Price Formation and Liquidity Provision in Short-Term Fixed Income Markets[1]

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Abstract

High levels of quote and trade transparency in European government securities markets and substantial quoting obligations ensure that prices are informationally efficient. Dealers are able to quickly absorb private information elsewhere in the market by observing order flow and changes in the limit order book. Consequently order flow, the relative depth on the bid and offer sides of the market, and spreads, are only slightly informative. Since order flow reflects both inventory management practices and private information it explains a smaller proportion of the variation in asset returns then in Canadian interdealer brokered markets where no quoting obligations exist.

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1. Introduction

The behaviour of market participants, and their trading and quoting decisions, will be affected by how a financial market is organized. The results of this paper confirm previous findings, and provide some new insight into how price and liquidity dynamics are affected by the structure of government bond markets in Europe and, by comparison, in Canada. In Europe, interdealer trading in the most liquid government bonds occurs on the Mercato Telematico dei Titoli de Stato (MTS) platform. This segment of the market functions as an electronic limit order book. With the introduction of a "liquidity pact" in 1999, MTS market makers are required to post buy and sell limit orders above a minimum size, within a maximum bid-offer spread, for a minimum number of hours each day. In contrast, Canadian dealers have no quoting obligations.

European and Canadian market structures also differ with respect to quote and trade transparency. The MTS platform makes pre- and post-trade information available to interested participants in real time via Bloomberg and Reuters. In Canada, only the best quotes available at each individual interdealer broker are observable to the market. This paper addresses whether differences in these market structures has an impact on the dynamics of prices, and more importantly, the process in which fundamental information is incorporated into prices. Bloomfield and O'Hara (1999) provide evidence from experimental settings that suggest that transparency significantly improves a market's informational efficiency but that spreads will widen and depth will fall as the risks borne by dealers increase. In this paper, we attempt to determine if markets remain efficient once quoting obligations are imposed on dealers in a transparent market.

Asymmetric information may exist in government securities markets even though these securities have fixed and known cash flows and a finite life. For example, market participants have heterogeneous models of interest rates relating macroeconomic fundamentals, including news announcements, to prices and yields. Since markets do not clear instantaneously, prices at any point in time may not reflect all fundamental information available in the market. To characterize all aspects of the price discovery process, we investigate the joint relationship between price changes, order flow, the relative depth on the bid and offer sides of the market, and spreads, across several short-term European and Canadian government securities markets. When information is incomplete and heterogeneous, market participants' subjective valuations of a security may be captured in the latter three variables.

Order flow is defined as the number of buyer- less seller-initiated trades. Green (2004), Brandt and Kavajecz (2004) and Pasquariello and Vega (2004) demonstrate that order flow has a permanent impact on the price of government securities. We extend their analysis by examining the role of relative depth in the market and spreads in the price discovery process. Relative depth is calculated as the difference between the quantity of a security available for purchase at the best bid quote in the market and the quantity available for sale as the best offer quote in the market. As usual, spreads are the difference between those best offer and bid quotes. Recent microstructure literature demonstrates that market participants may learn new information from the supply of liquidity in the market. Bloomfield, O'Hara and Saar (2003) illustrate how informed traders will use both market orders and limit orders strategically in an electronic limit order market. Goettler, Parlour and Rajan (2005) illustrate that limit orders placed by informed traders reveal new information about the underlying value of an asset. Thus relative depth and spreads, like order flow, may also convey information and have an impact on the price discovery process.

Depth and spreads are also associated with measures of liquidity in the market. Earlier microstructure studies demonstrated that the supply of liquidity and informed trading are related. Admati and Pfleiderer (1988) show that uninformed discretionary liquidity traders will trade around the same time, increasing liquidity in the market, and reducing the losses they suffer to informed traders. Kim and Verrecchia (1994), on the other hand, illustrate that if informed traders possess an informational advantage after an event, liquidity will remain low as long as those informed traders maintain that advantage. Therefore, the supply of liquidity in markets affects, and is affected by, the speed with which information is incorporated into prices. In addition, recent literature on the pricing of securities, most notably, Acharya and Pedersen (2005), Garleanu and Pedersen (2004), and Vayanos (2004) point out that illiquidity is priced in financial markets, and that investors will demand compensation in terms of an illiquidity premia on their required rate of return.

Motivated by questions associated with the relationship between price changes, order flow, relative depth and spreads, we utilize the framework of Hasbrouck (1991a, b), Chordia, Roll and Subrahmanyam (2000, 2001), Chordia, Sarkar and Subrahmanyam (2005) and examine the dynamic interactions between these variables via a reduced-form vector autoregression (VAR) model. We find relative depth in the market explains some of the variability in prices in Europe although the magnitude is relatively small. In addition, the absence of quoting restrictions contributes to informative market-wide spreads in the Canadian market. Generally, a liquidity premia will be demanded by investors when spreads widen to reflect a fall in liquidity. Last, when

there is a risk that private information in the market will not be resolved immediately, investors that are contemplating holding the security in their portfolio will demand a required rate of return that includes an information risk premium.

Order flow is more informative in the Canadian market. Restrictions on quotes in European markets allow dealers to share their inventory risk cheaply through the immediate execution of market orders. Consequently, order flow will reflect both inventory management and private information considerations, and for this reason explain a smaller proportion of the variation in returns then in Canadian interdealer brokered markets where no quoting obligations exist. While the results of this study suggest that market structure is important, within a couple of hours private information in either marketplace is found to have dissipated---revealed either through the relative depth in the market, spreads, or order flow.

Microstructure studies of government securities markets have predominantly focused on U.S. Treasury markets. For example, Green (2004) examines the impact of macroeconomic news announcements and their associated uncertainty on the U.S. benchmark five-year bond while Pasquariello and Vega (2005) examine the effect of unanticipated order flow on yield changes in the 2-year, 5-year and 10-year U.S. Treasury bond markets. In addition, little is known about the price discovery process in government fixed-income markets for securities with shorter maturities. In particular, the trading and quoting strategies of dealers may be different from those at the longer end of the yield curve. In the short-term sector, financial market participants build positions based on their views of the expected future path of overnight interest rates. There is one important exception. Brandt and Kavajecz (2004) examine the role that order flow and liquidity in price discovery across the entire U.S. yield curve. The authors utilize traditional yield curve modeling techniques to isolate the major latent factors driving order flow and liquidity. Findings suggest that the effect of order flow is strongest when liquidity is low. We address a similar question but instead uncover the direct relationships between order flow, depth, spreads and prices. We also analyse individual government securities markets outside the extremely liquid U.S. Treasury market.

2. Institutional Structure and Data

There are some important differences between the organization of European and Canadian Treasury markets. In Europe, the dominant interdealer electronic trading platform for fixed-

income securities is MTS.[3] Given the large and unpredictable inventory shocks typically faced by dealers in their trades with customers, interdealer debt markets have developed to facilitate inventory management and risk sharing. Interdealer trading accounts for more than half of all trades.[4] A number of dealers active on MTS are designated as primary dealers. They are assigned to individual securities and must fulfill a number of requirements. In particular, primary dealers must provide two-sided quotes continuously for a minimum amount of time each day. In addition, minimum quote amounts and a maximum bid-offer spread are imposed. Compliance with these quoting obligations is strictly monitored by MTS. In return for meeting these commitments, primary dealers are allowed to bid in Treasury auctions and enjoy privileged relations with the issuing authorities. They also receive confidential information about their trading activity on MTS, market and economic conditions, and policy information from issuers.

In Government of Canada bond markets, government securities dealers may also be designated as primary dealers. If dealers provide evidence of sufficient resources and a desire to participate actively in the market-making activity of Government of Canada securities they will enjoy preferential access to securities auctions. While there are incentives to actively make markets, unlike European markets, there are no specific quoting obligations in Canada. Dealer behaviour is not governed by rules that limit bid-offer spreads or enhance depth. Further, dealers can freely enter and exit the market at any time.

