.

6.1.1 Auction Performance

First, we present descriptive statistics for all the variables defined in section 5.1. Table 6.1 shows an overview of *underpricing*, *auction dispersion* and *coverage ratio*. For each of these three variables, we have calculated statistics for three samples: bill auctions separately, bond auctions separately, and all auctions together. For *underpricing*, we have data for 371 auctions in total: 199 bill auctions and 172 bond auctions. The three missing data points are not calculated due to missing quotes from the secondary market[1]. For *coverage ratio* and *auction dispersion*, secondary market quotes are not needed to perform the calculations. However, we calculate descriptive statistics for the reduced sample of 371 auctions to keep the data comparable[2].

Consider *underpricing*. The values are reported as percentages of face value. The mean underpricing in auctions of bills is 0.06% of face value, which is lower than the mean underpricing of 0.16% of face value observed in bonds auctions. Both of these numbers are significant at a 1% level. The mean underpricing observed when considering all auctions is 0.11% of face value. The finding of underpricing is not unexpected. As it is not without risk to participate in the auctions, participants must be rewarded for doing so. As discussed in chapter 2, various

[1]The relevant auctions are NST38 (03.04.2017), NST36 (24.04.2017) and NST475 (04.07.2018). The two former are bill auctions, while the latter is a bond auction. All auctions were reopenings of instruments previously issued.

[2]Including the three auctions has a negligible impact on the statistics. Median coverage ratio in bill/bond auctions increases/decreases by 0.01 to 2.43 and 2.36, respectively. Auction dispersion is unaffected.

primary dealer privileges may offer such a reward. Both the remuneration scheme and the syndication mandates have recently been introduced to the primary dealers in Norway[3]. However, these reward systems are unlikely to be affecting the auctions studied as they did not exist for most of the period we consider. Before the introduction of these privileges, the only direct way of obtaining reward was through underpricing in the auctions. Bjønnes (2001) reports a mean underpricing of 0.04% of face value in Norwegian bill auctions, while Nyborg et al. (2002) reports a mean of 0.02% of face value in Swedish bill and bond auctions. Nyborg et al. (2005) finds a mean underpricing of 0.04% of face value in their study of Finish bond auctions. However, comparing underpricing must be done with caution. Thus, we conduct a comparison in detail subsequently. We also point out that not all auctions result in underpricing, as the minimum underpricing for bills and bonds was -0.04% and -0.24% of face value, respectively.

Next, consider *auction dispersion*. Similar to underpricing, this measure is denoted as per cent of face value. The average dispersion was 0.10% of face value for bills and 0.57% of face value for bonds. These observations of dispersion indicate that bidders disagree more about the true value of bonds than that of bills. The most substantial dispersion for bills was 0.70% of face value, and the largest for bonds was 3.03% of face value. Finally, the minimum dispersion for bills and bonds was 0.01% and 0.06% of face value, respectively.

Finally, consider *coverage ratio*. As this measure is calculated as aggregate demand per supply, it is unitless. The mean coverage ratio for bills and bonds are 2.52 and 2.53 respectively, meaning that the auctions are on average significantly oversubscribed. We observe that the minimum coverage ratio is 1.16 for bills and 1.13 for bonds, meaning that no auction was undersubscribed. However, the minimum observations indicate that the auctions can experience low competitive intensity. This can potentially lead to sub-optimal issuing terms for the seller.

We now present the descriptive statistics for the exogenous variables in table 6.2. σ is the daily volatility of bond returns estimated by a GARCH(1,1)-model. *VIX* is the CBOE Volatility Index denominated as daily volatility and *CDS* is the index measuring average credit default swap spread for the 5 largest Eurozone economies. *Auction size* is the supplied volume in the

[3]See section 3.2 for additional detail on the remuneration scheme. See Appendix A.1 for details regarding the syndication mandates.

Table 6.2: Descriptive statistics for exogenous variables

	Mean	Median	Std. Dev	Max	Min	Observations
σ	0.129	0.030	0.160	1.115	0.003	371
VIX	1.123	0.963	0.498	3.870	0.592	371
CDS	3.536	3.782	1.165	5.433	1.030	362
Auction Size	3.787	3	1.418	8	2	371
Bidders	4.933	5	1.100	11	4	371
Key Policy Rate	1.776	1.5	1.236	5.75	0.5	371

Note: σ is the daily standard deviation of bond returns (%), VIX is the daily volatility implied by index options on S&P500 (%) and CDS is an index value of Eurozone credit default swap spreads. Auction size is the amount issued expressed in billions of NOK and bidders is the realised number of bidders. The key policy rate in Norway at the time of the auction is denominated in percentage points.

auctions, *bidders* is the number of bidders submitting at least one tender, and *key policy rate* is the key policy rate in Norway at the time of the auction. The units of σ, *VIX* and *key policy rate* are percentage points, and the unit of *auction size* is billions of Norwegian kroner. *CDS* represents an engineered index value as opposed to a clean credit default swap premium. Therefore, the unit lacks an intuitive interpretation. For all the variables except *CDS*, we have 371 observations. This corresponds to one per auction for which we calculate performance indicators. Due to data sparsity, we have 362 observations for the CDS index.

The average volatility of bond returns is 0.13%, varying between 0.00% (rounded form 0.003%) and 1.11%. The mean value of *VIX* is 1.12%, and the maximum and minimum values are 3.87% and 0.59% respectively[4]. The mean auction size is NOK 3.79 Bn, varying between NOK 2 Bn and NOK 8 Bn. On average, 4.93 bidders participated, with a maximum of 11 bidders and a minimum of 4 bidders. The mean key policy rate in Norway was 1.78% in our data sample, with a minimum of 0.50% and a maximum of 5.75%. The minimum interest rate of 0.50% is the lowest key policy rate Norges Bank has operated with historically.

Next, we compare the performance observed in our study with performance reported in the existing literature. One must be careful when comparing underpricing for two reasons. The first is that the underpricing is averaged over the securities in the study, which means that it is averaged over securities of different durations. Secondly, the quotes from the secondary market may not be used equivalently when estimating the secondary market price. To overcome

[4]VIX is transformed to daily standard deviation. Corresponding annualised mean is 17.78%.

Table 6.3: Comparison of underpricing and volatility for various duration bands

Years	Duration 2	3	4	5	6	7	8	All	Observations
	Panel A: Underpricing								
Norway	0.054	0.108	0.051	0.076	0.102	0.183	0.222	0.120	100
Sweden	-0.001	0.061	0.017	0.086	0.204	0.195	0.109	0.120	93
Finland	0.019	0.010	0.004	0.043	0.028	0.128	0.067	0.041	156
	Panel B: Volatility								
Norway	0.047	0.093	0.121	0.178	0.244	0.366	0.343	0.219	101
Sweden	0.259	0.334	0.408	0.546	0.600	0.509	0.888	0.496	93
Finland	0.174	0.238	0.337	0.314	0.439	0.399	0.361	0.346	175

Note: Our findings of underpricing and volatility in conjunction with the findings of Nyborg et al. (2002) and Nyborg et al. (2005). The underpricing is defined in subsection 5.1.1 and is denoted as per cent of face value. The volatility is the daily standard deviation of bond returns (%). The underpricing of Sweden (1990–94) and Finland (1992–99) are gathered from Nyborg et al. (2002) and Nyborg et al. (2005) respectively. The numbers corresponding to Norway are the results from our study. The underpricing and volatility in the "all"-column is the average of bonds with 2–8 years of duration. The estimated volatility in Sweden and Finland are estimated with an ARCH(2) model, while volatility in Norway is estimated with a GARCH(1,1)-model.

these challenges of comparability, we examine whether there is a consistency in underpricing across duration bands. We control for the possibility that volatility drives underpricing by also considering the estimated volatilities for each duration band. The connection between underpricing and volatility is intuitive; higher volatility yields greater uncertainty about the true value. Therefore, the underpricing should increase in order for the auction participants to avoid losses. Proceeding, we compare our findings of underpricing to those of Nyborg et al. (2002) and Nyborg et al. (2005). A summary can be found in table 6.3.

Consider the underpricing in Norway and Sweden for bonds with 2–8 years of duration presented in Panel A. The underpricing in Norway is on average higher for auctions of bonds with 2, 3, 4 and 8 years duration. Nonetheless, the average underpricing across all duration bands is measured to be 0.120% of face value both in Norway and Sweden. In Sweden, the underpricing is measured using the bid quote, as Nyborg et al. (2002) claim that this benchmark is the best proxy. Our measure of underpricing uses the mid-quote, as empirical analysis shows that this measure is the most appropriate (see subsection 5.1.1 for a discussion on measures of underpricing). Consider now the difference in volatility between the studies of Norway and

Sweden. Panel B shows that the volatility of bond returns in Norway is consistently lower compared to the volatility in Sweden for all duration bands. It should be noted that the volatility is measured over different periods, which may have an influence. Nonetheless, the higher volatility intuitively suggests that the underpricing in Sweden could be higher than in Norway. However, table 6.3 shows that they are quite similar.

Now compare the underpricing found in Norway with that found in Finland for all duration bands. The underpricing is consistently higher in Norway. On average over the duration bands, the underpricing is 0.120% and 0.041% of face value in Norway and Finland respectively. In addition, we observe in Panel B that the volatility in Norway is lower for all duration bands. Again, it should be noted that the volatility is measured over different periods. On average, the volatility is 0.219% in Norway and 0.346% in Finland. As the benchmark measures used in our study and in Finland both are representative of the true transaction yield, they do not invalidate the evidence of higher underpricing in Norway. Testing for difference in mean underpricing between Norway and Finland shows that the difference is significant at a 1% level. Taking all of the presented moments into account, the data suggests higher underpricing in Norwegian Treasury auctions when compared to Finnish Treasury auctions. As previously mentioned, the Norwegian state does not need to borrow money as an effective oil-corrected budget deficit is covered by the Government Pension Fund Global. It is therefore unexpected to find the disproportionately high levels of underpricing in the auctions we study when compared to other countries.

With regards to *auction dispersion*, it is not meaningful to compare the numbers across the studies. The reason is that Bjønnes (2001), Nyborg et al. (2002) and Nyborg et al. (2005) all report intrabidder dispersion as they examine individual bidder behaviour. In this part of our analysis, we look at total dispersion across all bidders in an auction because we examine performance on an auction level. Later, in subsection 6.2.1, we comment on our observed intrabidder dispersion compared to other studies. As for *coverage ratio*, Bjønnes (2001) finds the average coverage ratio to be 2.79, while Nyborg et al. (2002) report an average coverage ratio of 2.41. The average values in these studies are of similar magnitude to our finding of 2.52. Nyborg et al. (2005) do not report coverage ratio in their study of Finland. In the auctions we study, there are on average 5 participants in the auctions. By comparison, there were on average 13 bidders in Bjønnes (2001), 14 bidders in Nyborg et al. (2002) and 8 bidders in Nyborg et al. (2005). It is reassuring for the Norwegian government that the low number of bidders participating in the auctions does not seem to influence the competitive intensity.

