Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal of Financial Markets 16 (2013) 127–151

Journal of FINANCIAL MARKETS

www.elsevier.com/locate/finmar

Price discovery in government bond markets ☆

Siri Valseth*

UiS Business School, University of Stavanger, Norway

Received 7 April 2011; received in revised form 12 April 2012; accepted 28 April 2012
Available online 1 June 2012

Abstract

Price discovery in government bond markets is explored using Norwegian data including trades from both tiers of the market and dealer identities. The results show that while aggregate interdealer order flow explains one-fourth of daily yield changes, aggregate customer order flow has little explanatory power. Dealers are heterogeneously informed and appear to have different sources of information. While some dealers mainly rely on their customer trades, others appear to rely on skill in acquiring and interpreting other relevant information, suggesting that dealers play an independent role in the price discovery process.

JEL classification: G12; G14

Keywords: Dealers; Government bond markets; Order flow; Price discovery

1. Introduction

The process of price formation is largely ignored in traditional economic models that assume that prices adjust instantaneously to new information. This assumption applies equally to public and private information. The market microstructure literature advocates a different view. In microstructure models, the process of price formation is crucial and private information plays a key role. Information is incorporated into prices through two

☆I would like to thank an anonymous referee, Richard Priestley, Anders Andersson, Geir Bjønnes, Carol Osler, and Bernt Arne Ødegaard for useful comments and suggestions, Mette Petersen in DNB Markets for sharing insight on bond trading, and Bodil Østby at the Oslo Stock Exchange for providing data.
*Tel.: +47 93206881.
E-mail address: siri.valseth@uis.no

1386-4181/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.finmar.2012.04.005

channels: a direct channel where prices adjust immediately to new public information, and an indirect channel, referred to as price discovery, where prices adjust over time to private information conveyed through order flow.[1]

Lyons (2001) defines private information as information, not known by all, that produces a better price forecast than public information alone. Several studies confirm that price discovery is an important part of the price formation process in asset markets. Hasbrouck (1991), Evans and Lyons (2002), and Brandt and Kavajecz (2004) document that contemporaneous order flow explains a substantial part of daily price changes in stock markets, foreign exchange markets, and government bond markets, respectively. The gradual adjustment of prices through order flow implies that prices do not fully reflect all available information at any point in time and suggests that market participants have asymmetric information.

The purpose of this paper is to investigate the role of different market participants in the process of price discovery in government bond markets. Government bond markets are characterized by a two-tier structure, reflecting that customers can trade with dealers only while dealers can trade both with their customers and with other dealers. The tier where dealers and customers trade is referred to as the customer market and the tier where dealers trade with other dealers is referred to as the interdealer market. A new data set including trades in both the interdealer and customer markets, as well as the identities of the buying and selling dealers allows for an investigation of how different dealers contribute in the price discovery process and of the type of information embedded in interdealer order flow.

In sovereign bond markets, private information can be divided into types along two dimensions. The first dimension is whether information is fundamental or non-fundamental. Fundamental private information is related to macroeconomic factors, for example heterogeneous interpretations of macroeconomic indicators like consumer and producer surveys on future inflation, employment, and GDP growth. Non-fundamental private information is related to other factors like changes in liquidity conditions, investor risk preferences, auction volumes or hedging demands. Fundamental private information can influence expected future short rates and risk premia through the macroeconomic outlook, while non-fundamental private information can, for example, influence liquidity risk premia.

The second dimension of private information is the source. Two sources of information are considered: dealer skill and customer trades.[2] This paper defines dealer skill as a dealer's ability to acquire and interpret relevant information including public news and the order flow of other dealers. If the information in interdealer order flow reflects the information in customer order flow only, it indicates that the dealer does not add any information by trading. In this case, dealers are passive intermediaries of customer orders and customer trades are considered to be the source of information in interdealer order flow. If interdealer order flow is more informative than customer order flow, it suggests that dealers possess more information than their customers. Dealers can obtain extra information by using effort and skill in collecting and interpreting other relevant

[1]Order flow is a measure of the net buying pressure in the market, and is calculated by subtracting seller-initiated trades from buyer-initiated trades during a time interval. A buyer-initiated trade will have a positive sign and a seller-initiated trade will have a negative sign.

[2]These sources are in line with Goodhart (1988), who considers three sources of information for better informed dealers. These are better and faster public information, access to and trained interpretation of the order flow of other dealers, and access to own customer orders and order flow.

information. In this case, dealer skill is considered to be the source of information. Anand and Subrahmanyam (2008) find that dealers contribute more to price discovery than their customers and conclude that dealers are better informed than other market participants. In equity markets, insider information related to firm earnings or firm mergers may be a third source of information, but this type of information is unlikely to be of importance in sovereign bond markets.

This study has two major contributions. The first is to compare the informational content of interdealer order flow to that of customer order flow to investigate in which tier of the market private information originates. Previous studies employ either interdealer order flow or customer order flow. Evans and Lyons (2002), Brandt and Kavajecz (2004), and Anand and Subrahmanyam (2008) use interdealer order flow from the bond, equity, and currency markets, respectively. Evans and Lyons (2005) use customer order flow from the currency market while Menkveld, Sarkar, and van der Wel (2012) use customer order flow from the bond futures market. This paper employs a unique data set including all trades in both tiers of the market, which makes it possible to investigate the price impact of interdealer order flow relative to customer order flow. The data set also identifies different types of trades. A type of particular interest in this study is delayed publication trades. These are trades chosen by dealers to be temporarily hidden from the other dealers. They become visible in the trading system only after a period of delay. Dealers are likely to choose this alternative if the trades contain private information as they can benefit from private information before it becomes available to their competitors. Delayed publication customer trades are therefore used as a proxy for informed customer trades. By using this proxy, I attempt to separate the effects of *informed* customer order flow from the effects of *total* customer order flow.

The second contribution is to explore whether dealers are heterogeneous and play different roles in the price discovery process. Are dealers differently informed and do they have different sources of information? Are some dealers pure intermediaries while other dealers possess skill in collecting and interpreting relevant information that they subsequently trade on? This type of individual dealer analysis has not been undertaken so far due to a lack of data. Peiers (1997) and Sapp (2002) investigate information asymmetries between dealers in the foreign exchange market by using indicative quote data from currency dealers. They find that some dealers are price leaders and conclude that the results are consistent with news being incorporated into prices through trading among heterogeneously informed agents. However, as they use quote data instead of using transactions data directly they cannot document the trading behavior of the dealers who appear to have an informational advantage. The present study adds to the literature by employing individual dealer order flow in both the interdealer market and the customer market to explore where the information held by the informed dealers comes from. By studying the characteristics of each dealer, including market share, relative activity in the interdealer market, and the correlation between customer order flow and interdealer order flow, I infer whether the main source of information of the different dealers is customer order flow or dealer skill in acquiring and interpreting other relevant information.

The results show that interdealer order flow in the Norwegian government bond market contains information about bond yields. Aggregate interdealer order flow explains one-fourth of daily yield changes in 3-, 5-, and 10-year government bonds. This is in line with the findings of Brandt and Kavajecz (2004). Order flow is divided into short-, medium-, and long-term order flow according to the remaining time to maturity of the bonds

included.[3] All three order flow groups have a significant impact on yield changes of all maturities, but the strongest effect is on the same maturity yield change. Short-term order flow thus has the highest impact on 3-year yield changes, but also has a significant impact on 5- and 10-year yield changes. These results indicate that there is information in the order flow of short-term, medium-term, and long-term bonds and that this information to a large extent causes parallel shifts in this part of the yield curve.

The results further document that customer trades are far less informative than interdealer trades. Aggregate customer order flow explains up to 1% of daily variation in yields. The differences in the explanatory power of interdealer order flow and customer order flow suggest that dealers are better informed than their customers. When using a proxy for informed customer order flow, the explanatory power increases somewhat. This indicates that dealers, at least partially, are able to identify their informed customers. By aggregating information from their own customer trades, the trades of other dealers, and by processing public information related to bond markets, dealers have better access to relevant bond information than most customers.[4]

At the dealer level, the results show that dealers are heterogeneous and contribute differently to the price discovery process. The order flow of large dealers, measured by market share, has the largest price impact. The interdealer order flows of the two largest dealers have the highest price impact on 3- and 5-year bonds, whereas the order flows of the fourth largest dealer has the highest price impact on 10-year bonds. Also, order flows at different maturities have a different price impact depending on the dealer. Whereas the medium-term order flow has the highest price impact on all yield changes for one dealer, the long-term order flow has the highest price impact for other dealers. This suggests that dealers specialize in trading at different segments of the yield curve and therefore concentrate their informed interdealer trading to this segment. The observation that a dealer's interdealer order flow in one segment influences both short-, medium-, and long-term yields confirms the results at the aggregate level that much of the information contained in the order flow of government bonds is common for all the segments of the yield curve included in this study.

The results at the dealer level also show that the correlation between customer order flow and interdealer order flow varies among dealers. Whereas customer order flow explains a substantial part of interdealer order flow for some dealers with high price impact, customer order flow appears to be unrelated to the interdealer order flow of other high-impact dealers, suggesting that some dealers possess information additional to what they learn from their customer trades. This is in line with the findings of Manaster and Mann (1996), who study the market for commodity futures, Anand and Subrahmanyam (2008), who study the equity market, and Osler, Mende, and Menkhoff (2011), who study the foreign exchange market. Additional information can be acquired through dealer skill. Examples of this type of information are the interpretation of early macroeconomic indicators or private information acquired through trading in the interdealer market. The findings in this study indicate that dealers play an important and independent role in the price

[3]Short-term order flow includes the trades in bonds with a remaining time to maturity from 1 to 4 years, medium-term order flow includes trades in bonds with a remaining time to maturity greater than 4 years up to 7 years, and long-term order flow includes trades in bonds with a remaining time to maturity greater than 7 years up to 11 years.

