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Information Content of Order Flow and Cross-market Portfolio Rebalancing: Evidence for the Chinese Stock, Treasury and Corporate Bond Markets

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Abstract

This paper examines the within-market and cross-market information content of order flow for stocks, corporate bonds and Treasury bonds in China. With daily-aggregated tick-by-tick data over three years on the Shanghai Security Exchange, we find negative cross-asset effects of order flow on returns, both between stocks and bonds and between corporate and Treasury bonds. Our results provide evidence that not only cross-market portfolio rebalancing under general market conditions, but also flight-to-quality, which occurs particularly under extreme market conditions, are responsible for the cross-market effects of order flow. In particular, while Treasury bonds play a dominant role in stock-bond portfolio rebalancing, corporate bonds can replace Treasury bonds as a safe "haven" during extreme stock market conditions or during a fall in Treasury bond market returns.

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1. Introduction

Cross-market linkages involving both returns and order flow have become an active area of study. Previous studies have shown that cross-market portfolio rebalancing, particularly flight-to-quality or flight-to-liquidity under extreme market conditions, could be the main reason driving such linkages. Flight-to-quality or flight-to-liquidity is present when investors adjust their portfolios to include respectively less risky and more liquid assets when they are scared (Barsky, 1989; Amihud, 1990; Li and Zou, 2008; Beber *et al.*, 2009), or when market return correlations turn from positive to negative during a crisis (Baur and Lucey, 2008; Underwood, 2009). Accordingly, this paper views flight-to-quality and flight-to-liquidity, which occur particularly under extreme market conditions (Beber *et al.*, 2009), as two types of *general* portfolio rebalancing.[1] We suggest enlarging the scope of this enquiry in four directions.

First, previous studies usually restrict themselves to the interactions between only two markets, typically stock and Treasury bond markets. By contrast, we take into account the corporate in addition to the Treasury bond market to examine cross-market portfolio rebalancing both between the stock and bond markets and between the corporate and Treasury bond markets. Second, existing work only focuses on major OECD countries where microstructure data is more easily available. We enlarge the scope of this analysis by studying these three markets in the largest emerging economy by far, China, which presents special features compared to advanced markets. Third, studies investigating market linkages or flight-to-quality in China, e.g., Li and Zou (2008), usually examine returns and volatility, not buying and selling activities.[2] Avoiding the necessity to sign volume, we use a unique database which provides records identifying each trade as buyer-initiated or seller-initiated, in order to examine cross-market effects through not only returns but also order flow (i.e., the trading volume that buyers initiate over that initiated by sellers). Finally, departing from Underwood (2009) and Gyntelberg *et al.* (2009) who also examine market linkages through order flow for the USA and Thailand respectively, we analyze the relationships between asset liquidity and cross-market portfolio rebalancing, and provide evidence indicating which type of asset is associated with cross-market linkages.

Our work thus provides an important addition to existing empirical studies which are only concerned with quality-driven portfolio rebalancing (flight-to-quality) between stocks and Treasury bonds that have a very different fundamental risk level (Underwood, 2009), liquidity-driven portfolio rebalancing (flight-to-liquidity) between Treasury and agency (Refcorp) bonds that have a similar fundamental risk level (Longstaff, 2004), or flight-to-liquidity accompanied by flight-to-quality (Goyenko and Ukhov, 2009; and Brunnermeier

1 In addition to flight-to-quality and flight-to-liquidity, the general portfolio rebalancing could also include investment adjustment due to reasons other than liquidity or quality problems of the assets themselves, such as the “liquidity trading” for reasons outside the stock market shown by Admati and Pfleiderer (1988). Connolly *et al.,* (2005, 2007) and Underwood (2009) also refer to cross-market rebalancing as cross-market hedging, as return correlations between the stock and Treasury bond markets are likely to be negative during crisis periods on the stock market.

2 Li and Zou (2008) also ignore the corporate bond market, which plays an important role in developed countries.

and Pedersen, 2009). By nature, cross-market asset allocation or risk management ranges over all available assets, and the safe assets (i.e., bonds) in the portfolio may include not only Treasury bonds but also (high-grade) corporate bonds; therefore, leaving out corporate bonds when examining cross-market portfolio rebalancing probably generates biased results.