6.1.2 Determinants of Auction Performance

In this subsection, we examine the relationships between exogenous variables and auction performance. We first present our initial hypotheses regarding how the exogenous variables affect auction performance, before we present and discuss the results.

Hypotheses

First, consider the uncertainty measures. Intuitively, increased uncertainty is expected to yield higher underpricing. High uncertainty concerning the terms to be offered in the secondary market makes the bidders submit bids below their expected true value of the security. This is to make sure that they do not lose money by participating in the auction. Given that the true value is less clear to the auction participants, we expect them to disperse their bids to a greater extent as well. The way uncertainty affects the coverage ratio is less obvious. One can argue that greater uncertainty in the bond markets will reduce the incentive to submit bids. This is because bidders are less sure about whether they can make money on the securities being auctioned.

We expect that there is a static component in the demand for government debt so that demand does not increase (decrease) proportionally with supply. Thus, greater supply is expected to yield lower coverage ratios, while lower supply is expected to yield higher coverage ratios. Given this reduction in competition, greater volume supplied is also expected to yield higher underpricing. The effect on auction dispersion is not apparent, but opportunistic bidders may be inclined to disperse their bids more in case many bids are needed to fill the supply.

An increase in the number of bidders participating is expected to yield higher a coverage ratio

Table 6.4: Summary of hypotheses concerning how exogenous variables impact the auction performance

	Underpricing	Auction Dispersion	Coverage Ratio
Uncertainty	+	+	-
Auction Size	+	+	-
Number of Bidders	-	-	+
Key Policy Rate	+	+	-

Note: The table summarises the hypotheses regarding the relationships between the performance indicators and the exogenous variables. "+" indicates that a positive relationship is expected between the performance indicator and the regressor. "-" indicates that a negative relationship is expected.

as more bids are submitted in the auction. We expect bidders to disperse their bids less as the competitive intensity becomes greater. The same argument goes for why more bidders intuitively will reduce underpricing. In addition, an increase in the number of participants makes collusion harder to maintain in any market where collusion exists.

Lastly, an increase in key policy rate is expected to yield higher underpricing and greater auction dispersion. This is because a higher interest rate leads to decreased popularity for low-yielding government debt as other low-risk investments may provide equally good or better returns. Thus, bidders may be tempted to disperse their bids downwards and submit bids below their expected true value in an effort to increase their return from the auctioned securities. Following the same line of reasoning, we expect a negative relationship between key policy rate and coverage ratio. The hypotheses are summarised in table 6.4.

Regression Results

To examine the determinants of auction performance, we estimate the following equation for all three performance indicators:

$$y = c + \beta_1 \cdot \sigma + \beta_2 \cdot new * \sigma + \beta_3 \cdot VIX + \beta_4 \cdot CDS + \beta_5 \cdot size + \beta_6 \cdot bidders + \beta_7 \cdot KPR \quad (6.1)$$

where y is one of the three performance variables, σ is the GARCH-estimated volatility and *new* is a multiplicative dummy equal to 1 for auctions of new securities and 0 for reopening auctions. *VIX* is the daily volatility implied by index options on S&P500 and *CDS* is the credit default swap index. *Size* is the auction size, *bidders* is the realised number of bidders and *KPR* is the key policy rate. The results are listed in table 6.5. The relationships with all explanatory variables tested in a univariate manner can be found in Appendix A.4. The regressions with *coverage ratio* and *auction dispersion* as dependent variables both exhibit signs of heteroskedasticity. These regressions have therefore been estimated with Huber-White-Hinkley robust standard errors. The regression with *underpricing* as a dependent variable exhibits signs of both heteroskedasticity and autocorrelation. We have therefore estimated this regression with Newey-West heteroscedasticity and autocorrelation consistent (HAC) robust standard errors.

The models suggest that uncertainty affects performance along the lines of our previous reasoning. *Volatility* (σ), estimated by a GARCH(1,1)-model, has a positive effect on both underpricing and auction dispersion. As can be seen in Appendix A.4, this is the variable that best explains underpricing and auction dispersion univariately. In order to evaluate the economic magnitude of these effects, we can discuss standardised coefficients for the predictor variables. It is indicated that a change of one standard deviation in volatility will yield 0.08 additional percentage points of underpricing and 0.24 percentage points of additional dispersion. The relationship with the coverage ratio is negative, as expected. Volatility has a stronger effect on auction dispersion if the auctioned paper is a new issue, shown through *new**σ. An increase of one standard deviation in the volatility measure will cause additional dispersion of 0.13 percentage points in the auction of a new security. *VIX* has a positive effect on the coverage ratio. An interpretation of this result is that volatility in the bond markets will, ceteris paribus, lead to lower coverage ratios as previously suggested. However, if the uncertainty in the global equity markets is high as well, then government debt regains popularity from investors and the coverage ratio is increased. Furthermore, *VIX* is the single variable that has the greatest explanatory power on coverage ratio. This can be seen from the univariate specifications in Appendix A.4. Greater default risk in the Eurozone, denoted through *CDS*, corresponds to more bid dispersion and increased underpricing. This is consistent with the hypotheses.

Table 6.5: Influence on auction performance from exogenous variables

	Underpricing	Auction Dispersion	Coverage Ratio
Constant	-0.193***	0.107	2.128***
	(0.064)	(0.069)	(0.314)
σ	0.511***	1.521***	-0.542*
	(0.075)	(0.127)	(0.297)
New*σ	0.189	0.809**	0.082
	(0.302)	(0.321)	(0.541)
VIX	0.043	-0.055	0.335**
	(0.042)	(0.035)	(0.131)
CDS Index	0.015**	0.041***	0.026
	(0.006)	(0.013)	(0.051)
Auction Size	0.018***	-0.004	-0.137***
	(0.005)	(0.006)	(0.025)
Bidders	0.007	-0.027**	0.130**
	(0.015)	(0.013)	(0.051)
Key Policy Rate	0.015*	0.039***	-0.072
	(0.009)	(0.011)	(0.040)
R^2	0.307	0.641	0.128
Adj. R^2	0.293	0.634	0.110
Observations	362	362	362

Note: Underpricing and auction dispersion is measured as per cent of face value. Coverage ratio is unitless. σ is the GARCH(1,1)-estimated standard deviation of daily returns (%) and "new" is a multiplicative dummy equal to 1 for auctions of new securities and 0 for reopening auctions. VIX is the daily volatility implied by index options on S&P500 (%), while CDS is an index value representing Eurozone credit default swap spreads. Auction size is expressed in billions of NOK, bidders is the realised number of bidders, and the key policy rate is denominated in percentage points. Standard errors are reported below the coefficients: Newey-West for underpricing and Huber-White-Hinkley for auction dispersion and coverage ratio.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Increased *auction size* is found to yield to more underpricing and lower coverage ratios, which comport with the hypothesis previously presented. *Number of bidders* has positive impact on coverage ratio and negative impact on auction dispersion. The interpretation is that an additional bidder leads to 0.03 percentage points lower weighted standard deviation in the submitted bids and a 0.13 increase in coverage ratio. Finally, a 1 percentage point increase in *key policy rate* gives 0.04 percentage points greater dispersion and 0.02 percentage points higher underpricing. These results are in line with our hypotheses.

A comparison of our findings and those of Bjønnes (2001), Nyborg et al. (2002) and Nyborg et al. (2005) is summarised in table 6.6[5]. Bjønnes (2001) finds a positive relationship between *volatility* (σ) and *dispersion*, which is in line with our results. The study finds *new**σ to have a positive relationship with both *dispersion* and *underpricing*. This is consistent with our findings for *dispersion*. However, we do not find a significant relationship between this regressor and *underpricing*. *Auction size* is reported to have negative impact on *dispersion*. In our study, we do not find a significant relationship between these variables. Furthermore, the study reports that the *number of bidders* has a positive coefficient when explaining *dispersion*, i.e. more bidders lead to greater dispersion. This is contrary to our findings. It should be mentioned that Bjønnes considers Treasury bills only, which may explain the difference[6]. Nyborg et al. (2002) finds that *volatility* has a positive impact on *underpricing* and *dispersion*. An increase in *auction size* is found to increase the level of dispersion. The impact of *volatility* is consistent with our findings, while we do not find *auction size* to have significant impact on *dispersion*. Finally, Nyborg et al. (2005) finds *volatility* to have a positive effect on both *underpricing* and *dispersion*. Thus, all significant relationships from the study of Finland comport with the ones found in our study. None of the studies uses *coverage ratio* as a regressand, making a comparison of this variable's determinants infeasible.

[5] We list the results from the full specifications shown in table 6.5 for our study, as the purpose of the table is to compare our findings to those of other studies. For robustness, we run regressions with only the regressors in table 6.6 and no coefficient sign, magnitude or significance level changes.

[6] When estimating the regression on auction dispersion using data from bill auctions only, we find bidders to have a positive but insignificant coefficient.