[4]Customers in the government bond market include insurance companies, institutional investors, domestic firms, foundations, and individuals.

formation process in the Norwegian government bond market as both customer trades and dealer skill appear to be important sources of information.

The rest of the paper is organized as follows. Section 2 discusses related literature. Section 3 describes the market settings and data. Section 4 discusses possible dealer strategies. Section 5 presents the econometric framework and the results. Section 6 concludes.

2. Related literature

This study is related to Brandt and Kavajecz (2004), who examine the price formation process in the U.S. Treasury market. They divide interdealer order flow into six maturity groups along the yield curve and control for the effect of lagged yields by including the lagged three first principal components of yields. They separate days with macroeconomic news from days with no news and investigate the effect of order flow on contemporaneous yield changes on no-news days. They find that up to 26% of daily yield changes on no-news days can be accounted for by interdealer order flow. They control for inventory effects by investigating whether the yield changes are reversed within the next few days, and conclude that the yield changes are permanent and therefore due to new information. This paper employs a similar method by dividing order flow into three maturity groups and by including the lagged first principal component of bond yields in the price impact regressions. The paper extends the work by Brandt and Kavajecz (2004) by including both customer order flow and interdealer order flow, as well as individual dealer order flow.

This paper is also related to studies concerned with the sources of private information and the role of dealers in the price formation process. Manaster and Mann (1996) study the behavior of market-makers in various futures contracts at the Chicago Mercantile Exchange (CME). They conclude that market-makers are active profit-seeking individuals with heterogeneous levels of information and trading skill. Osler, Mende, and Menkhoff (2011) investigate the process of price discovery in currency markets, and find that it takes place in the interdealer market rather than in the customer market. Anand and Subrahmanyam (2008) study price formation in equity markets and find that intermediaries (dealers) are better informed than their clients because of their advantage and skill in actively seeking and trading on information. Menkveld, Sarkar, and van der Wel (2012) study the Treasury futures market, and find that customer order flow is crucial for price discovery since it conveys information about customers' risk preferences and endowments.

Asymmetrically informed dealers are discussed by Peiers (1997) and Sapp (2002). They use indicative quotes of individual dealers to investigate their price-setting behavior in the foreign exchange market. Both conclude that some dealers are price leaders because they consistently incorporate new information on central bank interventions into their prices before other dealers. While Peiers (1997) and Sapp (2002) investigate the role of different quote-setting behavior among dealers, this paper takes a different approach by investigating the role of different dealers' trading behavior in the price formation process. By using individual dealer order flow in both tiers of the bond market, the paper seeks to identify the sources of information in interdealer order flow.

This paper adds to the literature by employing a new, comprehensive data set including all the trades in the secondary market for government bonds. Instead of examining either the interdealer market, like Brandt and Kavajecz (2004), the customer market, like

Menkveld, Sarkar, and van der Wel (2012), or a purely electronic market including both dealer initiated and customer initiated trades, like Anand and Subrahmanyam (2008), the analysis in this paper includes the complete bond market and can therefore examine the relationship between the different parts. Osler, Mende, and Menkhoff (2011) also include both the interdealer and customer markets, but only for one dealer. Also, the paper differs from the existing literature because I can identify all major dealers and therefore explore the role of each dealer in both markets. It is thus possible to observe to what extent customer trades are reflected in the interdealer trades of the different dealers. This enables the investigation of the relative importance of customer orders as a source of information in interdealer order flow and the assessment of the importance of others sources of information.

3. Market structure and data

The market for Norwegian government bonds is organized similarly to major government bond markets and includes a system of primary dealers. Primary dealers are appointed by Norges Bank and their obligations include continuous quoting of firm bid and ask prices at a maximum spread and a minimum amount for each bond.[5] Primary dealer rights include an exclusive repo arrangement administered by Norges Bank. Under this arrangement, primary dealers can borrow a fixed amount in each benchmark bond at a low cost from the Treasury for a period from one to ten days. This contributes to a more liquid market by increasing the dealers' ability to quote prices for larger amounts without substantial price movements. The number of primary dealers varied between five and eight during the sample period.

The secondary bond market is, like other government bond markets, a two-tier market consisting of an interdealer market and a customer market. Dealers are intermediaries between the two tiers. In this paper dealers are defined as exchange members that are approved for bond trading. To be approved for bond trading, member firms must comply with a set of rules and obligations including technical requirements. Customers are defined as traders that are not exchange members and include financial firms, commercial firms, and individual investors. Dealers can trade with other dealers and with their customers, whereas customers must trade through a dealer and cannot trade directly with each other. Fig. 1 illustrates the connection between the customer and interdealer markets and how dealers report customer trades and interdealer trades into the SAXESS trading system. The trading system is administered by the Oslo Stock Exchange (OSE) and has features similar to other European systems such as the MTS system.

To promote liquidity, the government has limited the number of bonds to a few large benchmark bond issues. The number of outstanding issues varies between four and six benchmark bonds with a remaining time to maturity of between one and eleven years. Auctions in government bonds are held six to eight times a year according to a pre-announced auction calendar. Every other year a new 11-year benchmark bond is launched. It is reopened regularly until it has reached a size deemed sufficient. Table 1 lists the seven benchmark bonds that were outstanding and traded in the secondary market during the sample period from 1999 to 2005. The table shows that customer trades are on average

[5]Norges Bank is the Norwegian Central Bank.

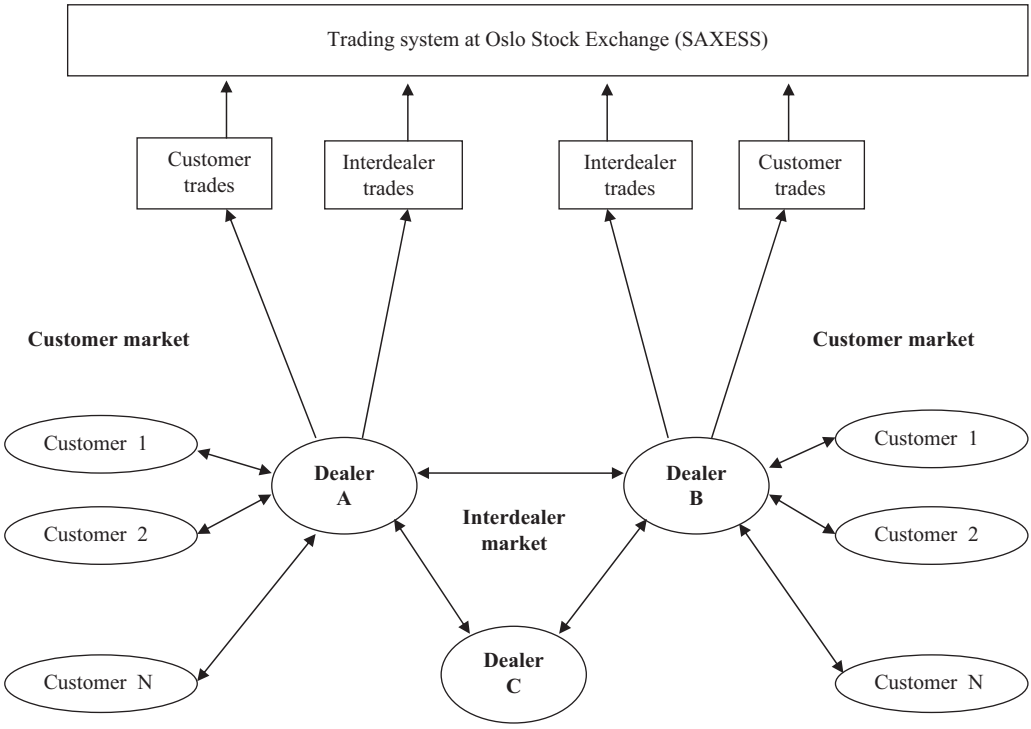

Fig. 1. Trading in the secondary market for government bonds in Norway.

Table 1
Benchmark bonds.

The table describes the government bonds that are included in the data set. It displays the bond short name, the coupon rate, date first issued, maturity date, the number of trades in each bond, the share of interdealer trades of these trades, and the average trade size measured in million Norwegian kroner (NOK) of interdealer trades and customer trades in each bond. The bonds are all bullet bonds with a remaining time to maturity of ten or 11 years when first issued. The trades included are all trades reported to Oslo Stock Exchange (OSE) during the period September 1999–September 2005 except repo trades, auction results, and trades with a trade size of less than 1 million NOK. The share of interdealer trades is measured as a percentage of the total number of trades in each bond.

Bond	Coup	Issued	Maturity	Number	Share	Avg. trade size (mill.NOK)	
name	%	date	date	of trades	interdealer	Interdealer	Customer
S463	9.50	10.31.92	10.13.02	6,518	36%	41.6	50.6
S465	5.75	11.30.93	11.30.04	12,307	34%	27.3	38.8
S467	6.75	01.15.96	01.15.07	14,519	36%	24.1	38.8
S468	5.50	05.15.98	05.15.09	14,692	36%	18.6	36.5
S469	6.00	05.16.00	05.16.11	10,966	35%	18.9	41.1
S470	6.50	05.15.02	05.15.13	5,956	41%	17.6	42.3
S471	5.00	05.15.04	05.15.15	1,688	24%	19.0	52.2
All				66,646	35%	23.6	40.5

larger than interdealer trades. The interdealer share of the trading activity is roughly 35%. The majority of interdealer trades involves primary dealers.