Three features of the Chinese financial markets both distinguish them from OECD markets and lead us to expect special features in cross-market portfolio rebalancing. Firstly, individual investors predominate on the Chinese stock market (e.g. Bailey *et al*., 2009), as opposed to the dominance of institutional investors on OECD markets. Previous theoretical studies about flight-to-quality or flight-to-liquidity behavior (or the *general* portfolio rebalancing) usually assume that market participants are fund managers or institutions, who usually allocate investment between stocks and bonds (e.g., Vayanos, 2004; Brunnermeier and Pedersen, 2009), and previous empirical studies only focus on OECD markets, which have more institutional than individual investors (e.g., Longstaff, 2004; Goyenko and Ukhov, 2009; Beber *et al.*, 2009; Underwood, 2009). In China, individuals, who represent more than 90% of investors, held 51.29% of the total capitalization of the stock market by the end of 2007.[3] Their ability to undertake cross-market asset allocation and hedging may be much weaker than institutional investors, and most individuals undertake little cross-market asset allocation between stocks and bonds, simply transferring funds between the stock market and bank accounts. Secondly, Chinese markets are characterized by a lack of international arbitrage due to the still-binding capital controls. Therefore, our study on the Chinese markets is able to focus on "pure" domestic cross-market effects. While previous studies on OECD markets suffer from "missing" international cross-market effects, ignoring stocks-to-foreign-stocks and bonds-to-foreign-bonds effects, Sheng and Tu (2000) and Connolly *et al.* (2007) show that such international effects should not be ignored. Thirdly, the Chinese bond market is a special case. The very strict conditions for the issuance of corporate bonds endow them with high quality, making them close to Treasury bonds. This makes the Chinese bond markets ideal for investigating the preferences of institutional investors between Treasury and corporate bonds in the stock-bond portfolio rebalancing and the stylized facts of portfolio rebalancing between bond markets, such as the substitution between Treasury and corporate bonds.

This paper examines market linkages through a study of the information content of order flow for both stocks and bonds. The database we use for the Chinese financial markets covers daily-aggregated tick-by-tick data over a three-year period spanning January 2004 through December 2006 for all stocks, Treasury and corporate bonds on the Shanghai Security Exchange (SHSE), which has more stocks and

[3] See the Report of the Chinese Capital Market published by the China Securities Regulatory Commission (see, http://www.csrc.gov.cn/n575458/index.html). Bailey *et al.* (2008) also find that, for a typical stock on a typical trading day in China, 91.76% of trades are initiated by individual investors, and the marginal explanation of individual investors' order flow on stock returns is higher than that of institutional or proprietary investors' order flow. Such findings suggest that in China the trading of individual investors has stronger effects on stock price movements than that of institutional investors.

bonds than the Shenzhen Security Exchange (SZSE).[4] Such data enables us to determine both the relative role of each market in cross-market portfolio rebalancing and its precise features.

We first find that under normal conditions the Treasury bond market serves more for stock-investor hedging than the corporate bond market, and, in addition to the stock-bond portfolio rebalancing, portfolio rebalancing between corporate and Treasury bonds is also significant. We find a negative cross-market effect of order flow on returns both between the stock and Treasury bond markets and between the corporate and Treasury bond markets. Namely, a rise in order flow on one market is associated with a fall in returns on another market. As aggregate order flow reveals information on preferences, endowments and the projection of news by market participants (Lyons, 2001; Evans and Lyons, 2002; Underwood, 2009), the negative effects of order flow in one market on returns in other markets imply widespread cross-market portfolio rebalancing.

Our second finding implies that when the stock market rises or falls sharply, or when Treasury bond market returns are falling, corporate bond order flow also significantly and negatively affects stock returns. With respect to portfolio rebalancing between the stock and bond markets in China, corporate bonds are able to replace Treasury bonds as the “haven” of stock investors, either during extreme stock market conditions or during a fall in Treasury bond market returns.