Table 6.6: Cross-study comparison of how exogenous variables affect auction performance

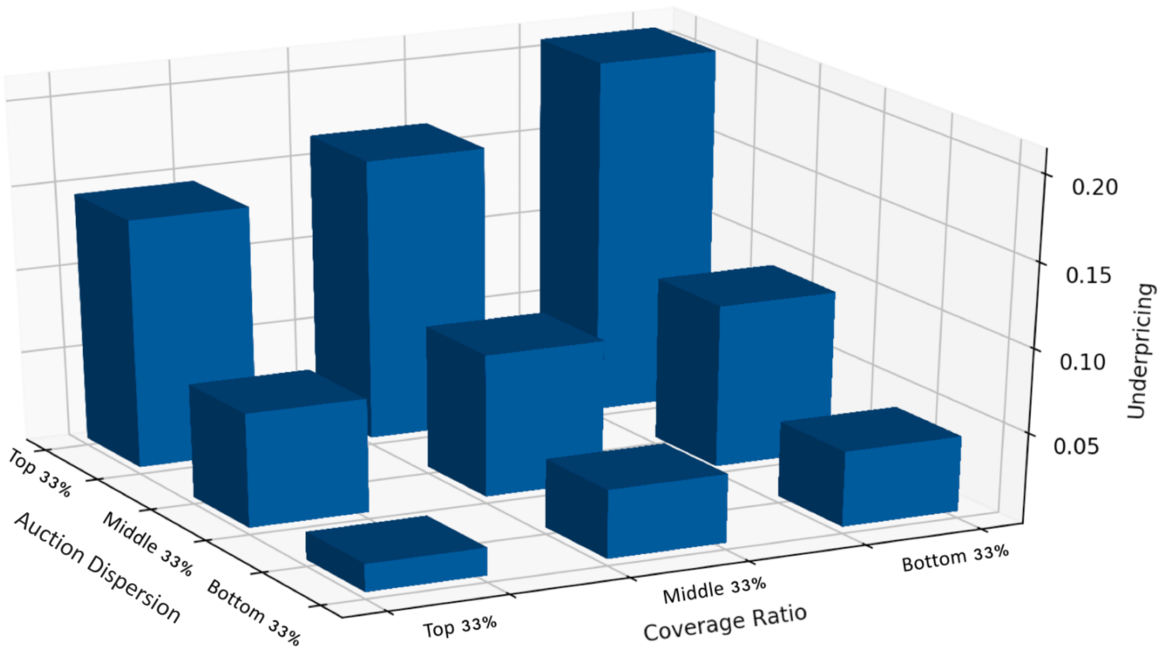
Study	Regressor					Observations
	σ	New*σ	Size	Bidders	R^2	
	Panel A: Underpricing					
Our study	0.511*	0.189	0.018*	0.007	0.293	362
Bjønnes (2001)	0.325	0.960*	0.000	0.001	0.465	68
Nyborg et al. (2002)	0.108*	-	-0.001	-	0.016	458
Nyborg et al. (2005)	0.215*	-	-0.009	-0.003	0.054	156
	Panel B: Dispersion					
Our study	1.521*	0.809*	-0.004	-0.027*	0.634	362
Bjønnes (2001)	0.188*	0.243*	-0.001*	0.001*	0.288	883
Nyborg et al. (2002)	0.203*	-	0.001*	-	0.442	5,831
Nyborg et al. (2005)	0.161*	-	-0.019	-0.003	0.222	175

Note: Our findings regarding the determinants of underpricing and auction dispersion in conjunction with the findings of Bjønnes (2001), Nyborg et al. (2002) and Nyborg et al. (2005). Bjønnes (2001) and Nyborg et al. (2002) report dispersion as intrabidder dispersion, while Nyborg et al. (2005) reports average intrabidder dispersion. We study the total dispersion for all bidders in an auction. Bjønnes (2001) and our study report adjusted R^2, the other studies report regular R^2.
* $p<0.05$

6.1.3 Relationship Between Performance Variables

In the previous subsections, we analysed and commented on the performance variables separately. Now, we present how the three performance variables interact and affect one another. We therefore introduce figure 6.1. We can see from the figure that *auction dispersion* and *underpricing* exhibit a positive relationship, i.e. higher observations of auction dispersion correspond to higher average underpricing regardless of the coverage ratio obtained in the auction. This is in line with the findings of Cammack (1991), who argues that the underpricing is positively related to the dispersion of bids. *Coverage ratio* exhibits a negative relationship with *underpricing*. We can see that observations with lower coverage ratios correspond to higher average underpricing, regardless of the bid dispersion in the auction. To our knowledge, this relationship is not empirically examined in the existing literature. Overall, the results implicate that in order to minimise underpricing in the auctions, it is desirable to obtain high coverage ratios and low auction dispersion. Inversely, the outcomes with the highest average underpricing are observed when auction dispersion is high and the coverage ratio is low.

Figure 6.1: Relationship between underpricing, auction dispersion and coverage ratio



Note: Average underpricing for combinations of the highest, middle and lowest 33% of observations of coverage ratio and auction dispersion. The 10 most extreme observations of coverage ratio and auction dispersion are removed. All variables are defined in subsection 5.1.1.

6.2 Bidder Level Analysis

In subsection 6.2.1, we present an overview of the bidder behaviour and performance observed in Norwegian Treasury auctions. We also compare the bidder behaviour with that observed in other countries. We study auctions with an issuer who has the uncommon trait of not needing to borrow money. In addition, few bidders participate in the auctions we study as compared to other markets. Thus, examining bidding behaviour and comparing it with other markets is of particular interest for our dataset. Furthermore, we take a novel approach by analysing the impact that individual bidder behaviour has on bidder success. The results are presented and discussed in subsection 6.2.2.

6.2.1 Bidder Behaviour and Success

We now present descriptive statistics for all the variables defined in section 5.2. Table 6.7 shows descriptive statistics for the bidder performance metrics, namely *return*, *share awarded* and *award ratio*. For each of the success measures, we present statistics for three samples: bill auctions, bond auctions, and all auctions together. As discussed in subsection 6.1.1, we only have market quotes for 371 of the 374 auctions. When calculating the return measure, this translates to having data for 1,830 of 1,842 bid schedules (1,016 bill schedules and 814 bond schedules). Although market prices are not a part of the calculation of *share awarded* and *award ratio*, we calculate descriptive statistics for the reduced sample of 1,830 bid schedules to keep the data comparable[7].

Consider *return*, which measures how much NOK underpricing a bidder earns relative to her tendered volume. As discussed when defining this measure in subsection 5.2.1, it is intended to capture a bidder's total return relative to other bidders regardless of the tenderer's size. The average return is higher in bond auctions than in bill auctions. The maximum return in bill and bond auctions is 1.48% and 1.58% respectively, which corresponds to the maximum auction underpricing given in table 6.1. The reason is that some bidders are awarded their full tendered volume in the auctions with the greatest underpricing. The minimum return is -0.03% in bill auctions and -0.16% in bond auctions. Given that these numbers are less negative than the minimum underpricing, it means that no bidder is awarded their full tendered volume in those auctions. Lastly, we observe greater deviation of returns in bond auctions than in bill auctions. Given that also the deviation of underpricing is higher in bond auctions than in bill auctions, this is sensible.

Next, consider *share awarded*. This variable measures the volume a bidder is awarded as a fraction of the auction supply, meaning it can never exceed 1. This measure is likely to be influenced by the size of a bidder but can uncover whether any single participant has an unparalleled influence on the auction outcome. The average share awarded in auctions overall

[7]Including the twelve bid schedules has negligible influence on the statistics. Median share awarded in bill auctions increases by 0.001 to 0.183. Average and median award ratio in bill auctions decreases by 0.001 and 0.002 to 0.443 and 0.419, respectively. All other metrics are unaffected.

Table 6.7: Descriptive statistics for bidder success measures

	Return			Share Awarded			Award Ratio		
	Bills	Bonds	All	Bills	Bonds	All	Bills	Bonds	All
Mean	0.030	0.081	0.053	0.196	0.211	0.203	0.444	0.452	0.447
Median	0.014	0.035	0.019	0.182	0.175	0.176	0.421	0.432	0.427
Std. Dev	0.072	0.154	0.119	0.167	0.164	0.166	0.296	0.269	0.285
Max	1.484	1.575	1.575	0.950	0.888	0.950	1	1	1
Min	-0.027	-0.155	-0.155	0	0	0	0	0	0
Observations	1,016	814	1,830	1,016	814	1,830	1,016	814	1,830

Note: Return, share awarded and award ratio are defined in subsection 5.2.1. The descriptive statistics for the variables are given for three samples; bill auctions only, bond auctions only and all auctions altogether. The unit of return is percent. Share awarded and award ratio are unitless.

is 20.3%, 19.6% in bill auctions and 21.1% in bond auctions. The maximum share awarded in bill auctions is 95.0%, and the maximum share awarded in bond auctions is 88.8%. Concerning the maximum values, we note two things: First, no auction is cornered, i.e. a single bidder is never allocated the full auction supply. Second, it is only occasional that a bidder is awarded a great majority of the supply[8]. Therefore, it does not seem to be any single bidder which de facto decides the auction outcome.

Finally, consider *award ratio*. This success measure is unaffected by a bidder's size. When a bidder demands NOK 2 Bn in an auction, this implies that she has made this amount available and is interested in exchanging it for the auctioned security. *Award ratio* measures how successful she is in this endeavour as it represents the fraction of the tendered volume that obtains allotment. The average award ratio is 44.4% in bill auctions and 45.2% in bond auctions, indicating small differences across the instruments. Furthermore, we can see that bidders are awarded their full tendered volume in both bill and bond auctions, and also that bidders end up submitting completely unsuccessful schedules in both auction forms[9].

Table 6.8 shows summary statistics for the bidder behaviour in the auctions we study. We consecutively compare the behaviour found with that of other countries, before we discuss the similarities and differences at the end of this subsection. We include two relative measures of

[8]The maximum share awarded of 95% is a one-time incident. In only 7 bill auctions and 8 bond auctions is any single bidder awarded more than 75% of the auction supply.

[9]130 bid schedules are awarded their full tendered volume (92 and 38 occurrences in bill and bond auctions respectively). Conversely, 147 bid schedules are completely unsuccessful in our sample (107 schedules in bill auctions and 40 schedules in bond auctions).

demand. First, consider *share of supply* which is a bidder's demand relative to the auction supply. A bidder on average tenders for 49.3% of the auction supply in bill auctions and 53.6% in bond auctions. This is a large amount compared to the mean values of 21.4% reported in Bjønnes (2001) for Norway and 18.8% reported by Nyborg et al. (2002) for Sweden. *Share of demand* is a bidder's demand reported as a fraction of the total demand in the auction. The average is 19.6% and 21.1% in bill auctions and bond auctions respectively. The minimum share of supply and minimum share of demand are reported as 0.000 for bond auctions and all auctions due to the choice of decimal places. However they can per definition not be zero, and the values are 3 basis points and 1 basis point respectively. *Share of demand* is a measure not used in the literature, which makes comparison with other studies infeasible.

Discount, i.e. the difference between the quantity weighted average bid and the secondary market price, is on average 0.152 per cent of face value in the auctions we study. This is high compared to 0.075, 0.092 and 0.081 per cent of face value found by Bjønnes (2001), Nyborg et al. (2002) and Nyborg et al. (2005) respectively. That being said, from the minimum values we observe that the bidders occasionally submit tenders with negative discounts. This means that they bid at a price level that is higher than what was observed in the market the last day before the auction.

Furthermore, we include two measures of dispersion. First, *intrabidder dispersion* is the quantity weighted standard deviation of bids in the full schedule. The average in bill auctions is 0.060 per cent of face value. This is high compared to the average of 0.022 per cent of face value found in bill auctions by Bjønnes (2001). The intrabidder dispersion found in Nyborg et al. (2002) is 0.046, which is also lower than our result even though it is calculated across both bill and bond auctions. Our finding is in line with the average of 0.065 per cent of face value from Nyborg et al. (2005). However, this paper studies bond auctions. The average intrabidder dispersion we find in bond auctions, 0.415 per cent of face value, looks disproportionately high compared to the findings of all the other studies. The second dispersion measure is *bottom spread*, calculated as the spread between the quantity weighted average bid in the full schedule and the quantity weighted average bid in the bottom 20% of the schedule. On average, the bottom spread is 0.110 per cent of face value in bill auctions and 0.772 per cent of face value in bond auctions. Similar to *share of demand*, this variable is not a measure used in the literature, making a comparison infeasible.