According to the Organisation for Economic Co-operation and Development (OECD, 2002), central government debt in 2000 amounted to USD 32.5 billion in Norway, USD 33.8 billion in Ireland, USD 137.2 billion in Sweden, and USD 593.7 billion in the United Kingdom. In the United States, government debt amounted to USD 3,395.5 billion in 2000.[6] Daily turnover in government bonds was USD 2.2 billion in Sweden and USD 290 billion in the U.S.[7] According to the Oslo Stock Exchange (2011), the total turnover in government bonds was NOK 489 billion in 2000, which implies an average daily turnover of NOK 2 billion equivalent to USD 222 million.[8] In 2000, the number of primary dealers in government bonds was 6 in Ireland, 8 in Norway, 8 in Sweden, 17 in the U.K., and 27 in the U.S.[9] Compared to other government bond markets, the Norwegian market is relatively small. However, as the market is organized in the same way and has a few, but relatively liquid bonds, the results in this study should be relevant for other sovereign bond markets.

The data set used in this study includes all transactions, as well as the best bid and ask prices submitted by dealers at the OSE over the period from September 6, 1999 to September 30, 2005. For each transaction, the date, time, price, amount, the identity of the buying and the selling dealer, and the type of trade is observed. Different types of trades include auto-match (electronic) trades, ordinary over-the-counter (by phone) trades, non-standard settlement over-the-counter trades, trades registered outside market opening hours, repo trades, delayed publication trades, and auction allocations in the primary market. Repo trades, auction allocations, and trades with a trade amount of less than NOK 1 million (USD 180,000) are excluded from the data set as the informational content of these trades is assumed to be limited. The total number of trades included in the analysis is 66,646.

Trading takes place both in the electronic trading book and in the over-the-counter market. The share of electronic trading and the average electronic trade size has increased gradually since the inception of an electronic order book in 1999. Still, over 60% of the volume in interdealer trades are over-the-counter trades. Almost all customer trades are over-the-counter trades. It is important to note that the customer trades and interdealer trades are distinguished by using the identities of the buying and selling dealers. Trades that have different dealers on the buy side and the sell side are defined as interdealer trades, and trades that have the same dealer on both sides are defined as customer trades. In a customer trade, the dealer will appear as both the buyer and the seller of the bonds because customers must trade through a dealer. When a trade with a customer is agreed upon, the dealer will enter both sides of the transaction into the OSE trading system. In addition, proprietary trades and brokered trades are registered with the same dealer as the buyer and

[6]These numbers include both government bonds and bills for all countries.

[7]The number for Sweden includes bonds only while the number for the U.S. includes both Treasury bills and bonds.

[8]According to Norges Bank (2011), the average USD-NOK rate was 8.80 NOK/USD in year 2000. Figures from OSE (2011) show that average daily turnover in government bonds without repos was about NOK 2.6 billion in 1999 and steadily declined to about NOK 1.3 billion in 2005. Average daily turnover in repos increased from NOK 4.1 billion in 2001 to NOK 10.3 billion in 2005.

[9]According to the Federal Reserve Bank of New York (2011), the number of primary dealers in U.S. Treasuries was 27 in 2000.

seller, and are thus classified as customer trades in this study.[10] Information on dealer identities is not available to all market participants, only to the dealers involved in the trade.

Delayed publication trades are trades that are unobservable for the other market participants for a certain time period. This type of trade is granted to make it easier for primary dealers to accommodate the requests of large customers and to allow market makers to unwind their inventory positions at minimal cost. The conditions including the period of delay changed over the sample period. From 1999 to 2002, there was a two-hour delay for trades of 200 million NOK or more. Since May 2002, the size limit was abandoned and the period of delay was extended to the end of the trading day, which is 4 pm, no matter when the trade was executed. Also, the system opened up for the possibility to choose delayed publication as a default setting. Some dealers opted for this and the number of delayed publication trades has increased substantially since mid-2002.

In this study, delayed publication customer trades are used as a proxy for informed customer trades. It is likely that dealers will choose to enter trades from informed customers as delayed publication trades in order to benefit from the trade information before it becomes available to other dealers. If dealers can identify their informed customers, and enter these trades as delayed publication trades, they will acquire private information that will be hidden from the other market participants. They can then trade on this information in the interdealer market before prices are updated with this information. When these trades become visible to the other dealers, prices will be, at least partially, updated accordingly. In the analysis, the sample is divided into two sub-periods, before and after May 2002, to control for the effects of the changes in the conditions for delayed publication trades in May 2002.

The bid–ask spreads prevailing at the time right before the trade are used to determine the direction of the trades. Since order flow is a measure of the net buying pressure in the market, it is necessary to know whether a trade is initiated by the buyer or the seller of the bond. As this information is not directly observed in the data set, the method of Lee and Ready (1991) is used to sign the trades.[11] A buyer-initiated trade is given a positive sign and a seller-initiated trade is given a negative sign. There are two ways to measure order flow. First, one can use equal weights, in which case each buyer-initiated trade is given the value $+1$ and each seller-initiated trade is given the value -1. Daily order flow is then a measure of the net number of buyer initiated trades per day. Second, one can use volume weights, in which case the trade volume in Norwegian kroner is used as a weight (e.g., $+20$ million kroner or -15 million kroner). Daily order flow is then a measure of the net volume in Norwegian kroner of buyer-initiated trades during a day. When investigating the impact of order flow on yield changes, this study employs the first measure of order flow. This is in line with Fleming (2003), who finds that using the number of trades gives better explanatory power than using the volume. However, when investigating the impact of customer order flow on interdealer order flow, the second measure is used. This is

[10]Proprietary trades are in a sense internal customer trades or informed customer trades. Brokered interdealer trades are interdealer trades through a broker where the real counterparty is unknown.

[11]Trades that are executed at a price less than the mid price are classified as seller-initiated, and trades that are executed at a price higher than the mid price are classified as buyer-initiated. For trades executed at the mid price, the tick rule is used. Of the trades employed in the study, 5.6% were below bid, 7.1% at the bid, 36.9% between bid and the midpoint, 6.7% at the midpoint, 33.1% between the midpoint and the ask, 5.3% at the ask, and 5.2% above the ask.

because trading strategies can vary according to the size of the trade. For example, dealers can pass on small customer trades directly to the interdealer market, while they can choose to pass on large customer trades as many small interdealer trades.

In order to measure the price impact of daily order flow, daily changes in synthetic 3-, 5-, and 10-year government bond yields are employed. These yields are based on end of day prices of the bonds in Table 1 and are calculated and published by Norges Bank. Order flow is divided into three matching maturity groups. The first, short-term order flow, contains trades in bonds with 12–48 months remaining time to maturity. The second, medium-term order flow, contains trades in bonds with 49–85 months of remaining time to maturity, and the third, long-term order flow, contains trades in bonds with 86–130 months to maturity. The three maturity segments of interdealer order flow are labelled OF^S, OF^M, and OF^L respectively, and the corresponding segments of customer order flow are labelled COF^S, COF^M, and COF^L respectively.

The data set contains 1,505 days. Several studies of bond markets distinguish between days with macroeconomic news and days with no news, and include either news days or no-news days depending on the questions addressed. Some studies exploring the role of

Table 2
Descriptives for yield changes, interdealer and customer order flow.

The table displays descriptive statistics for yield changes and interdealer and customer order flows in the period September 1999–September 2005. The table includes data for the whole sample and two sub-samples: no-news days and news days. News days are defined as the days of CPI announcements and MPC announcements and the two days surrounding the announcements, in total 361 days. Yield changes are daily changes in synthetic 3-, 5-, and 10-year government bond yields based on the benchmark bonds in Table 1. Yield changes are measured in basis points (0.01 percentage points). Order flow is divided into groups according to the remaining time to maturity of the bonds that are included. Short-term order flow, OF^S and COF^S, reflects bonds with maturity between 1 and 4 years; medium-term order flow, OF^M and COF^M, reflects bonds with maturity greater than 4 years up to 7 years; and long-term order flow, OF^L and COF^L, reflects bonds with maturity greater than 7 years up to 11 years. Numbers in parentheses are standard deviations.

	All days		No-news days		News days	
	Mean	Min/Max	Mean	Min/Max	Mean	Min/Max
Yield changes (bp)						
dY_t^{3y}	−0.17 (5.07)	−39.7/+24.8	−0.01 (4.59)	−26.0/+24.8	−0.74 (6.32)	−39.7/+21.6
dY_t^{5y}	−0.17 (4.88)	−38.4/+25.0	−0.01 (4.56)	−23.6/+25.0	−0.71 (5.76)	−38.4/+18.1
dY_t^{10y}	−0.16 (4.46)	−23.8/+21.1	−0.02 (4.40)	−22.5/+21.1	−0.60 (4.60)	−23.8/+14.9
Interdealer order flow						
OF^S	−0.75 (3.77)	−27/+22	−0.66 (3.64)	−27/+22	−1.04 (4.16)	−25/+15
OF^M	−0.17 (3.69)	−26/+28	−0.19 (3.44)	−19/+19	−0.10 (4.38)	−26/+28
OF^L	−1.30 (4.46)	−34/+20	−1.29 (4.46)	−34/+20	−1.31 (4.47)	−24/+14
Customer order flow						
COF^S	−0.32 (4.08)	−21/+15	−0.33 (3.94)	−21/+15	−0.32 (4.50)	−17/+13
COF^M	0.05 (3.49)	−16/+14	0.02 (3.39)	−16/+13	0.15 (3.80)	−14/+14
COF^L	−0.80 (4.20)	−20/+14	−0.84 (4.15)	−20/+14	−0.68 (4.34)	−13/+14

price discovery include no-news days only to eliminate price movements due to the release of public news. Brandt and Kavajecz (2004) eliminate the direct effect of public news on prices by excluding the three days surrounding announcement days from their sample. To assess the effect of public information, the data set in this study is divided into news days and no-news days in Table 2. News days are identified as the three days surrounding the release of the monthly Consumer Price Index and the press release from Monetary Policy meetings.