In the Canadian government securities market, dealer can trade directly or execute anonymous buy and sell orders at one of four interdealer brokers (IDB). Based on dealer statistics reported to the Canadian Investment Dealer Association and the Bank of Canada, the Canadian interdealer debt market represented approximately 46 per cent of the total secondary Government of Canada bond market trading volume during 2002, of which IDB trading accounted for 86 per cent (up from 50 per cent in 1991 and 75 per cent in 1997). The introduction of IDBs significantly reduced the role of direct interdealer trading in recent years. The current IDBs are screen-based voice brokers that allow dealers to trade anonymously with each other. Participants communicate with brokers over the telephone but each participant can observe best bid and offer quotes, and trade outcomes, on a computer screen once they are posted.[5]

[3] MTS was created in 1988 by the Italian Treasury and the Bank of Italy with the objective of increasing competition and efficiency in the market for government debt. MTS became a private company in 1997.
[4] The Bond Market Association (TBMA, 2005).
[5] The four Canadian IDBs are Freedom International Brokerage Company, Prebon Yamane (Canada) Ltd., Shorcan Brokers Limited, and Tullett Liberty (Canada) Ltd.

Transparency in the Canadian interdealer government securities market is provided by brokers who publish interdealer quotes.[6] At any one broker, only the best quotes and their respective quote amounts are visible. Participants observing quotes across the multiple IDBs may be able to determine a noisy measure of the overall depth of the market. The MTS limit order book market is more transparent. Dealing quotes are centralized and market participants observe the top 5 quotes on either side of the market and the associated quote amounts. In addition, the last traded price is observable.

European government bonds can be listed on a domestic MTS platform (such as MTS France) and/or the EuroMTS electronic trading system.[7] Those fixed income securities that satisfy a number of listing requirements, such as exceeding a required principal amount outstanding and certification that a number of dealers that will act as market markers in that security, can be listed on EuroMTS. All government marketable securities, in addition to benchmarks, are listed on their respective domestic MTS platform (subject to a given outstanding principal amount). Cheung, de Jong and Rindi (2005) find that trading costs are similar on both platforms. In our study, we examine trade and quote information for Treasury bills and short-term Treasury bonds listed on the domestic market platform since almost all trading in these securities occurs on the domestic MTS platforms.

The MTS dataset includes all updates of the best quotes and the associated quote amounts for each security in addition to transaction prices and traded quantities. The dataset also includes information about the time and the direction of each trade, i.e., whether the trade was executed against the offer or the offer side of the market. Our analysis focuses on European Treasury bills listed on the four largest domestic MTS platforms: MTS Italy, MTS Germany, MTS France and MTS Belgium. We analyse short-term government bill data for securities with a maturity from 6 months to 2 years. The MTS data set spans the period from 1 April, 2003 to 31 December 2004. The MTS market is open for trading from 8:15 to 17:30 (Central European Time, CET)[8]. Accounting for trade and quote activity, we divide the trading day into 30-minute intervals from 8:30 till 17:30. The bonds analysed in our study include: the 6-month Italian Treasury Certificate (BOT), the 6-month French Treasury Bill (FTB), the 6-month German Treasury Certificate (GTC), the 12-month Belgian Treasury Certificate, the 12-month Italian Treasury Certificate

[6] More recently, electronic platforms have been introduced in Canada that offer simultaneous multipledealer quote inquiries and trading in one case, and peer-to-peer, order-driven trading in another.
[7] EuroMTS was introduced in 1999.
[8] There is a pre-trade session in the MTS market from 7:45 to 8:15 (CET). During this time, dealers can post limit orders but they are not allowed to trade on these orders.

(BOT), the 12-month French Treasury Bill (FTB), and the 2-year German Treasury Bond (Schätze).

The Canadian dataset was obtained from CanPx---a data service that consolidates and disseminates to interested subscribers anonymous trade and quote data submitted by Canada's fixed-income interdealer brokers (IDBs). The CanPx data set is relatively complete, receiving quote and trade information from all IDBs. Dealers leave firm quotes with a broker, along with a minimum size that they are willing to trade. The best quotes across all the participating dealers are collected by CanPx. We focus the analysis on the 2-year Canadian bond since quote and transaction frequency is relatively small for Government of Canada 6- and 12-month bills in the IDB sphere.

The CanPx dataset spans the period from 1 October 2003 to 31 October 2004. We divide the trading day into 30-minute intervals from 8:30 (Eastern Daylight Time, EDT) to 17:30 (EDT). The following trade and quote information relating to a particular security is used: all updates of the best bid and offer prices across all IDBs, the total amount offered and bid at these best prices, the time at which the best bid and offer were last updated, and the time and direction of each trade. The raw data is filtered for outliers associated with data entry errors. The methodology employed is described in D'Souza, Gaa and Yang (2004). In addition, we discard days with less than 5 hours of trading. This alleviates problems associated with stale quotes.[9]

The datasets exclude days with major macroeconomic news announcements. Many authors, including Fleming and Remolona (1999), Balduzzi, Elton, and Green (2001) and Green (2004), find overwhelming evidence of a public information price discovery process that is distinct from that observed during normal trading periods. For the Canadian market, we exclude days in which a major U.S. or Canadian important macroeconomic new announcement occurred. These news announcements are based on the results of Gravelle and Moessner (2001). For each European security, days where there are either European-wide or individual country macroeconomic news announcements similar to those chosen for Canada and the U.S. are excluded. All important macroeconomics new announcements are listed in Table 1.

[9] We also discarded data for MTS on 2 August 2004. A liquidity shock occurred when Citibank sold 11.3 billion euros worth of government bonds on the MTS platform.

3. Variable Definitions and Descriptive Statistics

Dealers with private information regarding the mispricing of a security have a number of options that they may employ in order to maximize profits. If the information is likely to be discovered in a short amount of time, dealers may execute market orders against the prevailing best bid and offer quotes. If some degree of post-trade transparency exists in the market, executed trades will provide a signal to the rest of the market that current prices are not efficient. Kyle (1985) and Glosten and Milgrom (1985) illustrate how dealers revise their expectation when they observe trading in the market. If markets orders provide a signal to the market about the existence of private information, then order flow, defined as the signed number of trades over a give time period, will also be informative. Green (2004), Brandt and Kavajecz (2004) and Pasquariello and Vega (2006), have all shown that in fixed-income markets order flow captures the arrival of information and has a permanent impact on prices.

If traders are patient and believe that in the short-run their private information will not be revealed to the market, they have other options. In particular, they can post limit orders with either better bid or offer prices, or they may adjust their existing orders in terms of the relative quantities they are willing to buy and sell at the current best market quotes. For example, if private information suggests that a security is overpriced, i.e., the midpoint between the best offer and best bid quotes is too high, traders may improve upon the best offer price in the market, or they may increase the relative amount that they are willing to sell versus buy at slightly better prices. Bloomfield, O'Hara and Saar (2003) illustrate in an experimental setting how informed traders will use limit orders strategically in an electronic limit order market. Goettler, Parlour and Rajan (2005) show that less informed agents can learn about new information from quotes in the order book. In general, relative depth and market spreads, like order flow can be informative. Since significant levels of quote transparency are present in European and Canadian markets, private information will overtime trickle out into the market.

Quoting obligations and higher levels of transparency in Europe may prevent market participants from manipulating limit and market orders excessively. In particular, market participants are able to quickly absorb private information elsewhere in the market by observing changes in the limit order book and order flow. Restrictions on quotes allow dealers to share their inventory risk cheaply through the immediate execution of market orders. Consequently, order flow will reflect both inventory management and private information considerations, and for this reason explain a smaller proportion of the variation in returns then in Canadian interdealer brokered markets

where no quoting obligations exist. In general, while it is easier for dealers in MTS to manage their inventories it may also be harder to exploit information strategically. Quoting restrictions may also contribute to uninformative market-wide spreads. When there is a risk that private information in the market will not be resolved immediately, spreads will widen, and investors contemplating holding the security in their portfolio may demand a return that includes an information risk premium.

We analyse the interaction between price changes, order flow and two separate dimensions of the order book: relative depth and the best bid-offer spread. The change in the mid-quote is defined as

$$\Delta p_t = (mid\ quote_t - mid\ quote_{t-1}) * 1000$$

where $mid\ quote_t$ is the average of the best offer quote and the best bid quote at the end of each period *t*. Order flow of each security, $orderflow_t$, is the defined as the aggregate number of buyer-initiated orders minus that seller-initiated orders during the half-hour interval, *t*. The imbalance in depth, or relative depth, on the two sides of the market, $rdepth_t$ is defined as

$$(depth\ at\ best\ bid\ price_t - depth\ at\ the\ best\ ask\ price_t)$$

where $depth_t$ is the aggregate order size available for purchase or sale at the best price at the end of each period *t*. The best bid-offer spread is defined as the difference between the best offer price and the best bid price times 100,

$$spread_t = (best\ ask\ price - best\ bid\ price) * 100\ .$$

Table 2 presents a number of descriptive statistics for each variable. The variables are measured in 30-minute intervals resulting in 18 intervals per trading day. Since we have excluded days with important macroeconomic news announcements, and the number varies by country, we also report the number of days examined for each security.