Finally, consider *bids submitted* and *bids awarded*. On average, a bidder submits 9.6 bids of which 4.3 obtain allotment in bill auctions. In bond auctions, the equivalent numbers are 14.5 and 5.6. The average number of bids per schedule found by Bjønnes (2001), Nyborg et al. (2002) and Nyborg et al. (2005) is 5.2, 4.9 and 2.7 respectively. The minimum value for the number of awarded bids is 0 in both bill and bond auctions. This can indicate that bidders occasionally submit highly opportunistic bid schedules or that there are bidders with deviating valuations compared to the rest of the participants. Naturally, it can also be a combination of the two. Finally, we note that the average bid schedule in bond auctions contains five more bids than that of a bill auction, although only one more bid is accepted.

Overall, it is evident that the bidders tender for high demand through many bids compared to the existing literature. It is also clear that they bid with high discount and high dispersion of bids. To some extent, this may be explained by the low number of primary dealers participating in the auctions. In Norway, customer bids are concentrated to fewer dealers. Thus, the demand and number of bids per auction participant intuitively increase relative to a scenario with a larger number of primary dealers. With respect to bid dispersion and discount, however, the consequence of a low number of auction participants is less clear. High discount is intuitively connected with greater potential for underpricing in the auction at the cost of not obtaining allotment for the bids submitted. In subsection 6.1.3 we also established a positive relationship between dispersion and underpricing. Thus, the high values for discount and bidder dispersion may indicate that the bidders have some degree of market power or opportunity to behave strategically. That would be the case if the bidders are in a position where they can submit bid schedules which enhances their outcome without being concerned about obtaining allotment. If such a scenario is to occur, it would likely be in a market with a low amount of bidders. These findings further motivate the subsequent examination into how bidding behaviour influences bidder success.

Table 6.8: Descriptive statistics for bidder behaviour measures

	Mean	Median	Std. Dev	Max	Min	Observations
	Panel A: Treasury bill auctions					
Share of Supply	0.493	0.425	0.378	2.043	0.003	1,016
Share of Demand	0.196	0.176	0.138	0.643	0.001	1,016
Discount	0.087	0.043	0.169	1.894	-0.499	1,016
Intrabidder Dispersion	0.060	0.038	0.090	1.025	0	1,016
Bottom Spread	0.110	0.070	0.164	2.363	0.002	716
Bids Submitted	9.558	9	5.935	36	1	1,016
Bids Awarded	4.321	4	3.416	20	0	1,016
	Panel B: Treasury bond auctions					
Share of Supply	0.536	0.475	0.372	2.650	0.000	814
Share of Demand	0.211	0.194	0.127	0.652	0.000	814
Discount	0.232	0.200	0.409	3.326	-1.205	814
Intrabidder Dispersion	0.415	0.343	0.422	7.184	0	814
Bottom Spread	0.772	0.612	0.671	8.058	0.046	697
Bids Submitted	14.517	13	8.822	67	1	814
Bids Awarded	5.560	5	4.232	29	0	814
	Panel C: All auctions					
Share of Supply	0.512	0.450	0.376	2.650	0.000	1,830
Share of Demand	0.203	0.187	0.134	0.652	0.000	1,830
Discount	0.152	0.066	0.309	3.326	-1.205	1,830
Intrabidder Dispersion	0.218	0.086	0.339	7.184	0	1,830
Bottom Spread	0.437	0.210	0.588	8.058	0.002	1,413
Bids Submitted	11.764	11	7.762	67	1	1,830
Bids Awarded	4.872	4	3.850	29	0	1,830

Note: All variables are defined in subsection 5.2.2. Share of supply and share of demand are unitless. The units of discount, intrabidder dispersion and bottom spread are per cent of face value. Bids submitted is the number of bids submitted by a tenderer in an auction, while bids awarded is the number of awarded bids of a tenderer in an auction. This includes bids that are partially awarded due to the pro rata award system used on bids at the stop-out price. For bottom spread, there are fewer observations as not all bid schedules contain enough bids to meaningfully calculate the spread.

6.2.2 The Influence of Bidder Behaviour on Bidder Success

We now investigate how bidder behaviour impacts bidder success. To our knowledge, we are the first to examine these relationships empirically. We carry out the examination in three steps. First, we investigate the relationship between bidder success and the behaviour exercised by individual bidders. This analysis only regards measures describing the choices made by the bidders themselves. It therefore represents the relationship between behaviour and success that is observable for the auction participants. Since we are in possession of all bid schedules submitted, we further investigate whether the effects on a bidder's success originate from her own choices or from the overall bidding of all participants. Finally, we study how the auction outcome depends on the outcome in the previous auction. We do this to test for any patterns in success which may reveal strategic behaviour or an ability to utilise successful bidding strategies over time.

The goal of this analysis is partly to examine how the choices made by a bidder prior to submitting her bids affect her *return*, *share awarded* and *award ratio*. When doing so, we only include variables that are based on data known prior to the auction. To achieve this, we make a small change: the discount measure defined in subsection 5.2.2 compares the quantity weighted average bid with the secondary market price at the end of the auction day. This measure appropriately describes the realised discount in the auctions. Additionally, this definition makes our results comparable to those in the literature when we present the findings in subsection 6.2.1. However, the secondary market price at the end of the auction day is obviously not known when the tenderers submit their bid schedules. Therefore, we use a redefined discount measure in the subsequent analyses. The new definition is to compare the quantity weighted average bid with the secondary market price at the end of the last day before the auction.

The relationships with all explanatory variables tested in a univariate manner can be found in Appendix A.5. All of the regressions exhibit signs of both heteroskedasticity and autocorrelation, and they are consequently estimated with Newey-West heteroscedasticity and autocorrelation consistent (HAC) robust standard errors.

Table 6.9: Influence on return from individual bidding behaviour

	(a)	(b)	(c)
Share of Supply	-0.034***	-0.037***	-0.037***
	(0.010)	(0.012)	(0.011)
Intrabidder Dispersion	0.081***		-0.027
	(0.025)		(0.041)
Discount	0.036	0.045**	0.050**
	(0.022)	(0.022)	(0.023)
Bottom Spread		0.049***	0.063**
		(0.012)	(0.025)
Fixed Effects	Yes	Yes	Yes
R^2	0.138	0.133	0.134
Adj. R^2	0.128	0.126	0.126
Observations	1,830	1,413	1,413

Note: The return metric measures how much underpricing a bidder is awarded as a fraction of her tendered volume. Share of supply, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The unit of return is percent. Share of supply is unitless. The units of intrabidder dispersion, discount and bottom spread are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The Influence of a Bidder's Ex-Ante Choices

Consider first the specifications with *return* as the dependent variable presented in table 6.9. The models suggest that increased demand has an unfavourable effect on return, shown through the negative coefficient of *share of supply.* From the perspective of a bidder, it seems that increased dispersion of bids, represented both through *intrabidder dispersion* and *bottom spread*, affects return positively. In addition we can see that the spread between the bottom 20% of the bids and the average bid is more important than the overall dispersion in the bid schedule. This is implied by *intrabidder dispersion's* loss of explanatory power when also *bottom spread* is included in specification (c). The positive coefficient of *discount* might seem intuitive, but increasing the discount offers a trade-off: On one hand, a bidder may obtain a lower stop out price, and this will increase the return. On the other hand, however, the bid may not obtain allotment. In that case, the return will decrease.

Table 6.10: Influence on share awarded from individual bidding behaviour

	(a)	(b)	(c)
Share of Supply	0.253***	0.237***	0.237***
	(0.016)	(0.018)	(0.018)
Intrabidder Dispersion	0.059***		-0.011
	(0.010)		(0.029)
Discount	-0.116***	-0.131***	-0.129***
	(0.014)	(0.016)	(0.016)
Bottom Spread		0.044***	0.050***
		(0.007)	(0.016)
Fixed Effects	Yes	Yes	Yes
R^2	0.488	0.365	0.365
Adj. R^2	0.482	0.360	0.359
Observations	1,830	1,413	1,413

Note: The share awarded measures awarded volume as a fraction of the auction supply. Share of supply, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. Share awarded and share of supply is unitless, while the units of intrabidder dispersion, discount and bottom spread are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Next, we study the specifications with *share awarded* as the dependent variable given in table 6.10. Contrary to the results for *return*, we here observe that increased demand is positively related to the share awarded. This is sensible: All the time a bidder alters no other aspect of her bid schedule, increasing the volume demanded is the only way to increase the volume awarded. Increased dispersion of bids is also suggested to have a positive impact. In line with the results for *return*, it is clear that the dispersion in the bottom part of the bid schedule influences bidder success more than the dispersion in the overall schedule. This is made evident when *bottom spread* is included as an explanatory variable together with *intrabidder dispersion* in specification (c). We then observe that the latter has no significant explanatory power. Increased *discount* is implied to reduce the share awarded. This is intuitive: If a bidder increases her discount (bids at lower prices as compared to the secondary market price), her bids are, ceteris paribus, less likely to obtain allotment.

Finally, consider the specifications with *award ratio* as the dependent variable presented in

Table 6.11: Influence on award ratio from individual bidding behaviour

	(a)	(b)	(c)
Share of Supply	-0.202***	-0.196***	-0.196***
	(0.021)	(0.021)	(0.021)
Intrabidder Dispersion	0.131***		0.004
	(0.023)		(0.048)
Discount	-0.261***	-0.219***	-0.220***
	(0.037)	(0.033)	(0.034)
Bottom Spread		0.076***	0.074***
		(0.013)	(0.025)
Fixed Effects	Yes	Yes	Yes
R^2	0.195	0.204	0.204
Adj. R^2	0.186	0.198	0.197
Observations	1,830	1,413	1,413

Note: The award ratio measures the volume awarded as a fraction of the bidder's tendered volume. Share of supply, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. Award ratio and share of supply is unitless, while the units of intrabidder dispersion, discount and bottom spread are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

table 6.11. Similar to what was found for *return*, a negative relationship is suggested between demand and *award ratio* through the consistently negative coefficient of *share of supply*. Greater dispersion of bids is found to affect positively, and it is again suggested that *bottom spread* is the measure of dispersion with the greatest amount of explanatory power. *Intrabidder dispersion* becomes insignificant when also *bottom spread* is included in specification (c), and we observe the highest value for adjusted R^2 in specification (b). This is, in addition to univariate significance, testament to the explanatory power of *bottom spread*. For *discount*, the intuition regarding the negative sign follows that of its relationship with *share awarded*: Increased discount implies a lower price level in the bid schedule and consequently a lower probability of the bids obtaining allotment.