Table 2 displays descriptive statistics of daily yield changes, interdealer and customer order flow of different maturity groups on all days, no-news days, and news days. The table shows that the standard deviation of 3- and 5-year yield changes are higher on news days than on no-news days. This indicates that news on inflation and monetary policy has a considerable impact on short- and medium-term bond yields. The standard deviation of 10-year yield changes is only slightly higher on news days than on no-news days, indicating that macroeconomic news has less impact at the long end of the yield curve. Table 2 further indicates that while the standard deviation is about the same on news days and no-news days for long-term interdealer order flow, it is somewhat higher on news days for short- and medium-term order flow. Differences in the standard deviation of customer order flow between news days and no-news days are also relatively small. As order flow can contain interpretations of macroeconomic indicators, in addition to dispersed private information, I include both news and no-news days in the data set.

Table 3 shows the unconditional correlations between yield changes and order flows of different maturities. Yield changes are strongly and positively correlated with each other, indicating that a large part of yield changes occurs as parallel shifts in the yield curve. The correlations between yields and interdealer order flow are significant and negative, indicating that positive order flow is related to higher bond prices and lower yields. In contrast, the

Table 3
Correlations.

The table shows the unconditional correlations between yield changes, aggregate interdealer order flow and customer order flow for the period September 1999–September 2005. Yield changes are daily changes in synthetic 3-, 5-, and 10-year government bond yields based on the benchmark bonds in Table 1. The order flow variables are divided into short-term, medium-term, and long-term interdealer- and customer order flow, according to the remaining time to maturity of the bonds included. Numbers in parentheses are *p*-values.

	OF^S	OF^M	OF^L	COF^S	COF^M	COF^L	dY_t^{3y}	dY_t^{5y}	dY_t^{10y}
OF^S	1								
OF^M	0.24 (0.00)	1							
OF^L	0.19 (0.00)	0.23 (0.00)	1						
COF^S	0.10 (0.00)	0.01 (0.73)	−0.05 (0.04)	1					
COF^M	0.08 (0.00)	0.16 (0.00)	−0.02 (0.35)	0.15 (0.00)	1				
COF^L	0.06 (0.03)	0.05 (0.05)	0.14 (0.00)	0.04 (0.13)	0.08 (0.00)	1			
dY_t^{3y}	−0.35 (0.00)	−0.34 (0.00)	−0.30 (0.00)	0.00 (0.96)	−0.04 (0.13)	−0.04 (0.08)	1		
dY_t^{5y}	−0.30 (0.00)	−0.37 (0.00)	−0.34 (0.00)	0.02 (0.39)	−0.06 (0.02)	−0.05 (0.03)	0.90 (0.00)	1	
dY_t^{10y}	−0.23 (0.00)	−0.30 (0.00)	−0.41 (0.00)	0.00 (0.89)	0.01 (0.71)	−0.11 (0.00)	0.76 (0.00)	0.85 (0.00)	1

correlations between yield changes and customer order flow are much weaker and only significant for long-term customer order flow.

Table 4 shows common yield factors and common order flow factors extracted by performing principal components analysis. The principal components of the bond yields are in line with those found for the U.S. Treasury market in Brandt and Kavajecz (2004). The first common factor explains nearly 99% of the variation in yields and loads about equally on all maturities. This factor is therefore referred to as the "level" factor by Litterman and Scheinkman (1991). The second and third factors are the "slope" and the "curvature." The slope factor explains 1%, and the curvature factor almost none, of the variation in the 3- to 10-year bond yields during this period. There appears to be one dominant factor in interdealer order flow explaining 48% of the variation. The factor loads a little more on intermediate and short maturities than on long maturities. Customer order flow seems to have no dominant factor as the three factors explain about one-third of the variation each. The factor structure of interdealer order flow combined with relatively low correlations across maturities indicates that there is less commonality in different maturity order flows than in different maturity yields.

4. Dealer strategies

To explore the role of dealers and their sources of information, it is useful to discuss how different trading strategies influence the relationship between customer order flow and

Table 4
Principal components of yields and order flow.
The table presents the factor structures of yields and order flow. The table shows the loadings of the three orthogonal factors extracted from the correlation matrix of yields, short-, medium-, and long-term interdealer order flow, and short-, medium-, and long-term customer order flow. The principal components analysis is based on data including all days during the period September 1999–September 2005. The factors are ordered according to how much they explain of the total variation.

	$F1$	$F2$	$F3$
Bond yields			
3 year	0.577	−0.653	0.491
5 year	0.580	−0.096	−0.809
10 year	0.575	0.751	0.323
% explained	0.990	0.010	0.000
Interdealer order flow			
1–4 years	0.567	−0.679	0.467
4–7 years	0.604	−0.043	−0.796
7–11 years	0.561	0.733	0.385
% explained	0.482	0.270	0.248
Customer order flow			
1–4 years	0.616	−0.454	0.644
4–7 years	0.668	−0.134	−0.732
7–11 years	0.418	0.881	0.221
% explained	0.396	0.322	0.282

interdealer order flow. After a trade with a customer is executed, a dealer has two alternatives. First, she can pass the trade on to other dealers. Second, she can let her inventory change. If she chooses the first possibility, she can either use a market order (MO) or a limit order (LO). A MO will initiate a trade at the prevailing market price. A LO will enter a bid or an ask quote, different from the current market price, in the electronic order book. Unlike MOs, LOs have a risk of not being executed. An impatient dealer is thus likely to use MOs and a patient dealer is likely to use LOs. If the dealer uses a MO, the customer trade will be reflected in her interdealer order flow and her inventory will be unchanged. If she uses a LO, the customer trade will not be reflected in her interdealer order flow, but in her counterparty's order flow, while her inventory is unchanged. The use of LOs instead of MOs will thus reduce the link between the dealer's interdealer order flow and her customer order flow. If the dealer chooses the second alternative and lets her inventory change, no link between the customer and interdealer markets will occur.

The interaction between the customer market and the interdealer market can be discussed in the context of market microstructure models of the Glosten-Milgrom type.[12] In this type of model, there is one market-maker (dealer) and two types of traders (customers): informed and uninformed. An informed trader possesses private information about the true value of the asset, and will trade on this information. She will buy the asset only if she has positive information and sell it only if she has negative information. An uninformed trader, often called a liquidity trader, trades for reasons exogenous to the model. Uninformed trades can, for example, be related to the rebalancing of indexed portfolios or raising cash. An uninformed trader is expected to be equally likely to buy and sell the asset as the trades are independent of the expected future value of the asset. The market-maker in this model will set prices equal to her conditional expectation of the value of the asset depending on whether the trade is a buy or a sell. Expectations are assumed to be updated through a Bayesian learning model containing prior probabilities for the occurrence of informed versus uninformed traders and the occurrence of good versus bad news. The model is mainly concerned with the price process and how a market-maker sets quotes.[13] It does not describe the trading behavior of the dealer, but the logic of the model can be used to derive possible dealer trading strategies.

Based on the reasoning in the Glosten-Milgrom model, dealers will choose trading strategies conditional on whether they are trading on information or not. Informed dealers are more likely to be impatient than uninformed dealers and therefore more likely to use MOs. A dealer who has informed customer trades as a source of information is likely to choose the trading strategy depicted in Fig. 2. The strategy implies that a dealer uses MOs in the interdealer market after receiving informed customer trades and LOs when receiving uninformed customer trades. This assumes the dealer can identify her informed customers. A dealer can identify an informed customer based on conversations prior to the trade or on past trading history. The dealer first receives a customer trade and then decides whether or not the customer is informed. If the customer is considered informed, the dealer will subsequently use a MO (initiate a trade) in the same direction in the interdealer market.[14] The dealer prefers to trade right away in order to benefit from her private information. If she has to wait, the prices may change before she is able to utilize her informational

[12]See Glosten and Milgrom (1985) or O'Hara (1995) for a description of this type of model.

[13]Quotes are the bid and ask prices set by a market-maker.

[14]If the customer buys from the dealer, the dealer will buy in the interdealer market and vice versa.

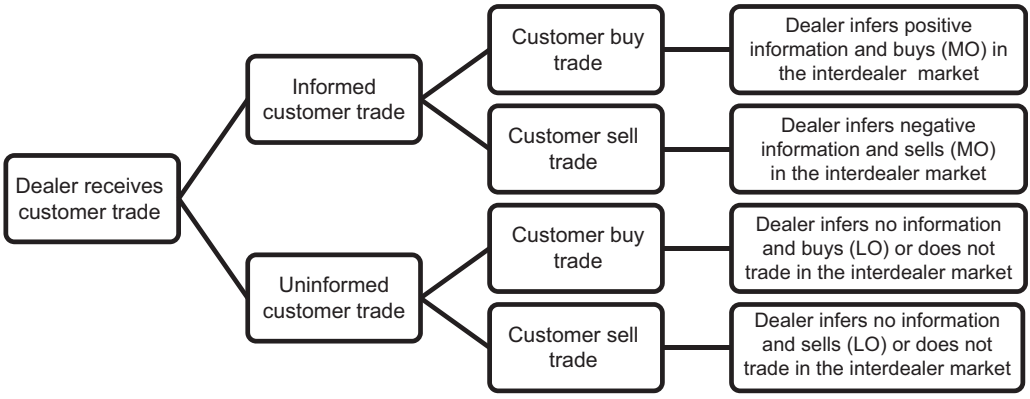

Fig. 2. Possible dealer strategy in the government bond market when dealers can identify their informed customers.

advantage. If the dealer identifies the customer as uninformed, she is likely to use a LO as the risk of a substantial price change is perceived as low.