There are a number of similarities across securities. Mid-quote changes, order flow and relative depth are not significantly different from zero. Bid depth is positively correlated with mid-quote changes while offer depth is negatively correlated with mid-quote changes. Dealers may take timely advantage of any improved liquidity on one side of the market by executing limit orders against it, which may then lead to an increase in the mid-quote.

There are other interesting patterns. Spreads increase with the maturity of a security. French, Italian and German 6-month bill spreads are lower than their one- or two-year national counterparts. The autocorrelation in order flow is small. This is consistent with the random walk nature regarding the arrival of information. Order flow is positively correlated with changes in the mid-quote across all securities. The correlation ranges from 0.06 in the German 2-year bond to 0.2 in the Italian 12-month bill. There is mixed evidence associated with the correlation between order flow and spreads, order flow and between relative depth and spreads.

Compared to European fixed income markets, the Canadian 2-year bond market has a lower average level of depth on either side of the market. This could be due to the fact that the quantity quoted in Canadian markets is only the lower bound that dealers are willing to trade. There are no obligations in Canada for dealers to post minimum levels of depth in the market. The Canadian market also exhibits a stronger correlation between order flow and the change in mid-quotes, and between spreads and the change in mid-quotes. As expected, depth and spreads are more persistent across European securities. The autocorrelation in spreads is greater than 0.5 in all European markets. Quoting obligations constrain the maximum spread dealers are allowed to post in the limit order book. The autocorrelation in bid and offer depth may also be larger for this reason.

4. Methodology: Econometric Specification

In the paper, we use a vector autoregression (VAR) model to capture the intertemporal associations between changes in quotes, order flow, relative depth, and spreads. The motivation for using this general setup is that all four variables are interrelated. Causality among these variables could potentially run in both directions. For example, the execution of a market order will directly affect the market depth on one side of the market. The execution of market orders will also affect the future placement and cancellation of limit-orders. In reverse, market orders will only be executed if a certain amount of depth is available in the market. Complicating things further, even after allowing for causality between order flow and relative depth in both directions, the relationship between depth and order flow will depend on the size of the existing bid-offer spread in the market. In order to determine the implied impact of order flow, relative depth, spreads and quotes, it is necessary to capture the dynamic relationship between all variables simultaneously.

We follow Hasbrouck (1991a, 1991b) and calculate two statistics derived from the estimates of a VAR. Impulse response functions and variance decompositions of mid-quote returns provide a measure of the informativeness of order flow, spreads, and relative depth in each market. In general, impulse response functions represent the expected future values of each variable in a system of equations conditional on an initial shock. In the current environment, they summarize the permanent impact of an innovation in each variable on prices. Any permanent impact must reflect private information available contained in that variable. The second measure we use is a variance decomposition of mid-quote returns. Observed mid-quotes can be thought of as the sum of an efficient price and a term reflecting short-term microstructure imperfections. We decompose the variance of these efficient prices into components that are attributable to order flow, spreads, and relative depth.

We estimate the following VAR system,

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_P y_{t-P} + D_1 + D_2 + \ldots + D_9 + v_t,$$

where y_t is defined as

$$y_t = [orderflow_t, rdepth_t, spread_t, \Delta mid\ \ quote_t]'$$

and the A_p's are $(p \times p)$ coefficient matrices of the endogenous variables, y_t. The disturbance, v_t is a column vector with mean zero, $E(v_t) = 0$, serially uncorrelated disturbances, and covariance matrix $E[v_t v_t'] = \Omega$. Hourly dummies, D_i, control for the intra-day seasonality. The parameters A_p and Ω are unknown and have to be estimated before the necessary impulse response and variance decomposition statistics can be calculated. Estimates of these parameters can be obtained from least squares. See Hamilton (1994) and Judge et al. (1982) for a discussion of these methods.

There is little theoretical guidance regarding the appropriate ordering of mid-quote changes, order flow, relative depth and spreads in the VAR. Since identification in crucial, all orderings of order flow, relative depth and spreads were examined to ensure robustness of our results. It is standard to place the change in the mid-quote last. The order of the VAR was chosen using the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC).

5. Empirical Results

Vector autoregressions are estimated for each of the eight securities in our sample, and consists of four equations that model the interaction between the change in the mid-quote, order flow, relative depth, and spreads. Three lags were chosen for most of the 6- and 12-month securities. For the 2-year bonds, two lags minimized the AIC or SIC criteria. The last row in Table 3 reports the chosen lag order for each estimated VAR.

To conserve space, the coefficient estimates are not presented in tables. There are a number of interesting findings. Across all securities, there is evidence of positive and significant own-lag effects in the order flow, relative depth, and spread equations. The coefficient on the first lag is in general positive and statistically significant at 10% level. With respect to the order flow equation, this result suggests that there is a certain degree of momentum buying and selling, which may be an indication of order fragmentation. In transparent markets, dealers will attempt to hide their orders, and any private information that they reflect, by breaking-up their trades. Autocorrelation in spreads and relative depth may reflect market conventions or the constraints on spread and quote amounts imposed on MTS dealers. Changes in mid-quotes are negatively autocorrelated and statistically significant at the 10% level in the case of the French 6-month bill, the Italian 6-month bill, the German 6-month bill, the Italian 12-month note, and the Canadian 2-year bond. These results suggest the existence of inventory control and lagged adjustment effects. In particular, quotes may over react to trades as dealers attempt to manage their inventories. Over time, these effects will dissipate. Amihud and Mendelson (1980) and Ho and Stoll (1981) illustrate how undesired inventories impose costs on dealers, and that these costs are reflected in bid and offer prices.

There are a number of interesting results associated with cross-effects. Lag order flow has a significant impact on mid-quotes in the Italian and German 6-month bill, the German and French 12-month bill, and the German and Canadian 2-year bond. Relative depth has a positive and statistically significant impact on mid-quotes in all markets except for the German 6-month bill and the Canada 2-year bond. Spreads have a statistically significant positive or negative in the following securities markets: Italian 6-month, Belgian 12-month, Italian 12-month, French 12-month and Canadian 2-year. These results suggest that order flow, relative depth, and spreads may indeed convey information about the mis-pricing of government securities in the fixed income markets. Nevertheless, the essential question we need to address is whether innovations in these variables have effects that are permanent.

One of the key questions that can be addressed with a VAR is how useful some variables are in forecasting others. Table 3 presents the results of pair-wise Granger-causality tests. One variable is said to Granger-cause another if past information about the latter variable helps to improve the forecasts of the former. We test the null hypothesis that variable *x* does not Granger-cause variable *z* by testing whether the lag coefficients of *x* are jointly zero in the equation with *z* as a dependent variable.

For the Canadian 2-year bond, Wald test statistics indicate that there is two-way causality between relative depth and mid-quote changes. In the Italian 6-month bill market, order flow, relative depth and spreads each Granger-cause mid-quote changes. There is no evidence of causality in the opposite direction. In the German 6-month market, spreads, relative depth, and order flow do not Granger-cause mid-quote changes. Instead, relative depth, spreads and mid-quote changes Granger-cause order flow. The results of the Belgian 12-month bill indicate that order flow, relative depth and spread variables do not Granger-cause changes in mid-quotes, but that order flow Granger-causes changes in the relative depth of the market. For the Italian 12-month security, relative depth Granger-causes changes in the mid-quote, though there is no evidence in the other direction. In the 12-month French bill market, relative depth Granger-causes changes in mid-quotes, spreads and order flow. For the German 2-year bond, relative depth is found to Granger-cause change in mid-quotes. Lastly, for the Canadian 2-year bond, there is evidence of two-way causality between mid-quotes and spreads. Order flow is also shown to Granger-causes mid-quote changes.

Overall, there is significant evidence across securities that order flow and relative depth forecast changes in the mid-quote. There is some evidence that spreads Granger-cause changes in quotes and that quote changes Granger-cause changes in spreads. But overall there is a lack of uniformity across securities. Looking at the results across securities it is impossible to conclude that any one variable is exogenous. In addition, two variables may affect one another through a third. More work is needed to properly identify the relationship between these variables. For now, we take an agnostic approach and include all four variables in the VAR in each market.