Finally, in line with previous studies on the relationship between liquidity and price discovery, e.g., Chordia and Swaminathan (2000) and Underwood (2009), we find that the within-market information content of order flow differs significantly both between index and non-index stocks and between liquid and illiquid bonds. However, on the Chinese stock market, the order flow for non-index stocks has stronger effects on overall-market returns than that for index stocks. On the bond markets, the order flow for more liquid bonds has higher information content. In particular, off-the-run Treasury bonds in China are more liquid (than on-the-run Treasury bonds), and their order flow thus has higher information content on Treasury bond market movements.

The rest of this paper is organized as follows. Section 2 describes the data. In section 3 we present the empirical results. Section 3 concludes.

2. Institutional Background and Data

This paper uses intraday tick-by-tick data for all A-share stocks, Treasury bonds and corporate bonds on

[4] For instance, by the end of 2006, there were 829 listed firms which issued equities on SHSE, but only 529 such firms on SZSE.

SHSE spanning January 2004 through December 2006, with a total of 724 trading days.[5] The data were provided by the CSMAR Corporation, one of the main database providers for the Chinese financial markets. Only securities on SHSE are considered because both the capitalization and number of securities, particularly bonds, outstanding on SHSE are more than that on SZSE,[6] and B-share stocks, which account for only 2% of the total market capitalization, are excluded here to eliminate the effect of exchange rate movements.

The Chinese corporate bond market differs significantly from the US and European markets. It is composed of three parts, convertible bonds issued by public firms, corporate bonds issued by public firms (without embedded options), and corporate bonds issued by large state-owned non-public firms. We only focus on corporate bonds without embedded option and issued by (non-public) state-owned firms. State ownership and strict issuing requirements imply that the credit quality of such bonds is high.[7] We do not consider the other two types of corporate bonds due to the option uncertainties for convertible bonds or the limited data available for corporate bonds issued by public firms.[8]

In the middle of 1997, an inter-bank bond market was established. Currently, three segmented bond markets, i.e., the inter-bank bond market, the exchange bond market (both on SHSE and SZSE) and the over-the-counter (OTC) bond market (for individuals to buy bonds from commercial banks), constitute the secondary bond markets. In examining cross-market effects of order flow, we do not consider the trading on the inter-bank bond market but include the inter-bank Repo rates (as shown later), because: i) tick-by-tick trading data on the inter-bank market is not available; ii) the small institutional and individual investors, who are the main participants in the stock market, cannot participate in the inter-bank market. We also do not discuss the OTC market because its trading volume is too low. When compared with the stock market, both the Treasury and corporate bond markets on SHSE are relatively small. However, such bond markets are also important and may play a very important role in investors' portfolio rebalancing, since there are no stock futures and option markets in China and stock investors have no other alternatives for hedging.

5 The Chinese stock market includes both an A-share market, that is only available for domestic investors (recently for some Qualified Foreign Institutional Investors, QFII), and a B-share market that is available only for foreign investors. The B-share market has been opened to domestic investors only since June 2001. For more information, see Li and Zou (2008), Chan *et al.* (2007, 2008), and the Report of the Chinese Capital Market published by the China Securities Regulatory Commission (http://www.csrc.gov.cn/n575458/index.html).

6 Moreover, according to the Report on the Chinese Capital Market published by the China Securities Regulatory Commission, while most companies listed on the Shanghai Stock Exchange are large and state-owned firms, those on the Shenzhen Stock Exchange are small, joint ventures, and export-oriented firms. This also leads to a different level of trading volume between the two markets. For instance, the yearly total stock trading volume in 2006 on SHSE is about 5.8 trillion RMB, but that on SZSE is only 3.2 trillion RMB.

7 These requirements include a debt-to-asset ratio less than 0.4, an average disposable profit in the past three years higher than the one-year interest payment, a rating higher than "A", and a qualified guarantor etc.

8 The first corporate bond issued by public firms without embedded option came to the market on 24th September 2007, and there were only two such bonds on the market by the end of 2007.

The CSMAR database provides records that directly identify each trade as buyer- or seller-initiated. With these records, we aggregate the total buyer-initiated trading volume in value over the total seller-initiated trading volume in value throughout one day to get the daily order flow for each stock and bond.[9] Our sample includes 845 stocks, 47 Treasury bonds and 62 corporate bonds. The total observations of daily-aggregated order flow are 549,597, including 509,537 for stocks, 23,429 and 16,631 for Treasury and corporate bonds respectively.[10]

Daily returns of stocks are computed as the first difference of the logarithm of daily close prices. To dampen extreme price movements and to provide a cool-off period in the event of overreaction, SHSE currently sets the daily price limit at 10%. The data with daily absolute returns higher than 10% are mainly connected to the stocks which were excluded from the Special Treatment (ST) or Particular Transfer (PT) classes,[11] and thus are not included in our study. Daily bond returns are computed as the first difference of the logarithm of daily close prices, and the data on interest payment days are excluded.