This strategy is in line with Osler (2009), who concludes that a dealer in the foreign exchange market is more likely to place a MO after trading with an informed customer than after trading with an uninformed customer. If dealers normally follow this strategy, aggregate interdealer order flow will reflect informed customer trades while aggregate customer order flow will reflect both uninformed and informed customer trades.

At the dealer level, the relationship between customer order flow and interdealer order flow will vary according to whether or not the dealer is informed and according to the source of information. If the dealer's source of information is her customer orders, these will be reflected in her interdealer order flow. In this case, we would also expect a high correlation between the customer order flow and interdealer order flow of the dealer. If she has a high share of informed customer trades, her interdealer order flow will be more informative than if she has a low share. It will be less informative if she has problems distinguishing between informed and uninformed customers. If the dealer's source of information is her skill in obtaining superior information, this will be reflected in her interdealer order flow. In this case, the dealer will trade in the interdealer market independently of her trades in the customer market and we expect the correlation between the customer order flow and interdealer order flow to be relatively low. Finally, if individual order flow is uninformative, the dealer appears to have no information, neither from informed customer trades nor from skill in processing and utilizing other available information.

5. The information content in order flow

In order to explore the role of dealers in the process of price discovery, I investigate the informational content of interdealer order flow and customer order flow both at the aggregate level and the individual dealer level. If interdealer order flow can explain daily yield changes, dealers have information relevant for future yields and play a role in the price formation process. If customer order flow can explain daily yield changes, customer trades contain information relevant for future yields. If both interdealer order flow and customer order flow can explain daily yield changes, the dealer is informed and customer

trades are a source of information. If customer order flow does not explain interdealer order flow, and the dealer's interdealer order flow is informative, the dealer is informed and dealer skill can be a source of information. These hypotheses are tested below.

5.1. Aggregate order flow

The following model is used to compare the price impact of aggregate interdealer order flow and aggregate customer order flow in the Norwegian government bond market:

$$dY_t^i = c + \gamma F1_{t-1} + \beta_1 OF_t^S + \beta_2 OF_t^M + \beta_3 OF_t^L + \beta_4 COF_t^S + \beta_5 COF_t^M + \beta_6 COF_t^L + e_t, \quad (1)$$

where dY_t^i is the yield change of the i'th maturity from day $t-1$ to day t and $i=3$, 5, and 10 years, c is a constant, OF_t^S, OF_t^M, and OF_t^L are short-, medium-, and long-term aggregate interdealer order flow, and COF_t^S, COF_t^M, and COF_t^L are short-, medium-, and long-term aggregate customer order flow on day t. The lagged first principal component of yields, $F1_{t-1}$, is also included in the model to control for the impact of past yield changes.

The results are presented in Table 5. The table shows that aggregate interdealer order flow has a much larger effect on daily yield changes than aggregate customer order flow. While interdealer order flow explains about one-fourth of daily yield changes, customer order flow has little explanatory power. The explanatory power of interdealer order flow is in line with Brandt and Kavajecz (2004) and indicates that the price formation process in the Norwegian government bond market is consistent with that of the Treasury market. This suggests that the findings in this study are relevant for sovereign bond markets in general. The results further show that interdealer order flows of all maturities have

Table 5
Response of daily yield changes to aggregate order flow.

The table presents the results of regressing 3-, 5-, and 10-year yield changes, dY_t^{3y}, dY_t^{5y}, and dY_t^{10y}, on day t on short-, medium-, and long-term interdealer order flow, OF^S, OF^M, and OF^L, and short-, medium-, and long-term customer order flow, COF^S, COF^M, and COF^L, between time $t-1$ and time t, and the first yield factor at time $t-1$. Order flow is measured as number of trades. The regressions are based on data for all days and include a constant, but the coefficients for the constant are dropped here. The coefficients are in basis points (0.01 percentage points) and corrected for autocorrelation and heteroscedasticity by the Newey-West method. An asterisk indicates that the coefficient is significant at the 5% level or better. T-statistics are in parentheses.

	dY_t^{3y}	dY_t^{5y}	dY_t^{10y}
$F1_{t-1}$	−0.06 (−1.19)	−0.06 (−1.22)	−0.04 (−0.98)
OF_t^S	−0.35* (−6.92)	−0.26* (−5.57)	−0.15* (−3.87)
OF_t^M	−0.32* (−7.04)	−0.34* (−7.26)	−0.24* (−6.07)
OF_t^L	−0.22* (−6.46)	−0.26* (−7.46)	−0.33* (−11.35)
COF_t^S	0.03 (0.66)	0.04 (1.32)	−0.00 (0.06)
COF_t^M	0.02 (0.02)	−0.02 (−0.46)	0.06* (1.99)
COF_t^L	0.01 (0.27)	0.00 (−0.07)	−0.05* (−2.00)
Adj. R^2	0.223	0.235	0.226

a significant effect on all yield changes, and that the effect is greatest on the same maturity yield changes. An increase in short-term interdealer order flow of one standard deviation will lead to a decrease in the 3-year yield of 1.3 basis points. Customer order flow has no impact on 3- and 5-year yield changes. Long-term customer order flow has a significant impact on 10-year yield changes, but the effect is much smaller than for long-term interdealer order flow. These results may indicate that there are many uninformed customers, and that their trades counter the trades of informed customers. They can also reflect that some dealers want to "square" or eliminate their positions by the end of the day, and do so in the customer market. Finally, Table 5 shows that the lagged yield factor, $F1_{t-1}$, has no significant effect on yield changes of any maturity.

According to market microstructure theory, price changes caused by order flow can be due to private information or to inventory effects. While inventory effects are expected to be temporary, new information will lead to a permanent change in prices. To control for inventory effects, a VAR model with interdealer order flow and yield changes as endogenous variables is employed. By calculating the accumulated impulse responses over a 10-day period, it is possible to observe whether the price impact is permanent or not.[15] The results are shown in Fig. 3, Panels A–C. Panel A shows that a one standard deviation shock to short-term interdealer order flow leads to a reduction of 2–3 basis points in the 3-year yield. Panels B and C illustrate that a one standard deviation shock to short-, medium-, or long-term interdealer order flow leads to a reduction of about 2 basis points in the 5- and 10-year yields. The panels confirm the results in Table 5, which show that each yield maturity has the largest response to the same maturity order flow. The accumulated impulse responses indicate that the effect of order flow on yield changes is permanent as the initial effects are not reverted. This suggests that interdealer order flow contains private information relevant for bond prices. This is in line with the findings in Manaster and Mann (1996), Brandt and Kavajecz (2004), Anand and Subrahmanyam (2008), and Osler, Mende, and Menkhoff (2011).

In order to check the consequences of including all days versus including no-news days only, I have compared the effect of order flow on yield changes in both cases. News days were identified as the three days surrounding the release of the monthly Consumer Price Index and the press release from Monetary Policy meetings. The results, which are not shown, indicate that the effects of order flow are higher on no-news days than on all days.[16] However, it is difficult to eliminate the direct effect of public news completely as there is a stream of more or less important public news every day. Also, some studies show that the indirect channel of price formation is at work on news days. Green (2004) finds that order flow helps determine the influence of new information on prices in the minutes after an announcement is made. These findings support the inclusion of all days when measuring the price impact of order flow.

5.2. *Informed customer order flow*

The results so far show that aggregate interdealer order flow contains information while aggregate customer order flow does not. This can be because dealers are skilled and collect information while customers do not, but it can also be because the trades of informed

[15] A lag-length of 2 is employed, which in line with the Schwarz information criterion.

[16] The results are available upon request.