We now examine the dynamics associated with innovations in quotes, order flow, relative depth and spreads. For each security market, impulse response functions are calculated to trace out the effect of a one-time shock to order flow, relative depth, and spreads. Because the innovations are correlated, we use the inverse of the Cholesky decomposition of the residual covariance matrix to

orthogonalize the impulses. While we present impulse response functions with the following ordering: order flow, relative depth, spreads and the change in the mid-quote, results are very similar across orderings.

Figure 1 illustrates the cumulative effect on the change in the mid-quote from three types of shocks: a one-standard deviation shock to order flow, to relative depth, and to spreads. Two standard error bounds are also shown in each graph. The long-term cumulative implied mid-quote change that occurs subsequent to an innovation in each variable may be interpreted as the informational content of that variable. An order flow shock has a permanent and positive impact on the prices of all European securities and Canadian 2-year bond. This finding is consistent with previous research in the fixed-income microstructure literature suggesting that order flow is informative since it has a permanent impact on prices. Specifically, it implies that dealers with private information execute market orders against the prevailing best bid and offer quotes.

Across all securities, relative depth has an initial negative impact on prices. There is one possible explanation for the initial and temporary drop in the mid-quote. A rise in depth on the buy side of the order book reduces the marginal cost of selling a security. Dealers attempting to manage their excess inventories use this opportunity to immediately execute market sell orders rather than use limit orders. Coefficient estimates suggest that in a number of markets relative depth has a negative effect on order flow. The execution of sell orders may inadvertently signal negative information to other dealers about the value of the security. Once dealers figure out their mistake, quotes will revert to their initial long-run equilibrium level.

An innovation in spreads generally has no impact on prices amongst the European securities. In contrast, innovations in the Canadian 2-year bond spread have a significant impact on price dynamics. An increase in spreads results in a permanent reduction in prices. From an informational perspective, large spreads in the market may convince dealers that informed traders may exist in the market. If liquidity decreases as a result, price may fall temporarily. If the information risk persists, investors will demand a required rate of return that includes a risk premia. Spreads, much like order flow, seems to be informative to dealers in the Canadian market. They have a permanent impact on the mid-quote. While there are some important differences across securities markets, within four to five time periods, or a few hours, private information in either marketplace has dissipated.

As an alternative approach to determine which variables are informative in the price discovery process, Table 4 presents a decomposition of mid-quotes in terms of each component in the VAR system. Results at the 20-period-ahead forecast horizon are shown. We examine this relatively long forecast horizon so as to focus only on the long-run, or permanent, explanatory power of each variable. Since the variance decomposition is based on a Cholesky identification assumption, the ordering of the variables will be important. The table displays the upper- and lower-bound estimates of the variance decomposition for each endogenous variable across all possible orderings of order flow, relative depth, and spreads. Each column gives the percentage of the overall forecast variance explained by innovations in each variable.[10]

Order flow has some explanatory power for certain European securities. For example, order flow explains around 3 or 4 % of the variation in quotes in the Italian and Belgian 12-month bill markets. The number is significantly larger for the Canadian of Canada 2-year bond (7%). In Europe, restrictions on quotes allow dealers to share their inventory risk cheaply through the immediate execution of market orders. Consequently, order flow will reflect both inventory management and private information considerations, and for this reason explain a smaller proportion of the variation in returns then in Canadian interdealer brokered markets where no quoting obligations exist. Order flow has little (<1%) explanatory power in the German 6-month and 2-year bond markets. Cheung, de Jong and Rindi (2005) find that trading of German fixed-income securities is concentrated in the liquid EUREX futures market. As a result, price discovery most likely occurs in the futures market.

Relative depth has some explanatory power only in the French 6-month bill (above 4%) and the French 12-month bill (around 3%) markets. In the Canadian market relative depth is not informative at all. This could be due to the fact that there are no constraints imposed on dealers in terms of maximum quoted spreads or the minimum quantity supplied to the market. As a result, dealers can adjust both spreads and relative depth, or exit altogether in times of uncertainty. Thus relative depth has less weight in explaining price dynamics.

There is a very small role for spreads in the long-run price-discovery process across European securities. Since minimum spreads are restricted in Europe, and pre-trade quote transparency is significant, the information content of spreads on the mid-quote is lower in these markets. Any variation in spreads must be related to the management of inventories, which will adjust in the short-run. In the Canadian 2-year bond market, the results are significantly different. Spreads

[10] Each row will not add up to 100 since we have reported maximums and minimums across all orderings.

explain around 12% of the long-term variability in prices. Dealers with private information in the Canadian market adjust their quotes strategically, and market spreads reflect these adjustments. Since quotes are not fully transparent this information may not be reflected in the mid-quote immediately.

6. Summary and Conclusion

In this paper, we examined the dynamics of prices, order flow, relative depth, and spreads in short-term European and Canadian government securities markets. Overall, the impulse response functions and the variance decompositions illustrate that in European markets, order flow, relative depth and spreads are only slightly informative. These results imply that European markets are usually efficient. Market participants are able to quickly absorb private information elsewhere in the market by observing changes in the limit order book and order flow. In Canadian markets, where order flow has a permanent and positive impact on quotes while spreads have a permanent and negative impact on quotes, market prices are not always at their efficient levels. The order flow result is a common finding in studies examining longer term U.S. Treasuries. Since quotes are to some extent transparent in Canadian markets, the combination of both quoting obligations and transparency may be required to generate greater levels of price discovery. While there are some differences in trade and quote dynamics, both Canadian and European short-term fixed-income markets reflect fundamental information in a short amount of time.

The results of this paper confirm some previous findings. For example, Albanesi and Rindi (2000) also find little evidence of asymmetric information in Italian bond trading. The comparison of European and Canadian markets illustrate which market structures maybe a contributing factor to greater market efficiency. There is still one possible drawback concerning the European system. The MTS liquidity pact is often characterized as "forced liquidity." It is not clear how these markets will behave in stressful or disorderly periods.

Liquid and efficient government securities markets are important to a country's overall economic well-being. They are necessary to ensure that savings and investment decisions are made optimally. They also perform a number of key roles. For example, given their virtually default-free nature, government securities are used as benchmarks for the pricing and hedging of other

fixed-income securities. Monetary policy makers, concerned about disorderly markets, can determine if future interest rate-setting decisions are going to surprise financial markets.[11]

In future research, we will build on the results of this paper and explore how trading and quoting decisions are jointly determined across on-the-run and off-the-run securities markets. Since dealers in fixed-income markets usually manage a portfolio of securities within a given maturity sector, if securities are substitutable, a dealer can have a long position in one security and an offsetting short position in another and bear little inventory risk. Primary dealers of both on- and off-the-run securities can manage risk in their portfolio by adjusting prices and liquidity supplies of the two securities jointly. We will also seek to determine if private information learned about one security is used in the pricing decisions of other similar securities. Inventory control effects may link on- and off-the-run securities.

[11] Johnson (2003) describes how simple expectations-based models can be utilized to extract expectations. Usually, securities with maturities of two years and less are employed in this exercise.

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Tables and Figures

Table 1: Macro news announcements.
Macroeconomic news announcements whose release days are excluded from the data

Country	News
Belgium	Business Confidence Level
Italy	Consumer Price Index
	Industrial Production
	Consumer Confidence
	Retail Sales
	Trade Balance
	Industrial Orders
	Business Confidence
	Produced Price Index
France	Consumer Confidence Indicator
	Consumer Price Index
	Trade Balance
	Production Outlook Indicator
	Industrial Production
	Consumer Spending
	Business Confidence Indicator
	Unemployment Change
Germany	Retail Sales
	Unemployment Change
	Factory Orders
	Trade Balance
	Current Account
	Industrial Production
	Producer Price Index
	IFO Survey
	ZEW Survey on Economic Sentiment
	Import Price Index
Euro-wide announcement	ECB Announcement on Interest Rates
	EU harmonised CPI
Canada	Current Account
	Industrial Production Prices
	Net Change in Employment
	Raw Materials Price Index
US	Change in Non-farm Payrolls
	Retail Sales Less Autos
	CPI Excluding Food and Energy
	PPI Excluding Food and Energy

Table 2: Summary statistics

The mid-quote change is the 30-minute change in mid-quote times 1000. Relative depth is defined as $(depth\ at\ best\ bid\ price_t - depth\ at\ the\ best\ ask\ price_t)$ in which $depth$ is measured in million. Order flow of the bond, $orderflow_t$, is the defined as the aggregate number of buyer-initiated orders minus that seller-initiated order during each half-hour interval. The best bid-offer spread is defined as (best offer price - the best bid price)*100.