Because previous literature such as Harford and Kaul (2005) and Underwood (2009) shows that index and non-index stocks have different information content of order flow and efficiency of price discovery, we split all stocks between index and non-index stock portfolios. The Shanghai Security 180 (SS180) index was created in July 2002 and is composed of the major 180 A-share stocks on SHSE. Subsequently, the index was adjusted according to the prices and number of shares outstanding for all component stocks. We construct index and non-index portfolios with the sample and adjustment information of the SS180 index. Bonds are usually classified as on-the-run and off-the-run, as existing literature (e.g., Goyenko *et al.*, 2008) suggests that the efficiency of price discovery between these two types of bond is different. Here, we use this distinction to construct bond portfolios.[12]

In Table 1, the daily average trading volume in value for different stock and bond portfolios is presented. We also provide statistics for the relative spread computed from tick-by-tick trading data. The relative spread is defined as

$$Pspread = \frac{Ask_1 - Bid_1}{(Ask_1 + Bid_1)/2}$$

9 Some literature, e.g., Brandt and Kavajecz (2004), defines the difference between buyer-initiated and seller-initiated trading volume in value as order imbalance, which is the same as the order flow defined here.

10 The number of corporate bonds is more than that of Treasury bonds in our sample. However, the observations of daily order flow for corporate bonds are fewer than that for Treasury bonds. The main reason is that more corporate bonds are issued in the latter part of our sample. For instance, the number of newly-issued corporate bonds is 37 after 2005, but only 28 for Treasury bonds.

11 Stocks are classified in a Special Treatment class when the respective firms have abnormal financial positions (e.g., earnings for two consecutive years are negative), and stocks are classified in a Particular Treatment class if earnings are negative for three consecutive years. More information about the ST or PT can be obtained on the website http://www.csrc.gov.cn/.

12 When a new bond is issued, it is classified as an on-the-run, and all other bonds with the same maturity become off-the-run.

Here, Ask_1 and Bid_1 are respectively the best ask and bid prices for each trade.[13] The relative spread is computed for each trade and the daily relative spread is averaged over all trades every day for each stock and bond. In addition, we provide statistics for Amihud's (2002) *illiquidity* measure. Following Amihud (2002), this paper defines the *illiquidity* for security i on day t as follows

$$ILIQ_t^i = \frac{|R_t^i|}{M_t^i}$$

Here, R_t^i is the return and M_t^i is the trading volume in value for security i on day t.[14] Both the relative spread and Amihud's *illiquidity* measure for a given market or a particular portfolio are equally weighted.

The trading volume in value for SS180-index stocks is much higher than that for non-SS180-index stocks (Table 1). Moreover, the relative spread and Amihud's *illiquidity* are lower for SS180-index stocks. Therefore, SS180-index stocks are more liquid. Similarly, on the corporate bond market, the trading volume in value is higher, and the relative spread and Amihud's *illiquidity* are lower for on-the-run bonds. Therefore, on-the-run bonds are more liquid than off-the-run bonds on the corporate bond market.

However, on the Treasury bond market, trading volume in value is higher, and the relative spread and Amihud's *illiquidity* is lower for off-the-run bonds. This is opposite to the common finding that on-the-run bonds are more liquid than off-the-run bonds. For instance, Sarig and Warga (1989), Houweling *et al.* (2005) etc. find that off-the-run bonds are more likely to be included in the buy-and-hold portfolios of investors and thus have low liquidity. Such a difference between the Chinese and other Treasury bond markets may be due to the relatively small size of bond-issuing in China, unable to satisfy investor demand, particularly for institutions. This easily leads to over-competition and biased prices when a new bond is just issued (see also, Schultz, 2001), thus giving rise to a high price-impact for on-the-run bonds.[15]

Descriptive statistics of order flow and returns for the three markets are shown in Table 2. Returns and volatility are the highest on the stock market and the lowest on the Treasury bond market. However, the standardized returns (i.e., mean returns divided by standard deviation) are lowest on the stock market, and much higher on the corporate than on the Treasury bond market. This indicates that returns for

13 *Spread* here is computed from bond prices but not bond yields. The bond market has almost the same trading system as the stock market on SHSE, e.g., double auction in an electronic trading system, bond prices expressed in decimal points and the minimum tick of 0.01 RMB.