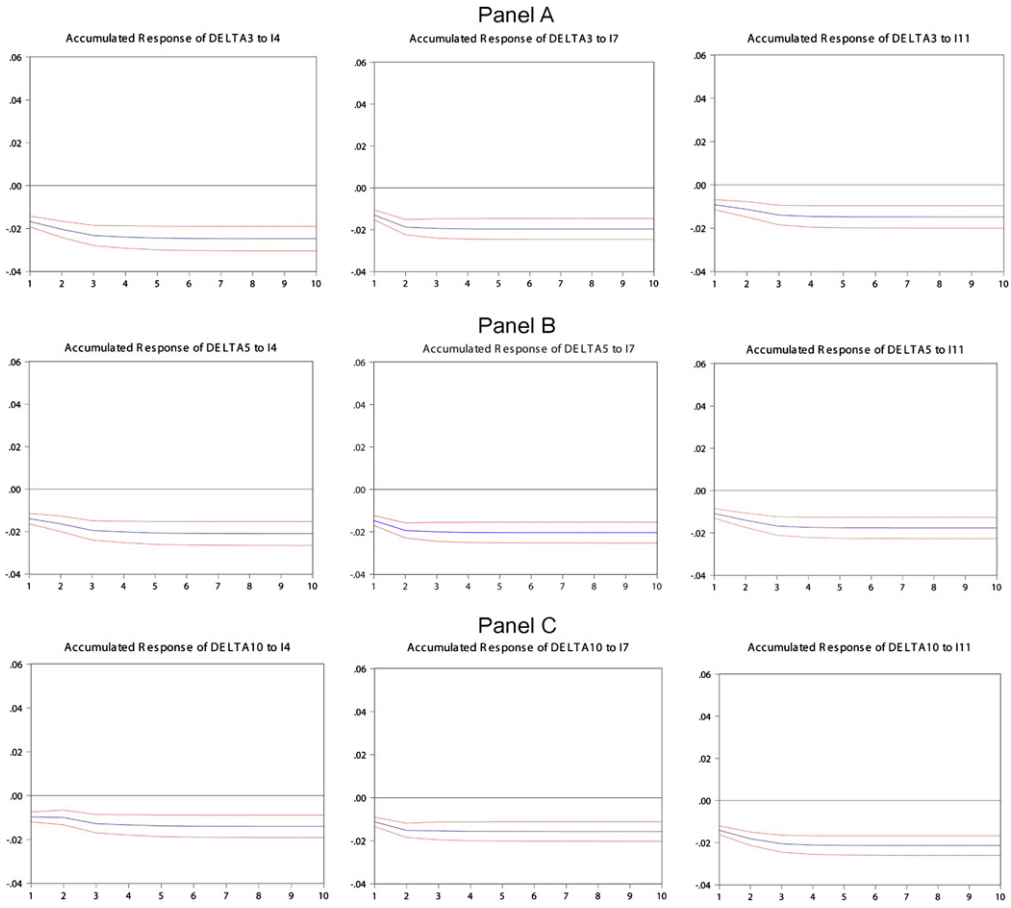

Fig. 3. The figures show the accumulated response of 3-, 5-, and 10-year yield changes to a one standard deviation shock in interdealer order flow. Panel A shows the response of 3-year yield changes to a one standard deviation shock in short-term order flow, OF^S, medium-term order flow, OF^M, and long-term order flow, OF^L, respectively. Panel B shows the accumulated response of 5-year yield changes and Panel C shows the accumulated response of 10-year yield changes to a shock in short-, medium-, and long-term order flow. Panel A. Accumulated response to Cholesky one standard deviation innovations ± 2 s.e. Panel B. Accumulated response to Cholesky one standard deviation innovations ± 2 s.e. Panel C. Accumulated response to Cholesky one standard deviation innovations ± 2 s.e.

customers are not reflected in aggregate customer order flow. One way to explore which is the case, is to employ a proxy for informed customer order flow. By utilizing the data set available in this study, it is possible to construct order flow based on the trade type delayed publication. Since dealers have the option to enter an additional code for delayed publication when they register a trade, it is likely that dealers will choose to do this when they receive a perceived informed customer trade. However, it is likely that some dealers include uninformed customer trades as well in this trade category. After the introduction of SAXESS in May 2002, it has been possible to set the code for delayed publication as a default in the trading system, and some dealers have opted for this. This change increases the probability of finding both informed and uninformed customer trades among delayed publication customer trades. We test for the possible change in the information content

in delayed publication customer trades by dividing the sample into two sub-periods, one before and one after May 2002. To explore whether or not informed customer trades are a source of information in interdealer order flow, we employ delayed publication customer order flow as a proxy for informed customer order flow in the following model:

$$dY_t^i = c_0 + \beta_0 F1_{t-1} + \sum_{j=S}^{L} \beta_1^j resOF_t^j + \sum_{j=S}^{L} \beta_2^j HCOF_t^j + \sum_{j=S}^{L} \beta_3^j resCOF_t^j + u_t, \tag{2}$$

where $HCOF_t^j$ is delayed publication customer order flow and $j = S, M, L$ denotes short-, medium-, and long-term order flow, respectively. $resOF_t^j$ is aggregate interdealer order flow orthogonal to delayed publication customer order flow and $resCOF_t^j$ is a proxy for uninformed customer order flow. Interdealer order flow orthogonal to delayed publication customer order flow is derived as follows:

$$OF_t^j = c_1 + \theta_i HCOF_t^j + \mu_t^j, \quad \mu_t^j = resOF_t^j, \tag{3}$$

where μ_t^j is the residual obtained by regressing delayed publication customer order flow on aggregate interdealer order flow for each maturity group. By orthogonalizing the interdealer order flow, we remove the part of the order flow that is related to delayed publication customer order flow. $resOF_t^j$ is thus a measure of interdealer order flow independent of informed customer order flow. The proxy for uninformed customer order flow is defined as the difference between aggregate customer order flow and delayed publication customer order flow as follows:

$$resCOF_t^j = COF_t^j - HCOF_t^j, \tag{4}$$

where $resCOF_t^j$ is the customer order flow for maturity group j, which is not reported with delayed publication. The model in Eq. (2) states that daily yield changes are explained by the lagged yield factor, interdealer order flow independent of informed customer order flow, informed customer order flow, and uninformed customer order flow. The model is estimated for the whole sample period and for the two sub-periods. In the first sub-period, before May 2002, delayed publication trades are 200 million NOK or larger and the period of delay is two hours. In the second period, after May 2002, the size limit is lifted and the period of delay is extended until 4 pm no matter when the trade is executed.

The results are presented in Table 6. The first column for the 3-, 5-, and 10-year yield changes shows the results for the whole sample period. Orthogonal interdealer order flow for each maturity group has significant explanatory power for all yield changes. Also long-term informed customer order flow has significant explanatory power for yield changes of all maturities for the whole sample period. The coefficients for interdealer order flow and the explanatory power of the model are consistent with the results in Table 5. The difference is that whereas long-term informed customer order flow has significant explanatory power for daily yield changes of all maturities, long-term aggregate customer order flow is only significant for 10-year yields. Uninformed customer order flow appears to have little explanatory power. For 3- and 10-year yield changes, long- and medium-term uninformed customer order flow are significant, but the coefficients are small and have a positive sign.

The second and third columns for each bond maturity in Table 6 show the results for the first and second sub-period, respectively. The table shows that the coefficients for interdealer order flow of all maturities are significant in both periods. The coefficient for

Table 6
Response of daily yield changes to interdealer order flow, informed customer order flow, and uninformed customer order flow.

The table presents the results of regressing daily yield changes on informed customer order flow, proxied by delayed publication customer order flow, $HCOF_t^S$, $HCOF_t^M$, and $HCOF_t^L$, uninformed customer order flow, $resCOF_t^S$, $resCOF_t^M$, and $resCOF_t^L$, and aggregate interdealer order flow orthogonal to delayed publication customer order flow, $resOF_t^S$, $resOF_t^M$, and $resOF_t^L$. Order flow is measured as number of trades. The regressions are based on data for the whole period 1999–2005 and the two sub-periods 1999–2002 and 2002–2005. The first principal component of bond yields at time $t-1$ and a constant are included in the regressions, but the coefficients are not included in the table. The coefficients are in basis points (0.01 percentage points) and corrected for autocorrelation and heteroscedasticity by the Newey-West method. An asterisk indicates that the coefficient is significant at the 5% level or better. *T*-statistics are in parentheses.

	dY_t^{3y}			dY_t^{5y}			dY_t^{10y}		
Period	99–05	99–02	02–05	99–05	99–02	02–05	99–05	99–02	02–05
$resOF_t^S$	−0.36* (−7.17)	−0.30* (−6.24)	−0.41* (−4.93)	−0.26* (−5.55)	−0.15* (−3.54)	−0.35* (−4.77)	−0.15* (−4.05)	−0.02 (−0.50)	−0.26* (−4.92)
$resOF_t^M$	−0.32* (−7.19)	−0.31* (−6.42)	−0.33* (−5.04)	−0.35* (−7.36)	−0.35* (−7.09)	−0.37* (−4.92)	−0.24* (−6.17)	−0.23* (−4.90)	−0.25* (−4.32)
$resOF_t^L$	−0.22* (−6.43)	−0.14* (−3.49)	−0.26* (−5.30)	−0.26* (−7.47)	−0.19* (−4.34)	−0.30* (−6.35)	−0.33* (−11.43)	−0.31* (−8.44)	−0.35* (−8.41)
$HCOF_t^S$	0.01 (0.17)	−0.18 (−1.66)	0.04 (0.64)	0.03 (0.64)	−0.20* (−1.99)	0.05 (1.26)	0.02 (0.46)	−0.18* (−2.28)	0.05 (0.99)
$HCOF_t^M$	−0.07 (−1.14)	−0.07 (−0.43)	−0.06 (−0.93)	−0.08 (−1.46)	0.05 (0.32)	−0.10 (−1.54)	−0.01 (−0.24)	0.05 (0.44)	−0.02 (−0.32)
$HCOF_t^L$	−0.13* (−2.34)	−0.26* (−2.95)	−0.10 (−1.52)	−0.10* (−2.12)	−0.18* (−2.22)	−0.07 (−1.25)	−0.19* (−4.72)	−0.22* (−2.84)	−0.17* (−3.82)
$resCOF_t^S$	−0.01 (−0.10)	0.04 (0.73)	−0.15 (−0.78)	0.01 (0.32)	0.04 (0.95)	−0.10 (−0.49)	−0.06 (−1.3)	−0.02 (−0.54)	−0.21 (−1.07)
$resCOF_t^M$	0.04 (0.80)	0.10* (1.99)	−0.12 (−1.13)	−0.01 (−0.21)	0.03 (0.73)	−0.15 (−1.45)	0.09* (2.39)	0.11* (2.56)	0.03 (0.32)
$resCOF_t^L$	0.08* (2.15)	0.06 (1.42)	0.13 (1.66)	0.05 (1.24)	0.03 (0.59)	0.07 (0.95)	0.00 (0.08)	−0.01 (−0.23)	0.03 (0.39)
Adj. R^2	0.226	0.255	0.223	0.235	0.236	0.251	0.227	0.212	0.255

the long-term informed customer order flow is significant for all yield changes in the first sub-period and for 10-year yield changes in the second sub-period. Short-term informed customer order flow is significant for all yield changes in the first sub-period only. The results indicate that the effect of informed customer order flow on yield changes is strongest in the first sub-period. This supports the assumption that delayed publication customer trades are more likely to contain both informed and uninformed customer trades in the second sub-period due to the changes in the trading system rules described above. Thus delayed publication customer order flow appears to be a better proxy for informed customer order flow in the first sub-period than in the second.