The Influence of Overall Bidding in the Auction

Next, we compare the influence individual bidders have on their success with the influence of the overall bidding in the auctions. This is done by introducing measures that account for overall bidding, namely *auction dispersion* and *coverage ratio.* These variables are both defined in subsection 5.1.1 and were included in the auction level analysis. In addition, we include *share of demand* which describes the demand of a bidder relative to the overall demand in the auction.

Consider first the specifications with *return* as the dependent variable presented in table 6.12. It is evident that the overall bidding in the auction is substantially more important than the behaviour of the individual bidder. This is manifested by the lack of significance for all relationships with individual bidder measures[10] in addition to the increase in R^2 when compared to table 6.9. Additionally, the low explanatory power from the individual bidder metrics is substantiated by the marginal alternation of R^2 values across the specifications. The absence of influence a bidder has on her own success is not obvious, especially given the low number of participants in the Norwegian Treasury auctions. As a reminder, return is effectively defined as *underpricing* · *fraction of bids awarded.* The finding that bidders individually have low influence on the underpricing indicates no or small market power for the bidders in this dimension of success. This is naturally positive from the perspective of Norges Bank, as it indicates an absence of strategic behaviour in the auctions. Intuitively, one might expect that a bidder to some extent is able to influence her return through the fraction of bids awarded. However, the results suggest that the overall bidding and its effect on underpricing influence the return obtained to a far greater extent. With regards to *auction dispersion* and *coverage ratio*, the variables affect return in a manner consistent with the findings in subsection 6.1.3: Increased dispersion yields higher returns, while higher interest in the auctions affects return negatively.

Next, we study the specifications with *share awarded* as the dependent variable shown in table 6.13. Contrary to the previously described results for *return*, we here observe that the individual bidder behaviour is what impacts success. Overall bidding in the auction is implied

[10] *Share of supply*, *share of demand*, *intrabidder dispersion*, *discount* and *bottom spread.*

Table 6.12: Influence on return from individual bidding behaviour and overall bidding in the auction

	(a)	(b)	(c)	(d)	(e)	(f)
Share of Supply	-0.001		-0.011	0.001		0.012
	(0.006)		(0.032)	(0.005)		(0.036)
Share of Demand		0.002	0.030		-0.001	-0.032
		(0.016)	(0.087)		(0.019)	(0.104)
Intrabidder Dispersion	-0.021	-0.021	-0.021			
	(0.019)	(0.019)	(0.019)			
Discount	0.030	0.030	0.029	0.027	0.027	0.027
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Bottom Spread				0.002	0.002	0.002
				(0.009)	(0.009)	(0.009)
Auction Dispersion	0.141***	0.141***	0.141***	0.116***	0.116***	0.116***
	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)
Coverage Ratio	-0.025***	-0.025***	-0.023***	-0.029***	-0.028***	-0.031**
	(0.007)	(0.007)	(0.009)	(0.009)	(0.008)	(0.012)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.233	0.233	0.233	0.222	0.222	0.222
Adj. R^2	0.223	0.223	0.223	0.215	0.215	0.214
Observations	1,830	1,830	1,830	1,413	1,413	1,413

Note: The return metric measures how much underpricing a bidder is awarded as a fraction of her tendered volume. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. Auction dispersion and coverage ratio are defined in subsection 5.1.1. The unit of return is percent. Share of supply, share of demand and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

to affect the outcome only in specification (a) and (d) where *coverage ratio* has a significant relationship. However, it seems that *coverage ratio* is significant in these specifications only because it, together with *share of supply*, approximates the relative demand of the bidder. This is evident from the loss of explanatory power in the specifications where *share of demand* is included. In addition, the specifications including *share of demand* have substantially higher R^2 values. As *share awarded* concerns awarded volume relative to other bidders, it is meaningful that demand relative to other bidders is the most relevant demand measure. In total, the results indicate that bidders are able to influence their outcome, also after adjusting for the overall bidding in the auctions. Although it is expected that the bidders are able to affect their outcome through the price level at which they bid, their influence through quantity demanded and dispersion of bids is less obvious. These findings indicate that the bidders inhabit some degree of market power in this dimension of success. This could potentially be related to the low number of bidders in Norway, as a higher number of auction participants intuitively would make it harder to influence the outcome in the auction. Furthermore, the relationships between the bidder behaviour variables and the share awarded are consistent with our findings in table 6.10. Increased demand, most significantly when represented relative to the other participants, has a positive effect. This is similar to the effect of an increase in the dispersion of bids, both when represented as *intrabidder dispersion* and as *bottom spread*. An increase in discount, however, affects negatively. As previously discussed, this is intuitive: If a bidder increases her discount (bids at lower prices as compared to the secondary market price), her bids are less likely to obtain allotment.

Finally, consider the specifications with *award ratio* as the dependent variable presented in table 6.14. While *return* is mainly determined by overall bidding and *share awarded* by the bidder's own choices, the award ratio is influenced by both concurrently. We see a considerable increase in R^2 values when compared with table 6.11, substantiating the importance of the overall bidding in the auction. In addition, the specifications with *auction dispersion* and *coverage ratio* yield the highest univariate R^2 values. Nonetheless, there are significant relationships with individual bidder variables as well. As the bidding behaviour has additional impact after adjusting for the overall bidding in the auction, it is indicated that the bidders have influence

Table 6.13: Influence on share awarded from individual bidding behaviour and overall bidding in the auction

	(a)	(b)	(c)	(d)	(e)	(f)
Share of Supply	0.330***		0.006	0.342***		0.024
	(0.018)		(0.036)	(0.020)		(0.048)
Share of Demand		0.971***	0.957***		0.976***	0.914***
		(0.040)	(0.085)		(0.045)	(0.115)
Intrabidder Dispersion	0.041***	0.040***	0.040***			
	(0.014)	(0.012)	(0.012)			
Discount	-0.114***	-0.116***	-0.116***	-0.136***	-0.134***	-0.134***
	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
Bottom Spread				0.041***	0.041***	0.041***
				(0.008)	(0.008)	(0.008)
Auction Dispersion	0.015	0.014	0.014	0.003	0.005	0.005
	(0.013)	(0.010)	(0.010)	(0.013)	(0.011)	(0.011)
Coverage Ratio	-0.067***	-0.002	-0.003	-0.087***	-0.004	-0.010
	(0.006)	(0.004)	(0.008)	(0.007)	(0.005)	(0.012)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.553	0.593	0.593	0.469	0.500	0.500
Adj. R^2	0.547	0.587	0.587	0.464	0.495	0.495
Observations	1,830	1,830	1,830	1,413	1,413	1,413

Note: The share awarded measures awarded volume as a fraction of the auction supply. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. Auction dispersion and coverage ratio are defined in subsection 5.1.1. Share awarded, share of supply, share of demand and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

on their success with respect to *award ratio*. In line with the discussion regarding a decrease in price level offered when presenting *share awarded*, *discount* has the expected sign. The relationship with *bottom spread* is positive and significant, indicating that bidders can influence the award ratio through the dispersion in the bottom part of their bid schedule. With regard to demand, it is evident that the overall demand in the auction, represented by *coverage ratio*, is more important than the demand from the individual bidder. According to intuition, increased overall demand in the auction lowers the likelihood that any random bid will obtain allotment. This resonates well with the negative coefficient on *coverage ratio*. Auction level dispersion has a positive relationship with award ratio, which also is sensible: Increased dispersion in the bids of all participants makes it more likely that a bidder's tenders will be awarded. This follows from the discussion presented when defining *auction dispersion* in subsection 5.1.1, suggesting that an increase in this measure corresponds to a tendency of bidders spreading their bids downwards.

The Influence of Past Performance

Lastly, we examine how bidder success is affected by the outcome in the previous auction. We do this by adding three new explanatory variables to the regressions: *last return*, *last share awarded* and *last award ratio*. The variables are assigned values from the relevant bidder's outcome in the last auction of the same instrument type. As an example, we may study bidder 3's bid schedule in bill auction number 150. *Last return* will then be the return bidder 3 obtained in bill auction 149. If she did not participate in that auction, the bid schedule is discarded from the data sample, and we proceed to review how the return in auction 150 is related to the return in auction 151. As not all bidders participate in all auctions, we have fewer observations in these regressions as compared to when only considering behaviour exercised in the same auction.

These specifications test whether the impact on bidding success from bidding behaviour can be regarded as a function of past success and the current bidding behaviour. In other words, we test if past performance is indicative of future success. If this is the case, it can have

Table 6.14: Influence on award ratio from individual bidding behaviour and overall bidding in the auction

	(a)	(b)	(c)	(d)	(e)	(f)
Share of Supply	-0.013		0.085	-0.002		0.053
	(0.022)		(0.068)	(0.021)		(0.060)
Share of Demand		-0.072	-0.287		-0.022	-0.159
		(0.058)	(0.180)		(0.057)	(0.161)
Intrabidder Dispersion	0.040	0.041	0.041			
	(0.033)	(0.034)	(0.033)			
Discount	-0.261***	-0.261***	-0.260***	-0.238***	-0.238***	-0.238***
	(0.043)	(0.044)	(0.044)	(0.037)	(0.037)	(0.037)
Bottom Spread				0.044***	0.044***	0.044***
				(0.013)	(0.013)	(0.013)
Auction Dispersion	0.101***	0.101***	0.101***	0.071***	0.071***	0.071***
	(0.027)	(0.027)	(0.027)	(0.021)	(0.021)	(0.021)
Coverage Ratio	-0.164***	-0.166***	-0.183***	-0.160***	-0.160***	-0.173***
	(0.015)	(0.014)	(0.023)	(0.014)	(0.013)	(0.023)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.334	0.334	0.335	0.370	0.370	0.370
Adj. R^2	0.326	0.326	0.326	0.364	0.364	0.364
Observations	1,830	1,830	1,830	1,413	1,413	1,413

Note: The award ratio measures the volume awarded as a fraction of the bidder's tendered volume. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. Auction dispersion and coverage ratio are defined in subsection 5.1.1. Award ratio, share of supply, share of demand and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

several interpretations contingent upon the relationships found. A positive relationship with the previous outcome may imply that bidders are able to find successful bidding strategies and replicate them over time. A negative relationship may indicate risk aversion, e.g. where a high volume awarded subsequently yields a poor outcome due to a reduced appetite for risk. It could also suggest strategic interaction between bidders, where they take turns obtaining outcomes more successful than they could have if they were competing in every auction. Such a cooperation could result in poor outcomes systematically succeeding successful ones. We comment more thoroughly on interpretations of the relevant relationships when presenting the results found. We refrain from commenting on the variables that have already been discussed as the coefficient sign, magnitude and significance is similar between the previously presented specifications and the ones we now present[11].