14 The logarithm of the trading volume in value is used to reduce the data dimension or scale problem.

15 Alternatively, according to the interpretation of Goyenko *et al.* (2008), off-the-run Treasury bonds could be viewed as responding to macroeconomic shocks faster and having higher information content for bond valuation and thus higher liquidity than on-the-run bonds.

bearing one unit of risk are much higher on the corporate bond market in spite of the close credit quality of the two bond markets. Kurtosis of order flow on the corporate bond market is highest among the three markets, indicating that order flow in this market is more likely to have extreme values.

Correlations between returns on the stock and corporate bond markets and between order flow on the stock and Treasury bond markets are significantly positive (Table 3).[16] The correlation of returns between the two bond markets is relative high, about 0.5, but the correlation of their order flows is weak. The correlation between returns and order flow in each market (lower left part of Table 3), thereafter *within-market* correlation, is highly positive on the stock market, about 0.79, intermediate on the Treasury bond market, about 0.48, and low on the corporate bond market, only 0.14, even less than the *cross-market* correlation between corporate bond returns and Treasury bonds order flow (about 0.20).[17] Furthermore, stock market order flow is also significantly positively correlated with Treasury bond market returns. These *cross-market* correlations between order flow on one market and returns or order flow on another market indicate that, on the whole, buying or selling of stocks may imply buying or selling of both stocks and Treasury bonds, and buying or selling of Treasury bonds may imply buying or selling of Treasury and corporate bonds as well as stocks. In line with Connolly *et al.* (2005) and Underwood (2009), such results imply that there are long-term positive correlations among the three Chinese markets, which are likely to be generated by many common economic factors.

Though the stock, corporate and Treasury bond markets play their own roles and have different fundamental factors of asset valuation, more and more studies find that their return correlations vary with market conditions or are altered when uncertainty increases. Thus for example Li and Zou (2008) find that correlations between Chinas's Treasury bond and stock markets vary with policy and information shocks. Particularly, due to cross-market portfolio rebalancing, stock-bond return correlations may change sign and become negative in the short term (Connolly *et al.*, 2005, 2007), and the highly positive Treasury-corporate bond return correlations may become either stronger or weaker.

Return correlations among the three markets under different market conditions are shown in Table 4. Here, we simply consider correlations conditional on the rise or fall of returns on the related markets. Thus, for return correlations between markets *i* and *j*, we split the whole sample into five subsamples by returns respectively on either market *i* or *j*, and then correlations are computed and their significance are tested by bootstrapping in each subsample. For example, with respect to return correlations between the

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16 As shown by Forbes and Rigobon (2002), return correlations between assets or markets are greatly affected by heteroskedasticity. Thus, to test the significance of correlations, we compute their p-values by bootstrapping. This is particularly important, as results in Table 3 show that with a value of 0.0799 the correlation between stock and Treasury bond market order flow is significant, but with -0.0796 the correlation between stock and corporate bond market order flow is insignificant. Thus, the heteroskedasticity between markets or between variables can greatly affect the significance of correlation tests. The details of bootstrapping are available upon request.

17 The relatively low within-market correlation between returns and order flow on the bond market is quite consistent with literature on OECD countries, such as Chordia *et al.* (2005), who (their Table 3) show that while the correlation between daily returns and order flow on the stock market is 0.79, such a correlation on the Treasury bond market is only 0.05, but still significant.

stock and corporate bond markets, i.e., $cor(r_t^S, r_t^C)$, we first split the whole sample respectively by the 20%, 40%, 60% and 80% quantiles of stock market returns r_t^S and the same quantiles of corporate bond market returns r_t^C, and then compute $cor(r_t^S, r_t^C)$ and its significance level (p-value) by bootstrapping in these subsamples. There are about 145 observations in each subsample.