In summary, the results based on aggregate order flow document that interdealer order flow contains information relevant for bond prices by explaining about one-fourth of contemporaneous yield changes in the government bond market. A one standard deviation increase in short-term interdealer order flow orthogonal to delayed publication customer order flow leads to a fall in the 3-year yield of 1.4 basis points from the previous day. The results further show that the proxy for informed customer order flow has a significant impact on yield changes, especially in the first sub-period when the proxy works best. This

suggests that dealers are able, at least partially, to identify their informed customers. Uninformed customer order flow appears to have little impact on yield changes. These findings are consistent with the trading strategy depicted in Fig. 2, where dealers acquire information from customer trades. The fact that interdealer order flow orthogonal to informed customer order flow explains most of the daily yield changes indicates that dealers have other sources of information as well. The results thus suggest that both customer trades and dealer skill can be sources of information in aggregate interdealer order flow.

5.3. Individual dealer order flow

The previous two sections document that dealers play an important role in the price formation process in government bond markets. In order to better understand how bond prices are formed, it would be useful to know whether dealers play different roles in the price formation process and whether they have different sources of information. One of the main contributions of this paper is to explore the effects of individual dealer order flow on yield changes. This facilitates an investigation of whether or not information is symmetrically distributed among dealers. By determining the relationship between a dealer's interdealer order flow and her customer order flow, it is possible to explore whether customer orders are an important source of information. Seven bond dealers, constituting about 85% of the sample, are included in this part of the analysis. These seven dealers have been trading in government bonds throughout the sample period.[17] The dealers can be characterized by size, their customer base, and effort to acquire information. Size is measured as a dealer's total market share in the customer market and the interdealer market combined. The size of the customer base is measured as a dealer's market share in the customer market. Effort is measured as the value of a dealer's initiated interdealer trades relative to the value of her customer trades. This ratio can indicate whether a dealer is actively collecting information in order to make profitable trades. If a dealer is exerting effort to acquire information about future price movements, she is likely to be impatient and initiate trades because she wants to utilize this information before other dealers learn about it. A high share of initiated interdealer trades can therefore indicate that a dealer is exerting effort. A low share of initiated interdealer trades may indicate that a dealer is not exerting effort.

Table 7 presents the characteristics of the seven bond dealers. The dealers are numbered according to size as shown in Column 1. Size, which is measured by the total market share of each dealer, is displayed in Column 2. There are four large dealers, with a total market share in the customer and interdealer market ranging from 17% to 24%, constituting 85% of the seven dealers' total market share. The remaining three dealers are small, with a total market share of 15%. Column 3 shows the size of each dealer's customer base as reflected in their market share in the customer market. The four large dealers also have the largest customer bases. Column 4 displays the measure of effort: initiated interdealer trades over customer trades. Among the four large dealers, Dealer 2 appears to be exerting little effort, while Dealer 3 appears to be exerting a lot of effort. Among the small dealers, Dealer 7 is very active in the interdealer market, although has a very small customer base.

[17]The trades of dealers who were not present in the market for a substantial part of the sample period and dealers who only sporadically traded, are not included in this section.

Table 7
Characteristics of individual dealers.
The table describes the seven dealers who were active in the government bond market during the period 1999–2005. They are characterized by size, size of customer base, and their effort in acquiring information. Size is measured as total market share, calculated as the gross value of customer trades and initiated interdealer trades by the dealer as a percentage of the total value of both markets combined. Customer base is measured as the market share in the customer market, calculated as the gross value of a dealer's customer trades as a percentage of total customer trades. Dealer effort is measured as the value of a dealer's initiated interdealer trades as a percentage of the value of her customer trades.

Dealer	Size	Customer base	Effort
	Total market share	Customer market share	Interdealer trades / Customer trades
1	24%	24%	31%
2	23%	25%	19%
3	21%	19%	42%
4	17%	17%	28%
5	9%	10%	33%
6	4%	5%	30%
7	2%	1%	435%

The following model is employed to measure the contemporaneous price impact of the order flows of the seven bond dealers:

$$dY_t^i = c + \beta_1 F1_{t-1} + \sum_{d=1}^{7} \gamma_d OF_{d,t}^S + \sum_{d=1}^{7} \varphi_d OF_{d,t}^M + \sum_{d=1}^{7} \lambda_d OF_{d,t}^L + \epsilon_t, \quad (5)$$

where $OF_{d,t}^S$, $OF_{d,t}^M$, and $OF_{d,t}^L$ are the short-, medium-, and long-term interdealer order flow of Dealer d at time t and $d = 1,2,3,4,5,6,7$. The results are displayed in Table 8 and suggest that dealers are heterogeneous. The effects on yields of each dealer's order flows vary substantially. The individual dealer effects vary with respect to order flow maturity and yield maturity, suggesting that some dealers specialize in trading and collecting information at certain segments of the yield curve. For example, Dealer 1 may specialize in the short- and medium-term segment as her short- and medium-term order flows have a larger impact on all yield changes than her long-term order flow. A one standard deviation change in Dealer 1's short-term order flow has the largest average effect on 3-year yield changes, nearly 1 basis point. Also, the long-term order flow of Dealer 2 has a larger impact on all yield changes than her short- and medium-term order flow, indicating that she specializes in trading at the long end of the yield curve. Dealer 4 also appears to have information about the long end of the yield curve, as a one standard deviation change in her long-term order flow has the largest impact on 10-year yield changes, nearly 0.75 basis point. Wald tests comparing the coefficients of short-, medium-, and long-term order flow for the seven dealers confirm that the coefficients vary among dealers.[18] Wald tests further indicate that the short- and medium-term order flows of Dealer 1 are more informative than the corresponding order flows of the other dealers. When Dealer 1 is removed from the sample, the Wald tests no longer find that the coefficients for short- and medium-term order flow differ among dealers.

[18]The results from the Wald tests are available upon request.

Table 8
Response of daily yield changes to individual interdealer order flow.

The table presents the results of regressing daily yield changes on individual interdealer order flow of all dealers over the period 1999-2005, where $OF^{S}_{d,t}$, $OF^{M}_{d,t}$, and $OF^{L}_{d,t}$ are the short-, medium-, and long-term order flow of Dealer d. Order flow is measured as number of trades. The coefficients are in basis points (0.01 percentage points) and corrected for autocorrelation and heteroscedasticity by the Newey-West method. An asterisk indicates that the coefficient is significant at the 5% level or better. T-statistics are in parentheses.

Dealer		dY^{3y}_t	dY^{5y}_t	dY^{10y}_t
1	$OF^{S}_{1,t}$	−0.69* (−5.64)	−0.41* (−3.22)	−0.20* (−1.97)
	$OF^{M}_{1,t}$	−0.67* (−4.80)	−0.66* (−4.51)	−0.51* (−4.21)
	$OF^{L}_{1,t}$	−0.03 (−0.29)	−0.09 (−1.11)	−0.26* (−2.96)
2	$OF^{S}_{2,t}$	−0.34* (−2.38)	−0.25 (−1.93)	−0.21 (−1.95)
	$OF^{M}_{2,t}$	−0.41* (−3.54)	−0.46* (−3.76)	−0.41* (−3.73)
	$OF^{L}_{2,t}$	−0.68* (−4.59)	−0.75* (−5.51)	−0.63* (−5.34)
3	$OF^{S}_{3,t}$	−0.26 (−1.71)	−0.16 (−1.10)	−0.08 (−0.80)
	$OF^{M}_{3,t}$	−0.08 (−0.66)	−0.18 (−1.43)	−0.10 (−0.98)
	$OF^{L}_{3,t}$	−0.23* (−2.61)	−0.20* (−2.37)	−0.31* (−3.76)
4	$OF^{S}_{4,t}$	−0.17 (−1.29)	−0.09 (−0.79)	−0.12 (−1.12)
	$OF^{M}_{4,t}$	−0.36* (−2.98)	−0.58* (−5.19)	−0.41* (−4.27)
	$OF^{L}_{4,t}$	−0.26* (−2.66)	−0.40* (−4.07)	−0.53* (−6.28)
5	$OF^{S}_{5,t}$	−0.27* (−2.47)	−0.21* (−2.25)	−0.06 (−0.71)
	$OF^{M}_{5,t}$	−0.55* (−3.64)	−0.51* (−3.53)	−0.40* (−3.37)
	$OF^{L}_{5,t}$	−0.21 (−1.72)	−0.23 (−1.76)	−0.23 (−1.88)
6	$OF^{S}_{6,t}$	−0.79* (−2.75)	−0.71* (−2.85)	−0.46* (−2.06)
	$OF^{M}_{6,t}$	−0.46 (−1.80)	−0.48 (−1.73)	−0.31 (−1.37)
	$OF^{L}_{6,t}$	−0.77* (−2.94)	−0.67* (−2.50)	−0.60* (−2.56)
7	$OF^{S}_{7,t}$	−0.35* (−2.57)	−0.29* (−2.28)	−0.14 (−1.71)
	$OF^{M}_{7,t}$	−0.25* (−3.49)	−0.27* (−3.66)	−0.18* (−2.50)
	$OF^{L}_{7,t}$	−0.10 (−1.65)	−0.16* (−2.82)	−0.19* (−3.41)
	Adj. R^2	0.259	0.261	0.237

The finding that interdealer order flow of individual dealers contributes differently to the price discovery process can indicate that dealers have different sources of information. I investigate this by examining the link between customer order flow and interdealer order

flow for each dealer in the following model:

$$OF^{j}_{d,t} = c + \gamma_1 COF^{j}_{d,t} + \gamma_2 COF^{j}_{d,t-1} + v_t, \tag{6}$$

where $OF^{j}_{d,t}$ is the interdealer order flow of Dealer d, $COF^{j}_{d,t}$ and $COF^{j}_{d,t-1}$ are the customer order flow of Dealer d in period t and $t-1$ for maturity $j=S, M, L$. The results

Table 9
Response of interdealer order flow to customer order flow.