First, consider the regressions with *return* as the dependent variable presented in table 6.15. It is evident that the outcome in the previous auction does not offer significant explanation for this success measure. This is manifested by the lack of significant relationships with the added variables[12] and the marginal impact on R^2 when compared to table 6.12. The result means that there is no readily available pattern in returns obtained by the bidders. Previously, we found the bidders to have low power with respect to influencing their return. Thus, it is not unanticipated that bidders do not seem to have found a successful bidding strategy to be replicated over time. We could have found signs of strategic interaction or risk aversion by establishing a negative relationship with past return. However, the data suggests no such relationships between past outcomes and current success.

Next we examine *share awarded* introduced in table 6.16. It is clear that the outcome in the previous auction seems to influence this performance measure. *Last share awarded* is consistently significant throughout all specifications, while *last award ratio* is significant in the specifications including *share of demand* (specifications (b), (c), (e) and (f)). In addition, both relationships are found to have high explanatory power univariately. The positive coefficient implies that bidder success with respect to the share awarded is clustered: Greater relative volume awarded

[11]The previously discussed variables are *share of supply*, *share of demand*, *intrabidder dispersion*, *discount*, *bottom spread*, *auction dispersion* and *coverage ratio*. See tables 6.12, 6.13 and 6.14 for further detail.

[12]The added variables are *last share awarded*, *last award ratio* and *last return*.

Table 6.15: Influence on return from individual bidding behaviour, overall bidding and the outcome of the previous auction

	(a)	(b)	(c)	(d)	(e)	(f)
Share of Supply	0.000		-0.001	0.002		0.014
	(0.005)		(0.030)	(0.006)		(0.037)
Share of Demand		0.000	0.002		0.002	-0.035
		(0.017)	(0.089)		(0.022)	(0.111)
Intrabidder Dispersion	-0.019	-0.019	-0.019			
	(0.019)	(0.019)	(0.019)			
Discount	0.030	0.030	0.030	0.027	0.027	0.027
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Bottom Spread				0.003	0.003	0.003
				(0.009)	(0.009)	(0.009)
Last Share Awarded	0.000	-0.001	-0.001	-0.011	-0.011	-0.010
	(0.017)	(0.018)	(0.019)	(0.024)	(0.024)	(0.024)
Last Award Ratio	0.021	0.021	0.021	0.027	0.027	0.027
	(0.017)	(0.017)	(0.017)	(0.026)	(0.026)	(0.026)
Last Return	-0.040	-0.040	-0.040	-0.055	-0.055	-0.054
	(0.044)	(0.044)	(0.044)	(0.050)	(0.051)	(0.051)
Auction Dispersion	0.139***	0.139***	0.139***	0.119***	0.119***	0.119***
	(0.037)	(0.037)	(0.037)	(0.036)	(0.036)	(0.036)
Coverage Ratio	-0.026***	-0.026***	-0.026***	-0.029***	-0.028***	-0.032***
	(0.007)	(0.006)	(0.008)	(0.009)	(0.008)	(0.012)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.227	0.227	0.227	0.228	0.228	0.228
Adj. R^2	0.218	0.218	0.218	0.219	0.219	0.219
Observations	1,759	1,759	1,759	1,396	1,396	1,396

Note: The return metric measures how much underpricing a bidder is awarded as a fraction of her tendered volume. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The three "last"-metrics give the outcome for the bidder from the last auction of the same instrument (bill/bond). Auction dispersion and coverage ratio are defined in subsection 5.1.1. The units of return and last return are percent. Share of supply, share of demand, last share awarded, last award ratio and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

in the previous auction indicates greater relative volume awarded in the next auction studied. This could, for example, originate from a momentum effect, where bidders are able to establish replicable strategies that yield successful outcomes with respect to their share awarded. Earlier, we found that bidders are able to influence their success in this dimension also when accounting for the overall bidding in the auction. Thus, it is reasonable to believe that the patterns we find between previous and current outcome are due to such successful strategies.

Finally, we study *award ratio* which is presented in table 6.17. The influence on *award ratio* from the previous auction is fairly similar to that on *share awarded*. The relationship with *last award ratio* is consistently significant, while the relationship with *last share awarded* is significant in specification (b) and (c). Following the discussion of the previous outcome's effect on *share awarded*, these relationships indicate clustering with respect to award ratio. Earlier we found that the bidders have some extent of power over their own award ratio, also when accounting for the overall bidding in the auction. The positive relationship with the previous outcome may therefore be due to bidders periodically following a replicable strategy to obtain larger amounts of auctioned securities. This could, for example, originate from bidders having excess cash on their balance to invest in low-risk securities.

Table 6.16: Influence on share awarded from individual bidding behaviour, overall bidding and the outcome of the previous auction

	(a)	(b)	(c)	(d)	(e)	(f)
Share of Supply	0.320***		0.007	0.335***		0.032
	(0.019)		(0.036)	(0.021)		(0.048)
Share of Demand		0.949***	0.931***		0.961***	0.877***
		(0.042)	(0.088)		(0.047)	(0.115)
Intrabidder Dispersion	0.042***	0.041***	0.041***			
	(0.013)	(0.012)	(0.012)			
Discount	-0.113***	-0.115***	-0.115***	-0.133***	-0.130***	-0.130***
	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Bottom Spread				0.040***	0.040***	0.040***
				(0.008)	(0.007)	(0.007)
Last Share Awarded	0.102***	0.070**	0.070**	0.077**	0.052*	0.053*
	(0.029)	(0.029)	(0.029)	(0.030)	(0.031)	(0.031)
Last Award Ratio	0.004	0.017*	0.017*	0.023	0.035**	0.035**
	(0.010)	(0.009)	(0.009)	(0.014)	(0.014)	(0.014)
Last Return	0.023	0.012	0.012	0.024	0.008	0.009
	(0.016)	(0.014)	(0.014)	(0.019)	(0.018)	(0.018)
Auction Dispersion	0.010	0.011	0.011	0.002	0.005	0.005
	(0.012)	(0.010)	(0.010)	(0.012)	(0.010)	(0.011)
Coverage Ratio	-0.067***	-0.002	-0.004	-0.086***	-0.004	-0.012
	(0.006)	(0.004)	(0.009)	(0.007)	(0.005)	(0.012)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.553	0.589	0.589	0.481	0.508	0.508
Adj. R^2	0.548	0.585	0.585	0.475	0.503	0.503
Observations	1,759	1,759	1,759	1,396	1,396	1,396

Note: The share awarded measures awarded volume as a fraction of the auction supply. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The three "last"-metrics give the outcome for the bidder from the last auction of the same instrument (bill/bond). Auction dispersion and coverage ratio are defined in subsection 5.1.1. Share awarded, share of supply, share of demand, last share awarded, last award ratio and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. The unit of last return is percent. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6.17: Influence on award ratio from individual bidding behaviour, overall bidding and the outcome of the previous auction

	(a)	(b)	(c)	(d)	(e)	(f)
Share of Supply	-0.023		0.069	-0.006		0.064
	(0.023)		(0.068)	(0.023)		(0.060)
Share of Demand		-0.099	-0.276		-0.039	-0.204
		(0.061)	(0.180)		(0.062)	(0.163)
Intrabidder Dispersion	0.044	0.044	0.044			
	(0.032)	(0.032)	(0.032)			
Discount	-0.254***	-0.254***	-0.253***	-0.231***	-0.231***	-0.231***
	(0.044)	(0.044)	(0.044)	(0.038)	(0.038)	(0.038)
Bottom Spread				0.043***	0.043***	0.043***
				(0.013)	(0.013)	(0.013)
Last Share Awarded	0.075	0.084*	0.084*	0.043	0.048	0.049
	(0.046)	(0.046)	(0.046)	(0.044)	(0.044)	(0.044)
Last Award Ratio	0.055*	0.052*	0.052*	0.093***	0.091***	0.090***
	(0.031)	(0.031)	(0.031)	(0.028)	(0.028)	(0.028)
Last Return	0.038	0.039	0.041	-0.006	-0.005	-0.003
	(0.059)	(0.059)	(0.059)	(0.039)	(0.039)	(0.040)
Auction Dispersion	0.094***	0.094***	0.094***	0.072***	0.072***	0.071***
	(0.026)	(0.026)	(0.026)	(0.020)	(0.020)	(0.020)
Coverage Ratio	-0.160***	-0.165***	-0.179***	-0.158***	-0.160***	-0.176***
	(0.015)	(0.014)	(0.023)	(0.014)	(0.013)	(0.023)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.329	0.330	0.330	0.382	0.382	0.383
Adj. R^2	0.322	0.322	0.322	0.375	0.376	0.376
Observations	1,759	1,759	1,759	1,396	1,396	1,396

Note: The award ratio measures the awarded volume as a fraction of the bidder's tendered volume. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The three "last"-metrics give the outcome for the bidder from the last auction of the same instrument (bill/bond). Auction dispersion and coverage ratio are defined in subsection 5.1.1. Award ratio, share of supply, share of demand, last share awarded, last award ratio and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. The unit of last return is percent. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

7. *Conclusion*

This paper studies auction performance and bidder behaviour in Norwegian Treasury auctions. Our unique dataset covers the period from 2003 to 2018, during which the securities were sold in uniform price auctions. We study auction performance not only at the auction level, but we also take a novel approach by analysing the impact that individual bidder behaviour has on bidder success. First, we provide an overview of the primary and secondary market for Norwegian Treasury securities. We document an average underpricing of 0.11% of face value, which corresponds to a total amount of NOK 1,605 million over the period studied. The underpricing is higher than in other countries, which is unanticipated given Norway's uncommon position where it does not need to borrow money. Although we study a market with a low number of bidders, aggregate demand to supply ratios (coverage ratios) are in line with findings from other countries and indicate high competition.

Next, we study determinants of auction performance. The volatility of bond returns, Eurozone sovereign default risk, auction size and key policy rate have a positive impact on underpricing. Moreover, the dispersion of all bids in the auction is positively affected by the volatility of bond returns, Eurozone sovereign default risk and the key policy rate, while the number of bidders affects negatively. The volatility of bond returns and auction size have a negative impact on coverage ratio, whereas VIX and the number of bidders affect it positively. For volatility of bond returns, auction size and the number of bidders, our results comport with findings of previous studies. The rest of the relationships are not previously examined in the literature. Finally, bid dispersion exhibits a positive relationship with underpricing, whereas the coverage ratio exhibits a negative relationship. While the relationship with bid dispersion confirms the result of previous studies, the relationship with coverage ratio is not empirically examined in the literature.