Both the stock-bond and corporate-Treasury bond return correlations vary with market conditions (Table 4). The stock-bond correlations are significantly positive when the return on either bond market is low, but they are significantly negative when returns on the stock market or on the Treasury bond market are high. In particular, return correlations between the stock and Treasury bond markets decrease with Treasury bond returns (i.e., the higher the Treasury bond market returns, the lower, or more negative, the stock-Treasury bond market correlations). In line with Connolly *et al.* (2007), a sharp rise in Treasury bond returns may imply portfolio rebalancing from stocks to Treasury bonds, and thus a fall in stock returns. In addition, the different trends between stock-corporate bond and stock-Treasury bond return correlations indicate that the two bond markets may play a different role in stock-bond market linkages.

Corporate-Treasury bond return correlations are highly positive over the whole sample, but differ substantially among subsamples (last two columns in Table 4). Generally, correlations between the two bond markets are high when either market falls, but their returns become more weakly (still significantly) correlated when either bond market rises. However, the return correlations are insignificant, or negative, when both markets neither rise nor fall sharply. This means that correlations between the bond markets vary with market conditions. The underlying reasons for such a phenomenon need to be examined even though most previous studies only focus on correlations between the stock and bond market returns.

3. Empirical Results

3.1 The Cross-market Information Content of Order Flow

Previous empirical studies have shown that order flow has a strong explanatory power for movements in returns on stock (Hasbrouck and Seppi, 2001; Chordia *et al.*, 2002), bond (Brandt and Kavajecz, 2004; and Harford and Kaul, 2005) and foreign exchange markets (Evans and Lyons, 2002). Moreover, in addition to within-market effects, order flow may have cross-market effects due to cross-market fund allocation and hedging. For instance, Chordia *et al.* (2005) show that order flow in one market may affect returns, volatility or liquidity on another market, and Underwood (2009) finds significant cross-market effects of Treasury bond market order flow on stock market returns due to cross-market portfolio rebalancing. Generally, order flow on the stock market will rise when more investment funds are transferred from bonds to stocks. Conversely, stock order flow may fall and bond order flow may rise when more funds are redirected to the bond market.

In order to examine cross-market portfolio rebalancing both between stocks and bonds and between corporate and Treasury bonds, we examine the contemporaneous effect of order flow in one market on returns in another market with a SUR (Seemingly Unrelated Regressions) model as follows,

$$\begin{aligned} r_t^S &= a_0 + a_1 OF_t^{index} + a_2 OF_t^{non-index} + a_3 OF_t^{C,on} + a_4 OF_t^{C,off} + a_5 OF_t^{T,on} + a_6 OF_t^{T,off} \\ &\quad + a_7 Spread_t^S + a_8 r_t^{Common} + a_9 Repo_t + \varepsilon_t^S \end{aligned} \tag{1}$$

$$\begin{aligned} r_t^C &= b_0 + b_1 OF_t^{index} + b_2 OF_t^{non-index} + b_3 OF_t^{C,on} + b_4 OF_t^{C,off} + b_5 OF_t^{T,on} + b_6 OF_t^{T,off} \\ &\quad + b_7 Spread_t^C + b_8 r_t^{Common} + b_9 Repo_t + \varepsilon_t^C \end{aligned} \tag{2}$$

$$\begin{aligned} r_t^T &= c_0 + c_1 OF_t^{index} + c_2 OF_t^{non-index} + c_3 OF_t^{C,on} + c_4 OF_t^{C,off} + c_5 OF_t^{T,on} + c_6 OF_t^{T,off} \\ &\quad + c_7 Spread_t^T + c_8 r_t^{Common} + c_9 Repo_t + \varepsilon_t^T \end{aligned} \tag{3}$$

$$E\left[\varepsilon_t^S\right]=0,\ E\left[\varepsilon_t^C\right]=0,\ E\left[\varepsilon_t^T\right]=0,\ E\left[\varepsilon_t^K \cdot \varepsilon_s^M\right]=\begin{cases}\sigma & \text{If } t=s \\ 0 & \text{Otherwise}\end{cases},\ K,M=S,C,T$$