French 6-month						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.02	1.48	-0.07	0.00	-0.02	1.00	0.01	0.10	-0.08	0.09	-0.13	292
Spread	0.73	0.34	0.74	0.64	0.58		1.00	-0.03	-0.01	-0.02	0.01	
Order flow	0.00	0.42	0.03	0.02	0.05			1.00	-0.02	0.00	-0.01	
Bid depth	15.48	12.65	0.43	0.30	0.27				1.00	0.17	0.70	
Offer depth	15.75	11.11	0.58	0.47	0.37					1.00	-0.58	
Relative depth	-0.27	15.38	0.45	0.32	0.26						1.00	

Italian 6-month						Correlations						
	Mean	Std. Dev.	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.01	2.19	-0.13	-0.02	-0.04	1.00	0.07	0.17	-0.04	0.02	-0.05	295
Spread	0.59	0.70	0.71	0.65	0.65		1.00	-0.03	-0.16	-0.17	0.05	
Order flow	0.02	1.25	0.03	0.03	0.01			1.00	-0.01	0.01	-0.02	
Bid depth	6.75	6.65	0.56	0.44	0.39				1.00	0.27	0.39	
Offer depth	7.53	9.73	0.62	0.51	0.47					1.00	-0.78	
Relative depth	-0.78	10.16	0.48	0.36	0.31						1.00	

Table 2 (continued)

German 6-month						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.05	1.43	-0.10	0.02	0.00	1.00	-0.03	0.10	-0.05	0.00	-0.03	269
Spread	0.80	0.31	0.75	0.65	0.57		1.00	-0.02	-0.01	-0.07	0.05	
Order flow	0.01	0.34	0.16	0.03	0.04			1.00	0.00	0.03	-0.03	
Bid depth	12.71	8.97	0.56	0.42	0.42				1.00	0.10	0.53	
Offer depth	13.89	12.49	0.65	0.46	0.38					1.00	-0.79	
Relative depth	-1.18	14.64	0.61	0.42	0.36						1.00	

Belgian 12-month						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.03	4.70	-0.02	0.02	0.00	1.00	-0.01	0.18	-0.02	0.05	-0.05	379
Spread	1.49	0.66	0.73	0.61	0.54		1.00	0.00	0.03	0.05	-0.01	
Order flow	0.00	0.50	0.11	0.06	0.00			1.00	-0.01	0.00	-0.01	
Bid depth	13.54	13.15	0.49	0.35	0.24				1.00	0.12	0.78	
Offer depth	12.80	9.55	0.46	0.35	0.29					1.00	-0.52	
Relative depth	0.74	15.29	0.41	0.30	0.20						1.00	

Italian 12-month						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.04	4.92	-0.03	-0.03	0.01	1.00	0.01	0.20	0.00	0.03	-0.02	295
Spread	0.84	0.63	0.66	0.51	0.45		1.00	-0.01	-0.20	-0.18	-0.01	
Order flow	0.08	1.32	0.08	0.04	0.02			1.00	-0.01	0.04	-0.04	
Bid depth	6.91	6.63	0.46	0.36	0.32				1.00	0.31	0.59	
Offer depth	6.46	6.67	0.42	0.34	0.28					1.00	-0.59	
Relative depth	0.45	7.82	0.27	0.16	0.09						1.00	

Table 2 (continued)

French 12-month						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.06	4.88	-0.03	0.01	-0.01	1.00	0.01	0.10	-0.04	0.07	-0.09	294
Spread	1.54	0.66	0.71	0.59	0.54		1.00	0.02	0.01	-0.07	0.06	
Order flow	-0.03	0.49	0.02	-0.01	-0.02			1.00	-0.05	0.00	-0.04	
Bid depth	16.26	12.65	0.45	0.37	0.28				1.00	0.11	0.72	
Offer depth	15.92	11.12	0.43	0.36	0.32					1.00	-0.61	
Relative depth	0.34	15.86	0.39	0.32	0.25						1.00	

German 2-year						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.09	14.89	0.00	-0.01	0.02	1.00	0.00	0.06	-0.03	0.04	-0.06	255
Spread	2.61	0.96	0.60	0.42	0.35		1.00	0.00	0.08	0.07	0.02	
Order flow	0.00	0.36	0.09	0.03	0.01			1.00	-0.01	-0.01	0.00	
Bid depth	32.81	29.97	0.54	0.41	0.34				1.00	0.19	0.74	
Offer depth	26.64	23.54	0.42	0.33	0.27					1.00	-0.52	
Relative depth	6.17	34.34	0.42	0.31	0.27						1.00	

Canadian 2 year						Correlations						
	Mean	Standard Deviation	?1	? 2	? 3	Mid-quote change	Spread	Order flow	Bid depth	Offer depth	Relative depth	Days
Mid-quote change	0.23	27.26	-0.17	-0.08	0.00	1.00	-0.15	0.26	0.00	0.03	-0.01	202
Spread	1.26	3.51	0.24	0.02	0.02		1.00	0.00	0.00	-0.01	0.00	
Order flow	0.06	2.13	0.10	0.02	0.01			1.00	0.02	0.00	0.02	
Bid depth	4.84	12.66	0.13	0.08	0.01				1.00	0.18	0.77	
Offer depth	4.25	9.29	0.05	0.01	0.07					1.00	-0.49	
Relative depth	0.59	14.33	0.12	0.05	0.01						1.00	

Table 3: Granger Causality Tests and Order of VARs

The table presents p-values of pair-wise Granger-causality tests and the lowest lag order that minimized the Akaike or Schwarz information criterion. Wald statistics were calculated under the null hypothesis that the lags of each endogenous variable in each equation are jointly zero. Pair-wise Granger causality tests determine whether an endogenous variable can be treated as exogenous. The mid-quote change, Δp_t, is the 30-minute change in mid-quote times 1000. Relative depth is defined as $rdepth_t$ = *(depth at best bid price*$_t$ *– depth at the best ask price*$_t$*)*, where depth is measured in millions of euros or dollars. Order flow of the bond, $orderflow_t$, is the defined as the aggregate volume of buyer-initiated orders minus seller-initiated orders during the half hour interval. The best bid-offer spread is defined as the difference between the best offer price and the best bid price times 100.

Chi-sq Test P-value								
Excluded Variable	French 6-Month	Italian 6-Month	German 6-Month	Belgian 12-Month	Italian 12-Month	French 12-Month	German 2-Year	Canadian 2-Year
Dependent variable: $orderflow_t$								
$rdepth_t$	0.408	0.104	0.000	0.588	0.055	0.004	0.019	0.253
$spread_t$	0.421	0.106	0.007	0.236	0.003	0.186	0.991	0.225
Δp_t	0.716	0.118	0.017	0.218	0.535	0.454	0.386	0.002
Dependent variable: $rdepth_t$								
$orderflow_t$	0.743	0.003	0.926	0.031	0.453	0.726	0.686	0.564
$spread_t$	0.179	0.622	0.304	0.246	0.333	0.577	0.708	0.630
Δp_t	0.437	0.656	0.848	0.434	0.412	0.865	0.026	0.734
Dependent variable: $spread_t$								
$orderflow_t$	0.064	0.390	0.821	0.974	0.009	0.450	0.974	0.000
$rdepth_t$	0.144	0.973	0.284	0.976	0.490	0.106	0.976	0.686
Δp_t	0.329	0.243	0.010	0.873	0.000	0.498	0.045	0.000
Dependent variable: Δp_t								
$orderflow_t$	0.557	0.001	0.056	0.765	0.349	0.096	0.088	0.000
$rdepth_t$	0.000	0.023	0.978	0.253	0.003	0.000	0.000	0.587
$spread_t$	0.334	0.000	0.496	0.134	0.004	0.148	0.544	0.000
VAR Lag Order	3	3	3	3	3	4	2	2