The average fraction of supply awarded to each bidder is 20.3%, and the percentage of bids that receives allotment is on average 44.7%. Our data shows that the bidders tend to bid for greater demand with higher discounts and more dispersion when compared to other countries. This can, to some extent, be explained by the relatively low number of primary dealers in the market.

Lastly, we study how a individual bidder's behaviour influences her own success. To our knowledge, we are the first to examine these relationships empirically. We find that the return obtained by a bidder is mainly determined by the overall demand in the auction and how much it is dispersed. Consequently, the individual bidder has low influence on her outcome, indicating little to no market power in this dimension of success. This is not an obvious outcome, since the low number of participants in the Norwegian Treasury auctions could lead to strategic behaviour. Considering the share of the auction supply a bidder is awarded (share awarded), her bidding behaviour affects her outcome more than the overall bidding in the auction. This implies that a bidder to a great extent is the master of her own faith in this success dimension. Finally, the fraction of her bids that receives allotment (award ratio) is affected concurrently by the bidder's behaviour and the overall bidding.

7.1 Future Work

Future work can take several directions. First, one can obtain similar datasets for other markets. This way, it is possible to perform the analysis in a similar manner with similar benchmarks across all markets. Doing so will provide an even richer background to draw conclusions from when considering auction performance in the various markets studied. Furthermore, there will be several exciting possibilities emerging from the introduction of the remuneration scheme and syndication mandates. Looking at potential shifts in bidder behaviour around the introduction of explicit compensation can yield interesting findings on how much the primary dealers value their roles. Lastly, several countries ask their primary dealers to note whether a bid is on behalf of a customer or the dealer itself. Should Norges Bank decide to do this, it would present an opportunity to examine the real value of seeing customer orders before the submission of bids. It would also present an opportunity to look at bidder heterogeneity, e.g. in the size dimension. This is not meaningful today, seeing that we do not know whether a bid belongs to the primary dealer submitting it or one of its customers.

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A. *Appendices*

A.1 Syndication in Norwegian Treasury Auctions

Besides arranging auctions, a second way to issue government debt instruments is syndication. This practice was introduced to the Norwegian primary market in April of 2018. A bond with 10 years to maturity, NGB 04/2028, was issued, and this is the first time the Norwegian government has issued a bond in Norwegian kroner by syndication[1]. The procedure was repeated for the second time ever when issuing the new 10-year bond NGB 09/2029, with settlement in March of 2019. The process of syndication is done by inviting multiple banks, which forms the syndicate, to collaborate on issuing the bond. The syndicate then uses its market resources to contact potential buyers to determine the interest for the issue.

As opposed to auctioning, where the price is decided after the bids are submitted, the purchasers of the syndication issues are informed on price and volume on a continual basis. It is assumed that syndication can reach more investors than auctions. Additionally, syndication is flexible concerning the volume borrowed and time of implementation, and the composition of investors can be influenced. The bookrunners forming the syndicate have in both cases been the primary dealers at the time. However, Norges Bank has declined to comment on whether participation in the syndicate is related to being a primary dealer and whether the syndicate members are explicitly compensated for this task. If the syndication process remains popular over time, it is probable that there will be a greater clarity in how the choice and compensation of the syndicate is implemented.

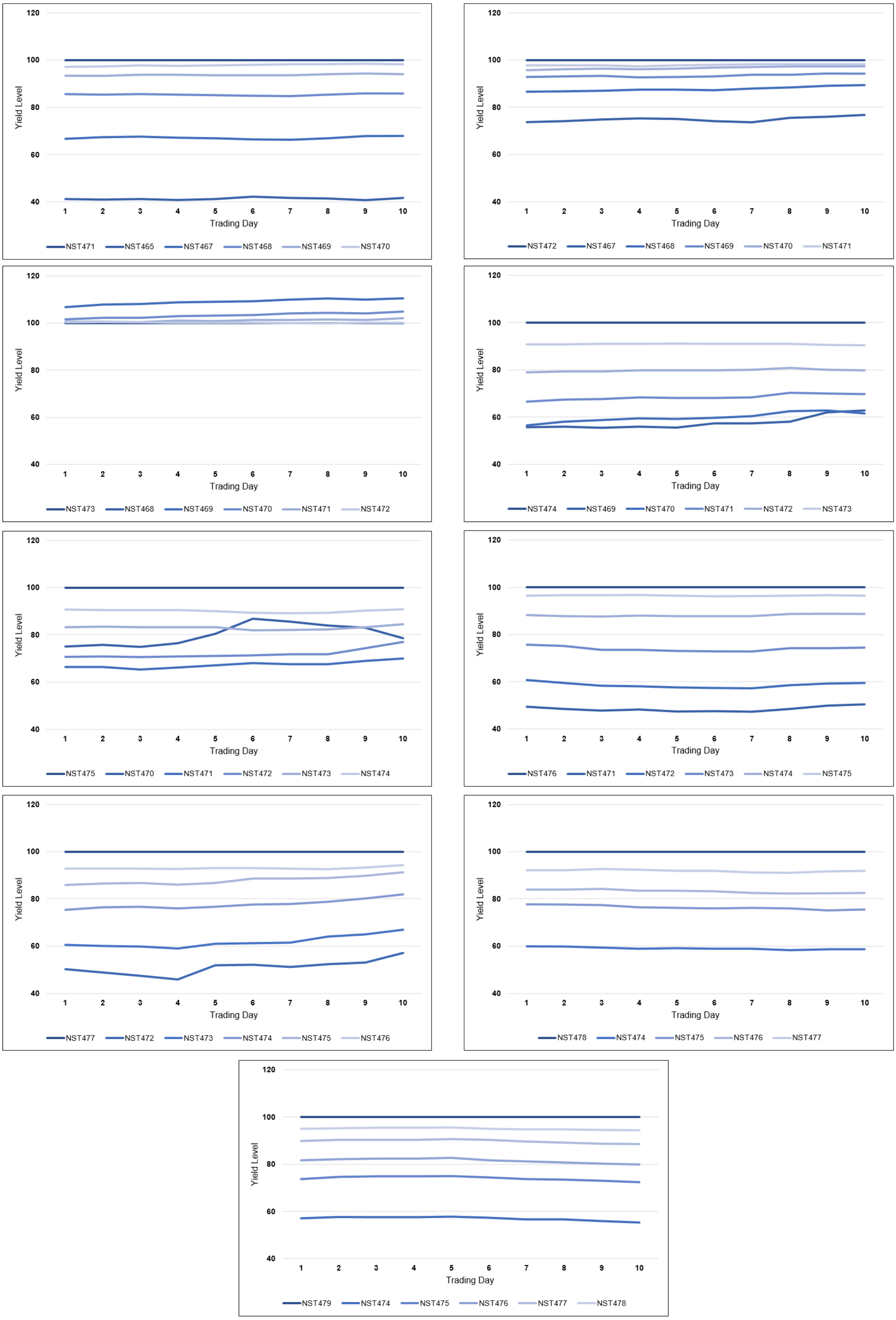
[1] Norges Bank. "Norway issued new Norwegian Government Bond (NGB 04/2028)", published 20.04.2018.

A.2 Yield Change Mimicking for Bonds

This analysis examines whether the bonds already trading in the market closely mimic the yield changes of the bond issued in an auction. To do so, we look at the trading yields for the issued bond over its first 10 days of active trading. The midpoint yield of the issued bond is reindexed to 100, and the yield of all other trading bonds are calculated relative to this. An example: if the issued bond, A, yields 5% and another bond trading in the market, B, yields 4%, these would be listed as 100 and 80 respectively. This is done for each of the first 10 days — the auctioned bond is always listed as 100 and the others as their yield relative to the auctioned one. This means that a constant relationship between the two corresponds to equal changes; if bond A experience a certain change in yield, bond B must experience the same relative change for their ratio to stay constant. Figure A.1 demonstrates this through plots for all new issues of bonds in the time period studied. Horizontal lines correspond to constant ratios, i.e. close mimicking.

Evident from figure A.1, there is always at least one bond that holds a rather constant ratio with the yield of the auctioned bond. In all but the top left plot (NST471) the bond mimicking the yield level most closely is the one with the closest maturity. In this particular case, NST469 mimics the yield level slightly closer than NST470 which is the one with the nearest maturity.

Figure A.1: Yield relationship plots for all new issues of bonds



Note: The leftmost legend in each plot represents the auctioned bond (darkest colour, constantly 100), while the rightmost legend represents the bond with the closest maturity (lightest colour).

A.3 Modelling Bond Volatility with a GARCH(1,1) Model

To estimate conditional volatility we use GARCH(1,1) modelling. We estimate a GARCH(1,1) model for returns of five bond indices with average duration of 0.25, 0.50, 1.00, 3.00 and 5.00 years respectively. First, we estimate the return equation for each index:

$$R_t = \phi_0 + \phi_1 \cdot R_{t-1} + \epsilon_t \tag{A.1}$$

where R_t is the logarithmic return of the index.

Second, we estimate the following variance equation for each index:

$$\sigma_t^2 = \omega + \alpha \cdot \epsilon_{t-1}^2 + \beta \cdot \sigma_{t-1}^2 \tag{A.2}$$

where σ_t^2 is the conditional variance of the return of the index on day t, and ϵ_{t-1}^2 is the squared residual of the regression in equation (A.1) from the previous period. The model is estimated with maximum likelihood. The coefficient estimates are given in table A.1. The column named "Index" indicates which index the coefficients are estimated for. ST1X, ST2X, ST3X, ST4X and ST5X have an average duration of 0.25, 0.50, 1.00, 3.00 and 5.00 years respectively. The $\hat{\phi}_0$ and $\hat{\phi}_1$ columns show the coefficients for the AR(1) specification in equation (A.1). The $\hat{\omega}$, $\hat{\alpha}$ and $\hat{\beta}$ columns show the coefficients from the GARCH(1,1) specification in equation (A.2).