where r_t^S, r_t^C and r_t^T are respectively the equally-weighted returns on the Shanghai stock, corporate and Treasury bond markets on day t; OF_t^{index} and $OF_t^{non-Index}$ aggregate order flow for the SS180-index and the non-SS180-index stocks on day t; $OF_t^{C,on}$ and $OF_t^{C,Off}$ aggregate order flow for the on-the-run and the off-the-run corporate bonds on day t; and $OF_t^{T,on}$ and $OF_t^{T,off}$ aggregate order flow for the on-the-run and the off-the-run Treasury bonds on day t. $Spread_t^S$, $Spread_t^C$ and $Spread_t^T$ are respectively liquidity variables (equally-weighted relative spread) on the stock, corporate and Treasury bond markets; r_t^{Common} is the principal component of returns decomposed by the sample correlation matrix for the vector of market-return series (r_t^S, r_t^C, r_t^T); and $Repo_t$ is the 7-day repo rate on the inter-bank Treasury bond market.

In equations (1) to (3), the central specification concerns the cross-market effect of order flow. We want to test whether order flow has information content not only on its own market, but also on another market. In addition to cross-market portfolio rebalancing, contagion from one market to the other is also a reason for market linkages, as shown by Forbes and Rigobon (2002) and Baur and Lucey (2008). Thus, contagion can also be responsible for the cross-market effect of order flow. Nevertheless, while both cross-market portfolio rebalancing and contagion may result in cross-market effects of order flow, their effects are greatly different. With cross-market portfolio rebalancing, order flow on one market should be *negatively* correlated with returns on another market. By contrast, if contagion is the essential reason for market linkages, order flow on one market and returns on another market should be *positively* correlated. Using the specification in equations (1) to (3), we can examine the two hypotheses and provide evidence on the direction of market linkages.[18]

We separate securities on each market into high and low-liquidity portfolios and estimate the difference in the information content of their order flow. The motivation behind such an asset separation is the wish to examine two aspects of the effects of order flow. First, assets with different liquidity would differ in the efficiency of price discovery. Here, we also expect that assets with different liquidity would provide different information on market movements.[19] Secondly, Harford and Kaul (2005) and Underwood (2009) show that the order flow for index stocks has a stronger effect on overall market returns. However, because the speculative individual investors, who are the main participants on the Chinese stock market, prefer small non-index stocks to large index stocks, we expect a larger information content of order flow for non-index than for index stocks.

Liquidity variables should also be included in the three equations because of the pricing effect of liquidity on the financial markets shown in previous studies.[20] The quote spreads between bid and ask prices are a standard proxy for the liquidity of a given security. We thus include the market liquidity variables $Spread_t^K$ ($K = S, C, T$) in each equation to capture such a liquidity effect. Using tick-by-tick data, we first compute the average relative spread for each stock and bond every day, and then market liquidity is defined as the simple average of such spreads over all stocks or bonds on each market.

The common factor of returns r_t^{Common} is also added to the three equations in order to control for common effects among the three markets. We extract the common factor of the three market returns by Principal Component Analysis, decomposing the sample correlation matrix for the vector of market return series (r_t^S, r_t^C, r_t^T). Our results show that the maximum eigen-value of the sample second moment correlation matrix is 1.51, and the first component (denoted r_t^{Common}) is able to explain more than 50% of their variance, implying that the common variation of the three market returns can be properly captured by r_t^{Common}. We also run Granger causality tests to examine the exogeneity of r_t^{Common}. All causal relationships from each of the three market returns (r_t^S, r_t^C or r_t^T) to r_t^{Common} are rejected.

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18 In addition, while the three markets under investigation exhibit different sizes and the bond markets are small when compared to the size of the stock market, including the order flow in the equations can reduce the influence of such differences on the results. Since the stock market with higher size also has higher trading volume and order flow, and the bond markets have both lower size and order flow.

19 In a single OLS regression of market returns on the order flow for high and low-liquidity portfolios for each market, order flow for index and non-index stocks or on-the-run and off-the-run bonds indeed presents different information content.

20 Such a pricing effect is documented by Amihud and Mendelson (1986), Amihud (2002), Acharya and Pedersen (2005) on the stock market, and Houweling *et al.* (2005), Chen, Lesmond and Wei (2007) on the bond market.