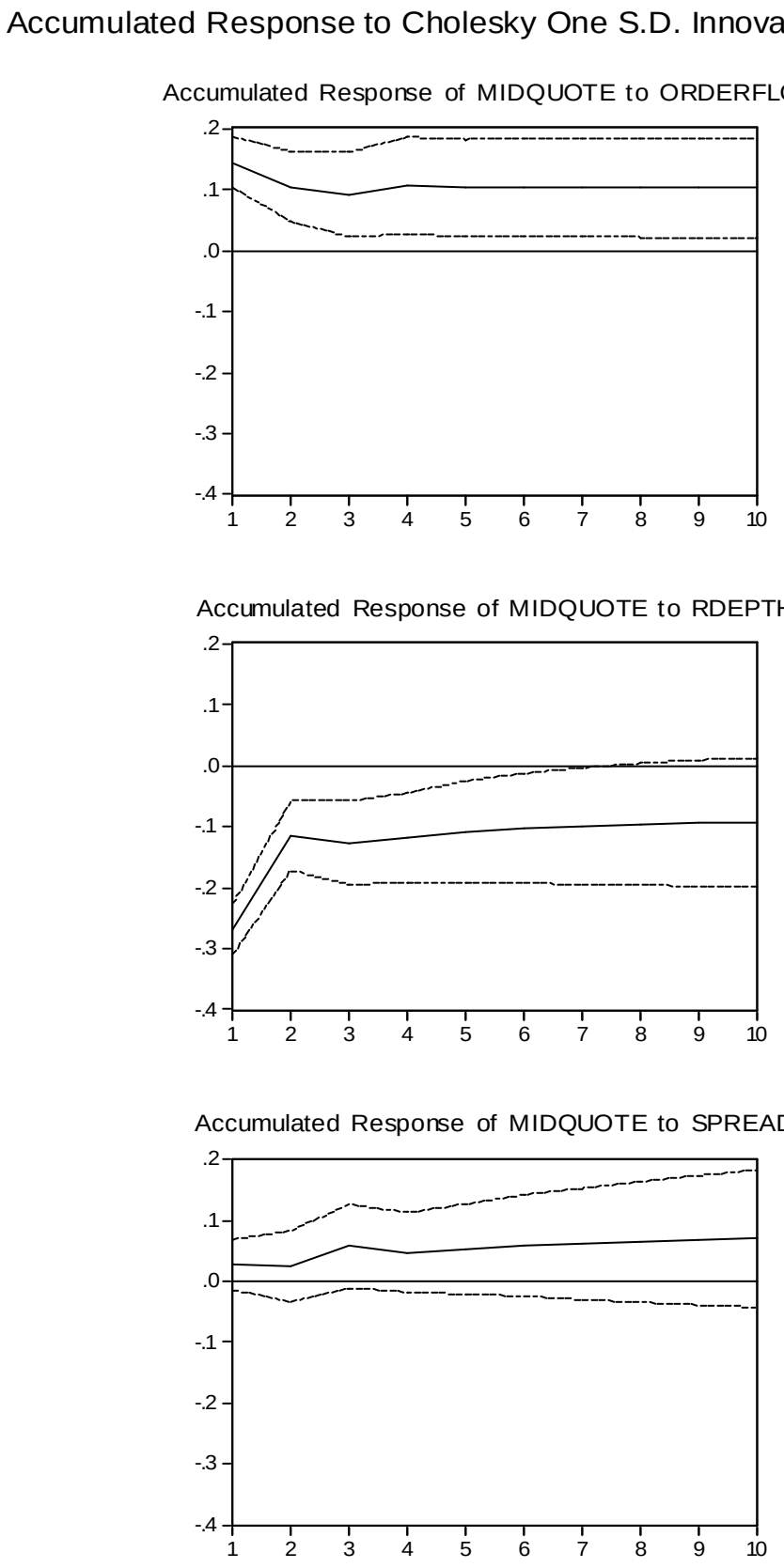
Table 4: Variance decompositions of Price Changes

The table reports the percentage of the 20-period ahead forecast variance in prices due to each innovation, with each row adding up to 100. Since the variance decomposition (based on a Cholesky identification assumption) can be affected by the ordering of the variables in the VAR, both lower and upper bounds are reported by looking at all combinations of $orderflow_t$ $rdepth_t$ and $spread_t$ in the VAR ordering. The second column, labelled "S.E.", contains the forecast error of the mid-quote at the 20-period forecast horizon. Standard errors from a Monte Carlo simulation with 100 repetitions are given in parentheses.

	S.E	$orderflow_t$ high	$orderflow_t$ low	$rdepth_t$ high	$rdepth_t$ low	$spread_t$ high	$spread_t$ low	Δp_t
French 6-Month	0.420	1.025 (0.281)	0.922 (0.237)	4.605 (0.514)	4.498 (0.636)	0.074 (0.096)	0.065 (0.081)	94.402 (0.724)
Italian 6-Month	1.255	2.973 (0.402)	2.887 (0.447)	0.930 (0.236)	0.818 (0.229)	2.601 (0.4513)	2.550 (0.437)	93.619 (0.676)
German 6-Month	0.344	1.004 (0.285)	1.001 (0.284)	0.172 (0.137)	0.147 (0.142)	0.569 (0.252)	0.545 (0.221)	98.279 (0.384)
Belgian 12-Month	0.503	3.438 (0.447)	3.421 (0.472)	0.426 (0.166)	0.4126 (0.186)	0.090 (0.090)	0.087 (0.101)	96.060 (0.457)
Italian 12-Month	1.320	3.959 (0.529)	3.890 (0.546)	0.399 (0.211)	0.333 (0.145)	0.275 (0.178)	0.266 (0.155)	95.437 (0.582)
French 12-Month	0.487	1.054 (0.267)	0.937 (0.266)	3.262 (0.431)	3.131 (0.414)	0.198 (0.141)	0.179 (0.116)	95.618 (0.531)
German 2-Year	0.364	0.394 (0.205)	0.376 (0.171)	1.399 (0.372)	1.3794 (0.310)	0.0325 (0.060)	0.028 (0.069)	98.194 (0.420)
Canadian 2-Year	2.130	7.287 (0.874)	7.143 (0.807)	0.072 (0.109)	0.052 (0.104)	12.028 (1.009)	11.892 (1.149)	80.761 (1.246)

Figure 1: Response of Price change to the Order Flow, Imbalance and Spread.

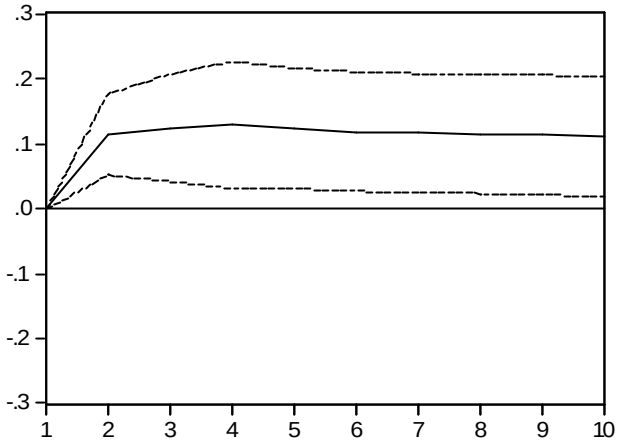
Panel A French 6-Month Bill



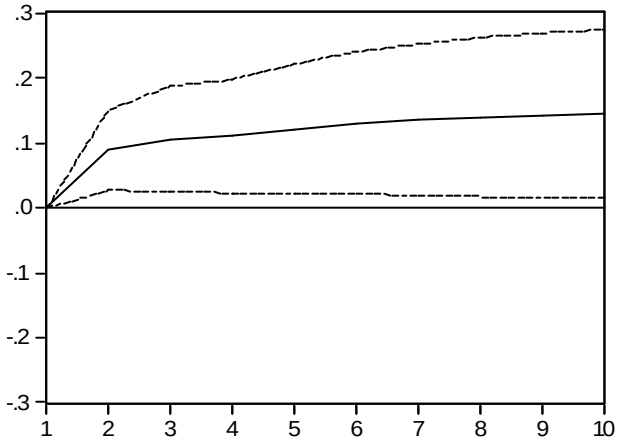
Panel B:Italian 6-Month Bill

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

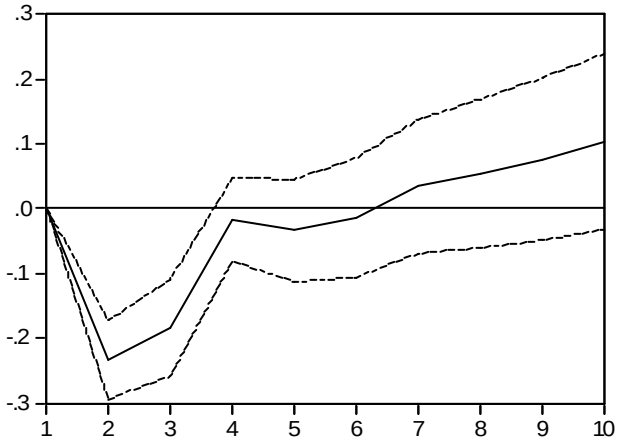
Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