The table presents the results of regressing the short-, medium-, and long-term interdealer order flow on day t on the short-, medium-, and long-term customer order flow on time t and $t-1$ for individual dealers. All order flow variables are measured in net volume (in Norwegian kroner). The coefficients are corrected for autocorrelation and heteroscedasticity by the Newey-West method. An asterisk indicates that the coefficient is significant at the 5% level or better. T-statistics are in parentheses.

Dealer		$COF^{S}_{d,t}$	$COF^{S}_{d,t-1}$	$COF^{M}_{d,t}$	$COF^{M}_{d,t-1}$	$COF^{L}_{d,t}$	$COF^{L}_{d,t-1}$	Adj. R^2
1	$OF^{S}_{1,t}$	19.83* (5.59)	5.86* (3.01)					0.129
	$OF^{M}_{1,t}$			4.71* (4.80)	2.19* (2.51)			0.038
	$OF^{L}_{1,t}$					5.79* (2.41)	1.02 (1.26)	0.040
2	$OF^{S}_{2,t}$	7.13* (4.26)	0.96 (0.88)					0.027
	$OF^{M}_{2,t}$			2.97* (3.40)	1.28* (2.28)			0.016
	$OF^{L}_{2,t}$					2.79* (2.36)	2.54 (1.19)	0.020
3	$OF^{S}_{3,t}$	10.80* (4.78)	1.10 (0.77)					0.032
	$OF^{M}_{3,t}$			5.49* (3.35)	2.43 (1.84)			0.029
	$OF^{L}_{3,t}$					8.89* (4.75)	1.75 (1.41)	0.046
4	$OF^{S}_{4,t}$	11.98* (3.20)	4.16* (2.50)					0.046
	$OF^{M}_{4,t}$			2.68* (2.17)	1.80 (1.49)			0.011
	$OF^{L}_{4,t}$					1.15 (1.56)	0.78 (1.34)	0.007
5	$OF^{S}_{5,t}$	7.87* (2.99)	2.02 (1.28)					0.041
	$OF^{M}_{5,t}$			4.58* (2.05)	−0.46 (−0.12)			0.012
	$OF^{L}_{5,t}$					4.06* (2.78)	1.91* (1.96)	0.015
6	$OF^{S}_{6,t}$	5.28 (1.10)	1.98 (1.54)					0.012
	$OF^{M}_{6,t}$			7.13* (2.51)	2.88 (1.83)			0.043
	$OF^{L}_{6,t}$					7.35 (1.91)	1.98* (2.48)	0.046
7	$OF^{S}_{7,t}$	38.28* (2.51)	−0.60 (−0.30)					0.027
	$OF^{M}_{7,t}$			27.71* (2.92)	4.18 (0.26)			0.007
	$OF^{L}_{7,t}$					15.05 (0.92)	−32.77 (−1.34)	0.011

are presented in Table 9. The explanatory power of contemporaneous and one day lagged customer order flow for interdealer order flow varies substantially between dealers. For Dealer 1, today's and yesterday's customer order flow explains a substantial part of the variation in her short-term interdealer order flow. This indicates that customer order flow is an important source of information for Dealer 1. For Dealer 4, there appears to be no link between long-term customer order flow and long-term interdealer order flow. The long-term customer order flows of today and yesterday have no explanatory power for today's long-term interdealer order flow. Since the long-term interdealer order flow of Dealer 4 plays an important role in the price discovery for 10-year yields, this result suggests that customer trades are not the main source of information for Dealer 4. Rather, this points to dealer skill as a source of information for this dealer. For the other dealers, customer trades can be one source of information, but the link between customer order flow and interdealer order flow is weaker than for Dealer 1. The exception is Dealer 6, who also has a strong link between customer and interdealer order flow at the long end of the yield curve. This can indicate that Dealer 1 and Dealer 6 have a higher share of informed customers than the other dealers.[19]

The results in this section indicate that all dealers play a role in price discovery. However, the impact of interdealer order flow varies between dealers, suggesting that some dealers are better informed than others. The results further indicate that dealers are relying on different sources of information. For some dealers, customer trades explain a considerable part of interdealer trades, up to 13%, while for other dealers customer trades have little explanatory power for their interdealer trades. This can be due to differences in the size or composition of their customer base, differences in dealer skill and effort to acquire other relevant information, but also in the objectives of the dealer institutions. The information conveyed in aggregate interdealer order flow is thus based on asymmetric dealer information. This suggests that both aggregation of asymmetric information from market participants and heterogeneous interpretation of public information are types of information imbedded into prices through interdealer order flow in the process of price discovery.

6. Conclusion

This study explores the price discovery process in government bond markets by employing a new data set with complete trading records and dealer identities from the Norwegian government bond market. The main contributions are to compare the information content of interdealer order flow to that of customer order flow in a two-tier market and to explore whether price impacts vary across dealers. Previous studies on the price discovery process use more limited data sets. Osler, Mende, and Menkhoff (2011) use customer and interdealer trades from one dealer only, Brandt and Kavajecz (2004) use aggregate interdealer order flow only, while Manaster and Mann (1996), Anand and Subrahmanyam (2008), and Menkveld, Sarkar, and van der Wel (2012) employ data from one-tier markets.

The results reveal that while aggregate interdealer order flow is highly informative, aggregate customer order flow is not. A proxy for informed customer trades, delayed publication trades,

[19] As a robustness check, I run an alternative model including the customer order flows of all maturities on day t and day $t-1$ as explanatory variables. The results confirm the findings in Table 9 and are available upon request. For Dealer 4, medium-term customer order flow has a small, significant impact on long-term interdealer order flow. However, the explanatory power is very low, indicating that the main source of information for Dealer 4 is not customer trades.

appear to contain some information indicating that at least some dealers are able to identify informed customers. The results further show that the interdealer flows of some dealers have a higher price impact than the interdealer order flow of others. These results are consistent with Peiers (1997) and Sapp (2002), who find that there are information asymmetries in the foreign exchange market and that some dealers are better informed than others. Dealers also appear to have different sources of information. While there is a strong link between the customer order flow and the interdealer order flow of some dealers, there is no such link for other dealers. This suggests that both customer trades and dealer skill in acquiring and interpreting other relevant information are sources of information in interdealer order flow. The results thus indicate that dealers in two-tier government bond markets are not mere intermediaries of customer trades, but play an independent role in the price discovery process. This is consistent with Osler, Mende, and Menkhoff (2011), who conclude that price discovery in the currency market mainly takes place in the interdealer market.

References

Anand, A., Subrahmanyam, A., 2008. Information and the intermediary: Are market intermediaries informed traders in electronic markets? Journal of Financial and Quantitative Analysis 43, 1–28.

Brandt, M., Kavajecz, K., 2004. Price discovery in the U.S. treasury market: the impact of orderflow and liquidity on the yield curve. Journal of Finance 59, 2623–2654.

Evans, M., Lyons, R., 2002. Order flow and exchange rate dynamics. Journal of Political Economy 110, 170–180.

Evans, M., Lyons, R., 2005. Meese-Rogoff Redux: Micro-based exchange rate forecasting. American Economic Review 95, 405–414.

Federal Reserve Bank of New York, 2011. Primary Dealers 〈http://www.newyorkfed.org/markets/Dealer_Lists_1960_to_2011.xls〉.

Fleming, M., 2003. Measuring treasury market liquidity. Economic Policy Review 9, 83–108.

Glosten, L., Milgrom, P., 1985. Bid, ask and transactions prices in a specialist market with heterogeneously informed traders. Journal of Financial Economics 14, 71–100.

Goodhart, C., 1988. The foreign exchange market: a random walk with a dragging anchor. Economica 55, 437–460.

Green, T.C., 2004. Economic news and the impact of trading on bond prices. Journal of Finance 59, 1201–1234.

Hasbrouck, J., 1991. Measuring the information content of stock trades. Journal of Finance 46, 179–207.

Lee, C., Ready, M., 1991. Inferring trade direction from intraday data. Journal of Finance 46, 733–746.

Litterman, R., Scheinkman, J., 1991. Common factors affecting bond returns. Journal of Fixed Income 1, 54–61.

Lyons, R., 2001. The Microstructure Approach to Exchange Rates. MIT Press, Cambridge, MA.

Manaster, S., Mann, S.C., 1996. Life in the pits: competitive market making and inventory control. Review of Financial Studies 9, 953–975.

Menkveld, A., Sarkar, A., van der Wel, M., 2012. Customer order flow, intermediaries, and discovery of the equilibrium risk-free rate. Journal of Financial and Quantitative Analysis 47, 821–849.

Norges Bank, 2011. Exchange rates 〈http://www.norges-bank.no/en/price-stability/exchange-rates/valutakurser_daglig_ukoplet.xls〉.

Organisation for Economic Co-operation and Development (OECD), 2002. Public debt markets trends and recent structural changes. OECD.

O'Hara, M., 1995. Market Microstructure Theory. Blackwell Publishers, Cambridge, MA.

Osler, C., 2009. Foreign exchange microstructure: a survey. In: Meyers, R.A. (Ed.), Encyclopedia of Complexity and System Science. Springer, New York.

Osler, C., Mende, A., Menkhoff, L., 2011. Price discovery in currency markets. Journal of International Money and Finance 30, 1696–1718.

Oslo Stock Exchange, 2011. Bonds, turnover by value (NOK million) excluding repo 〈http://www.oslobors.no/ob_eng/Oslo-Boers/Statistics/Annual-statistics/2011_omsetning_eks_repo.xls〉.

Peiers, B., 1997. Informed traders, intervention, and price leadership: a deeper view of the microstructure of the foreign exchange market. Journal of Finance 52, 1589–1614.

Sapp, S., 2002. Price leadership in the spot foreign exchange market. Journal of Financial and Quantitative Analysis 37, 425–448.