The volatility of the auctioned security is estimated as the duration-weighted average of the volatility of the bond index with the closest yet higher duration and the volatility of the bond index with closest yet lower duration. For example, if a T-bill with duration of 0.75 years is auctioned, we estimate the volatility by weighing 50 percent of the estimated volatility for the index with duration of 0.5 years and 50 percent of the estimated volatility for the index with duration of one year. The price we use to calculate the duration of the T-bill is the stop-out price of the auction. If a T-bill with duration lower than 0.25 is auctioned, the volatility of the index with a duration of 0.25 is used. If a bond with a duration longer than

Table A.1: Estimated coefficients for AR(1) and GARCH(1,1) models

Index	$\hat{\phi}_0$	$\hat{\phi}_1$	$\hat{\omega}$	$\hat{\alpha}$	$\hat{\beta}$
ST1X	$7.1e-05$	0.2018	$1.4e-11$	0.0500	0.9000
	$(1.9e-06)$	(0.0257)	$(7.7e-08)$	(0.0011)	(0.0034)
ST2X	$7.1e-05$	0.1967	$3.4e-11$	0.0500	0.9000
	$(2.6e-06)$	(0.0234)	$(7.3e-08)$	(0.0014)	(0.0041)
ST3X	$3.8e-05$	0.1666	$2.2e-10$	0.0517	0.9009
	$(3.2e-06)$	(0.0191)	$(5.8e-08)$	(0.0021)	(0.0053)
ST4X	$6.5e-05$	0.1628	$8.5e-09$	0.0520	0.9359
	$(1.6e-05)$	(0.0169)	$(2.0e-07)$	(0.0067)	(0.0074)
ST5X	$1.1e-04$	0.1591	$2.5e-08$	0.0564	0.9371
	$(3.0e-05)$	(0.0160)	$(5.0e-07)$	(0.0197)	(0.0188)

Note: $\hat{\phi}_0$ and $\hat{\phi}_1$ gives the estimated coefficients of the AR(1) specification in equation (A.1). $\hat{\omega}$, $\hat{\alpha}$ and $\hat{\beta}$ gives the estimated coefficients of the GARCH(1,1) specification in equation (A.2). Standard errors are listed in parenthesis below their respective coefficients.

5 years is auctioned, we use a scaling factor to account for the difference in volatility between the index of 5-year duration and the auctioned bond. The scaling factor is calculated as the ratio between observed standard deviations in returns for bonds in the relevant duration band and the unconditional volatility estimated by the GARCH model. These factors represent the average level of volatility expected to be observed for bonds of a certain duration band and the index of 5-year duration respectively. We assume that the relationship between the average unconditional volatility of bonds from a certain duration band and the index is representative for the relationship between the conditional volatility of the bond and the index on a given day. This can be expressed mathematically as:

$$\sigma_{d,t} = \sigma_{5y,t} \cdot \frac{SD(d)}{\sigma_{5y}} \tag{A.3}$$

where $\sigma_{d,t}$ is the volatility on day t of a bond in duration band d and $\sigma_{5y,t}$ is the GARCH-forecasted volatility of the index with duration of 5 years on day t. $SD(d)$ is the sample standard

Table A.2: Volatility correction factors for various duration bands

Duration Band	Unconditional Volatility 5-year Duration Index	Sample Standard Deviation	Correction Factor
5–6	0.198%	0.277%	1.40
6–7	0.198%	0.312%	1.57
7–8	0.198%	0.347%	1.75
8–9	0.198%	0.357%	1.80
9–10	0.198%	0.403%	2.04

Note: The correction factor is the sample standard deviation divided by the unconditional volatility for the index with 5 years duration.

deviation of returns for bonds in duration band d and σ_{5y} is the unconditional volatility of the index with 5 years duration. The correction factors for the various duration bands are listed in table A.2.

A.4 Univariate Regressions with Auction Performance Indicators as Dependent Variables

Table A.3: Univariate regressions with underpricing as dependent variable

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
σ	0.536***						
	(0.078)						
New*σ		0.703**					
		(0.304)					
VIX			0.105**				
			(0.042)				
CDS Index				0.029**			
				(0.011)			
Auction Size					0.013		
					(0.009)		
Bidders						0.016	
						(0.014)	
Key Policy Rate							0.022*
							(0.013)
R^2	0.214	0.059	0.079	0.032	0.010	0.009	0.021
Adj. R^2	0.212	0.057	0.076	0.029	0.008	0.007	0.018
Observations	371	371	371	362	371	371	371

Note: Underpricing is measured as per cent of face value. σ is the GARCH(1,1)-estimated standard deviation of daily returns (%), and "new" is a multiplicative dummy equal to 1 for auctions of new securities and 0 for reopening auctions. VIX is the daily volatility implied by index options on S&P500 (%), while CDS is an index value representing Eurozone credit default swap spreads. Auction size is expressed in billions of NOK, bidders is the realised number of bidders, and the key policy rate is denominated in percentage points. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: Univariate regressions with auction dispersion as dependent variable

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
σ	1.666***						
	(0.137)						
New*σ		1.736***					
		(0.347)					
VIX			0.087**				
			(0.034)				
CDS Index				0.081***			
				(0.017)			
Auction Size					-0.032***		
					(0.011)		
Bidders						-0.034**	
						(0.016)	
Key Policy Rate							0.005
							(0.011)
R^2	0.603	0.106	0.016	0.074	0.107	0.012	0.000
Adj. R^2	0.602	0.103	0.013	0.071	0.014	0.009	-0.002
Observations	371	371	371	362	371	371	371

Note: Dispersion is measured as per cent of face value. σ is the GARCH(1,1)-estimated standard deviation of daily returns (%), and "new" is a multiplicative dummy equal to 1 for auctions of new securities and 0 for reopening auctions. VIX is the daily volatility implied by index options on S&P500 (%), while CDS is an index value representing Eurozone credit default swap spreads. Auction size is expressed in billions of NOK, bidders is the realised number of bidders, and the key policy rate is denominated in percentage points. Standard errors are reported below the coefficients. All regressions are performed with Huber-White-Hinkley robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.5: Univariate regressions with coverage ratio as dependent variable

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
σ	-0.173						
	(0.230)						
New*σ		-0.881*					
		(0.510)					
VIX			0.293***				
			(0.098)				
CDS Index				0.022			
				(0.031)			
Auction Size					-0.096***		
					(0.021)		
Bidders						0.079**	
						(0.037)	
Key Policy Rate							0.041
							(0.036)
R^2	0.002	0.007	0.044	0.001	0.038	0.015	0.005
Adj. R^2	-0.001	0.004	0.041	-0.001	0.035	0.013	0.003
Observations	371	371	371	362	371	371	371

Note: Coverage ratio is unitless. σ is the GARCH(1,1)-estimated standard deviation of daily returns (%), and "new" is a multiplicative dummy equal to 1 for auctions of new securities and 0 for reopening auctions. VIX is the daily volatility implied by index options on S&P500 (%), while CDS is an index value representing Eurozone credit default swap spreads. Auction size is expressed in billions of NOK, bidders is the realised number of bidders, and the key policy rate is denominated in percentage points. Standard errors are reported below the coefficients. All regressions are performed with Huber-White-Hinkley robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.5 Univariate Regressions with Bidder Success Measures as Dependent Variables

Table A.6: Univariate regressions with return as dependent variable

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Share of Supply	-0.04***									
	(0.012)									
Share of Demand		0.001								
		(0.017)								
Intrabidder Dispersion			0.098***							
			(0.025)							
Discount				0.077***						
				(0.023)						
Bottom Spread					0.062***					
					(0.014)					
Last Share Awarded						0.009				
						(0.010)				
Last Award Ratio							0.012			
							(0.011)			
Last Return								0.028		
								(0.046)		
Auction Dispersion									0.142***	
									(0.031)	
Coverage Ratio										-0.032***
										(0.010)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.057	0.048	0.123	0.092	0.105	0.007	0.008	0.008	0.204	0.084
Adj. R^2	0.047	0.038	0.113	0.082	0.100	0.263	0.214	0.210	0.196	0.074
Observations	1,830	1,830	1,830	1,830	1,413	1,759	1,759	1,759	1,830	1,830

Note: The return metric measures how much underpricing a bidder is awarded as a fraction of her tendered volume. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The three "last"-metrics give the outcome for the bidder from the last auction of the same instrument (bill/bond). Auction dispersion and coverage ratio are defined in subsection 5.1.1. The units of return and last return is percent. Share of supply, share of demand, last share awarded, last award ratio and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.7: Univariate regressions with share awarded as dependent variable

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Share of Supply	0.263***									
	(0.017)									
Share of Demand		0.998***								
		(0.042)								
Intrabidder Dispersion			0.002							
			(0.007)							
Discount				-0.108***						
				(0.018)						
Bottom Spread					0.001					
					(0.005)					
Last Share Awarded						0.260**				
						(0.034)				
Last Award Ratio							0.038**			
							(0.012)			
Last Return								0.017		
								(0.019)		
Auction Dispersion									0.003	
									(0.005)	
Coverage Ratio										-0.003
										(0.002)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.448	0.553	0.236	0.281	0.079	0.268	0.219	0.215	0.236	0.237
Adj. R^2	0.442	0.548	0.228	0.273	0.073	0.263	0.214	0.210	0.228	0.229
Observations	1,830	1,830	1,830	1,830	1,413	1,759	1,759	1,759	1,830	1,830

Note: The share awarded measures awarded volume as a fraction of the auction supply. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The three "last"-metrics give the outcome for the bidder from the last auction of the same instrument (bill/bond). Auction dispersion and coverage ratio are defined in subsection 5.1.1. Share awarded, share of supply, share of demand, last share awarded, last award ratio and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. The unit of last return is percent. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.8: Univariate regressions with award ratio as dependent variable

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Share of Supply	-0.18***									
	(0.020)									
Share of Demand		0.006								
		(0.065)								
Intrabidder Dispersion			0.018							
			(0.018)							
Discount				-0.182***						
				(0.037)						
Bottom Spread					0.033**					
					0.010					
Last Share Awarded						0.172**				
						(0.043)				
Last Award Ratio							0.117**			
							(0.030)			
Last Return								0.014		
								(0.074)		
Auction Dispersion									0.069***	
									(0.023)	
Coverage Ratio										-0.165***
										(0.010)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.127	0.093	0.094	0.136	0.077	0.083	0.088	0.075	0.100	0.262
Adj. R^2	0.118	0.084	0.084	0.127	0.071	0.077	0.082	0.069	0.090	0.254
Observations	1,830	1,830	1,830	1,830	1,413	1,759	1,759	1,759	1,830	1,830

Note: The award ratio measures the awarded volume as a fraction of the bidder's tendered volume. Share of supply, share of demand, intrabidder dispersion, discount and bottom spread are defined in subsection 5.2.2. The three "last"-metrics give the outcome for the bidder from the last auction of the same instrument (bill/bond). Auction dispersion and coverage ratio are defined in subsection 5.1.1. Award ratio, share of supply, share of demand, last share awarded, last award ratio and coverage ratio are unitless. The units of intrabidder dispersion, discount, bottom spread and auction dispersion are per cent of face value. The unit of last return is percent. Fixed effects means that the regression includes a dummy variable for each bidder which is 1 if the bid schedule was submitted by the corresponding bidder and 0 otherwise. Standard errors are reported below the coefficients. All regressions are performed with Newey-West robust standard errors.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$