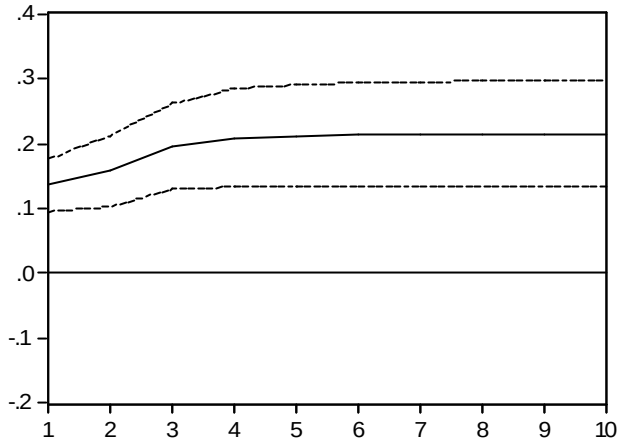
Accumulated Response of MIDQUOTE to SPREAD



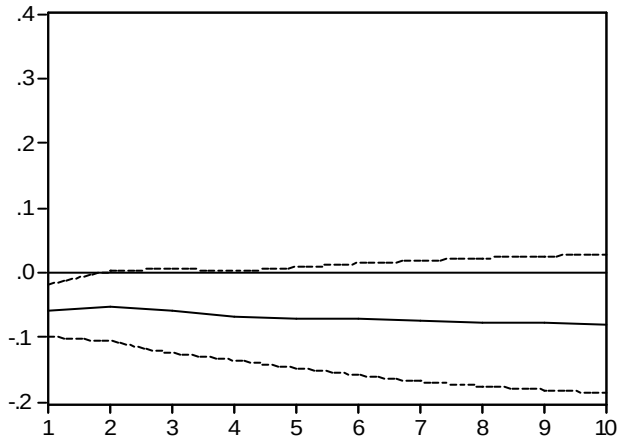
Panel C: German 6-Month Bill

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

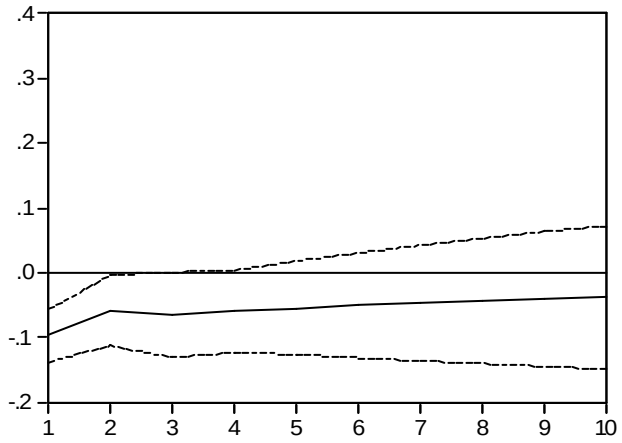
Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



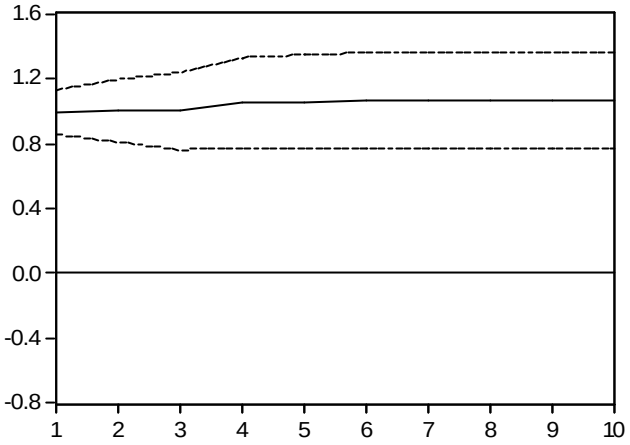
Accumulated Response of MIDQUOTE to SPREAD



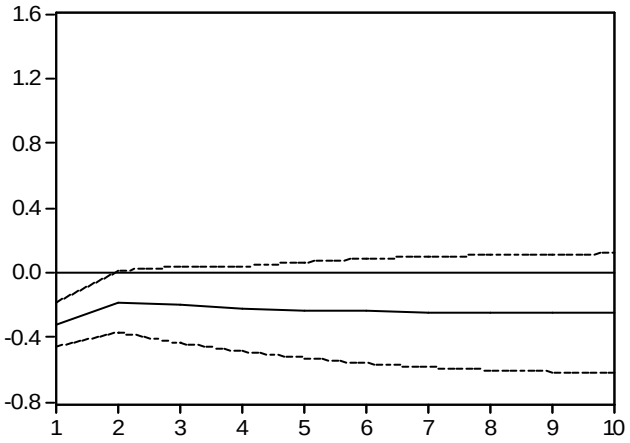
Panel D: Belgian 12-Month Bill

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

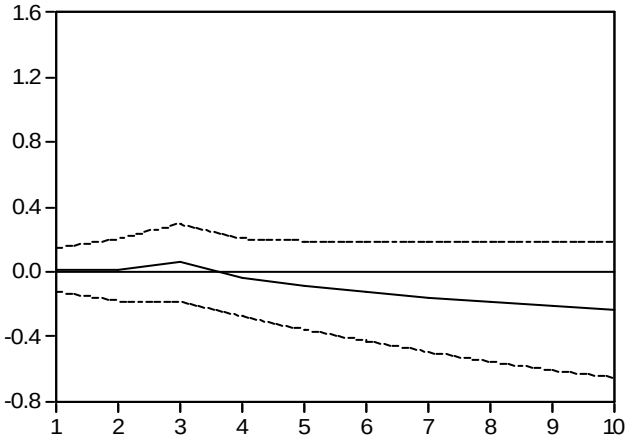
Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



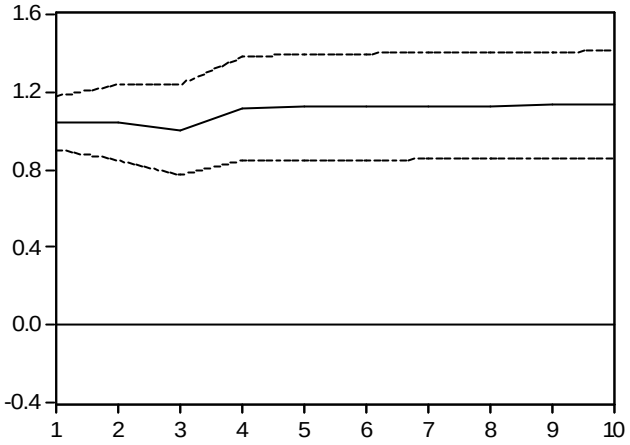
Accumulated Response of MIDQUOTE to SPREAD



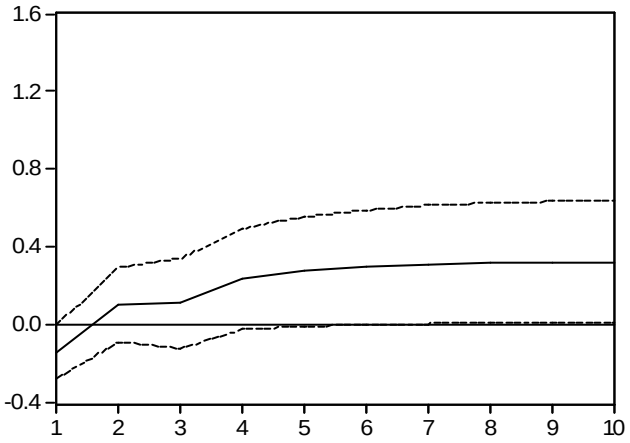
Panel E: Italian 12-Month Bill

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

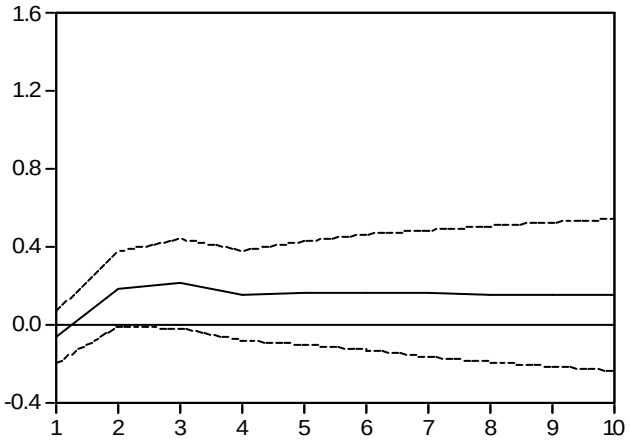
Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



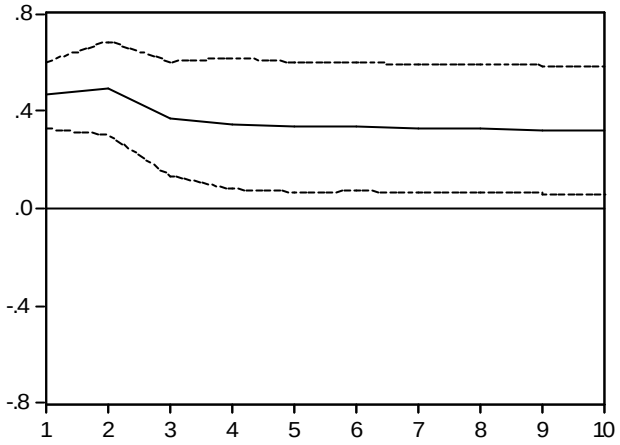
Accumulated Response of MIDQUOTE to SPREAD



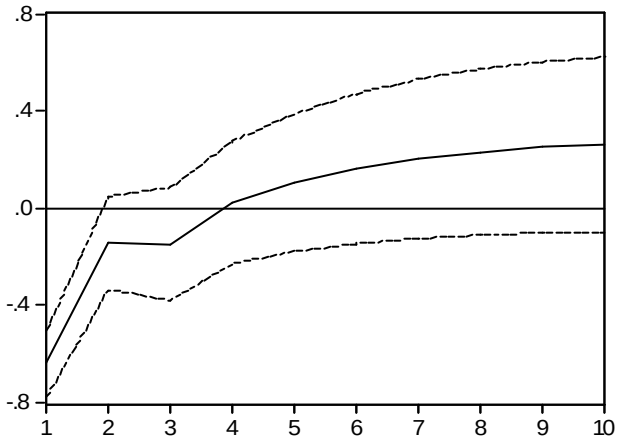
Panel F:French 12-Month Bill

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

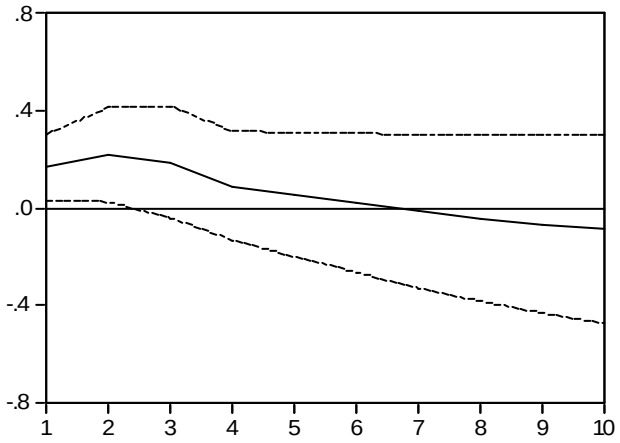
Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



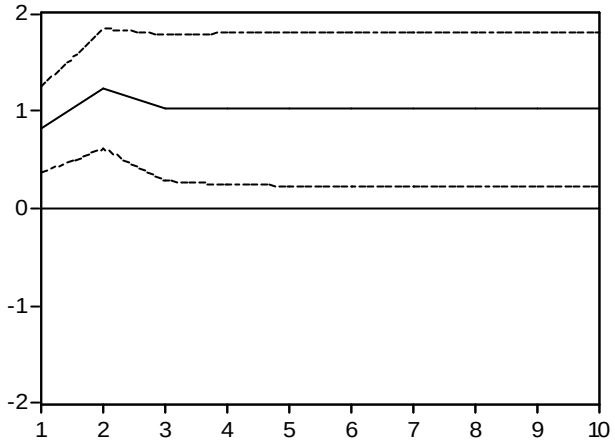
Accumulated Response of MIDQUOTE to SPREAD



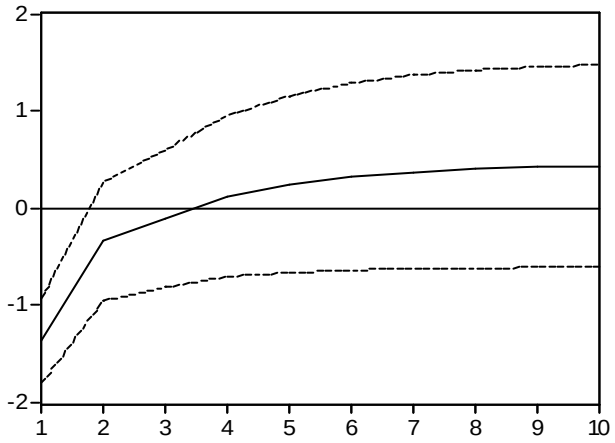
Panel G: German 2-Year Bond

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



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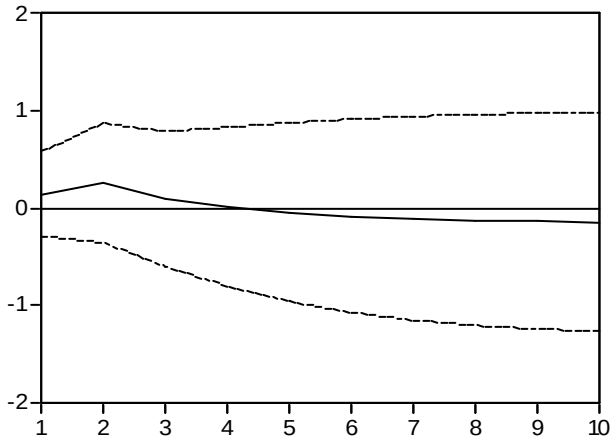
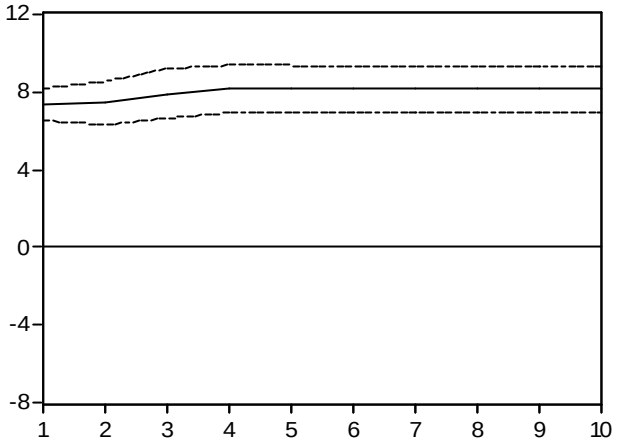


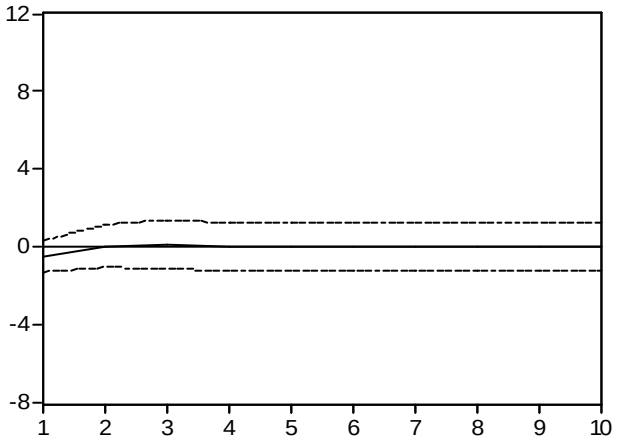
Panel H: Canadian 2-Year Bond

Accumulated Response to Cholesky One S.D. Innovations ± 2 S.E.

Accumulated Response of MIDQUOTE to ORDERFLOW



Accumulated Response of MIDQUOTE to RDEPTH



Accumulated Response of MIDQUOTE to SPREAD