In addition to the common movements of returns among the three markets, we also add the repo rate on the inter-bank Treasury bond market, i.e., $Repo_t$, to the model as another common factor. Fan and Zhang (2007) show that investment opportunities on the stock market have a significant effect on repo rates, since the repo market in China is the main location for borrowing or lending funds. Thus, when the stock market rises, investment demand is high and the cost of financing on the repo market rises. By contrast, when the stock market falls, more money leaves the stock market, and the demand for, and the cost of, financing on the repo market fall. Therefore, $Repo_t$ is expected to be positively correlated with stock market returns, i.e., a_7 should be positive in equation (1). Furthermore, b_7 and c_7 are also expected to be positive since repo rates are highly correlated with the risk-free rate and spot bond trading.

Before model estimation, we run two separate vector autoregressive (VAR) models with five lags, i.e., VAR (5), on market returns (r_t^S, r_t^C, r_t^T), and on market liquidity variables $(Spread_t^S, Spread_t^C, Spread_t^T)$. In addition, we also run separate VAR (5) models on order flow for all within-market asset portfolios respectively for the stock, corporate and Treasury bond markets, i.e., a VAR (5) model respectively on the vectors $(OF_t^{index}, OF_t^{non-index})$, $(OF_t^{C,on}, OF_t^{C,off})$ and $(OF_t^{T,on}, OF_t^{T,off})$ in turn. Then equations (1) to (3) are estimated on the residual series of these models. All these filters ensure that the regression estimates of the order flow effects do not include any lagged effects but the true unanticipated component of trading suggested by Hasbrouck (1991) and Underwood (2009).[21]

After the autocorrelation or lead-lag relationships for all endogenous and exogenous variables are removed, we can estimate equations (1) to (3) with the SUR method. However, our results show that the order flow for all less-liquid assets (i.e., non-index stock, off-the-run corporate and on-the-run Treasury bonds) in the three equations present little cross-market effect.[22] By contrast, the order flow for all more-liquid assets (i.e., index stock, on-the-run corporate and off-the-run Treasury bonds) presents significant cross-market effects on other market returns. Accordingly, we construct a simpler SUR model as follows,

$$\begin{aligned} r_t^S = a_0 &+ a_1 OF_t^{index} + a_2 OF_t^{C,on} + a_3 OF_t^{T,off} + a_4 OF_t^{non-Index} \\ &+ a_5 Spread_t^S + a_6 r_t^{Common} + +a_7 Repo_t + \varepsilon_t^S \end{aligned} \tag{4}$$

$$\begin{aligned} r_t^C = b_0 &+ b_1 OF_t^{index} + b_2 OF_t^{C,on} + b_3 OF_t^{T,off} + b_4 OF_t^{C,off} \\ &+ b_5 Spread_t^C + b_6 r_t^{Common} + b_7 Repo_t + \varepsilon_t^C \end{aligned} \tag{5}$$

$$\begin{aligned} r_t^T = c_0 &+ c_1 OF_t^{index} + c_2 OF_t^{C,on} + c_3 OF_t^{T,off} + c_4 OF_t^{T,on} \\ &+ c_5 Spread_t^T + c_6 r_t^{Common} + c_7 Repo_t + \varepsilon_t^T \end{aligned} \tag{6}$$

21 In addition, liquidity may have cross-market effects on returns (Chordia *et al.*, 2005), or order flow may be affected by past returns for the operation of technical traders. Therefore, we also use a VAR model in which the endogenous variables include returns, spread and order flow on all the three markets (together) to remove the lead-lag relationships and autocorrelations. However, the results will not be qualitatively changed when such a "heavy" filter is applied.

22 These results are not reported here to save space but available upon request.

$$E\left[\varepsilon_t^S\right]=0,\; E\left[\varepsilon_t^C\right]=0,\; E\left[\varepsilon_t^T\right]=0,\; E\left[\varepsilon_t^K \cdot \varepsilon_s^M\right]=\begin{cases}\sigma & \text{If } t=s \\ 0 & \text{Otherwise}\end{cases} \quad, K, M = S, C, T$$

where all variables are defined in the same way as in equations (1) to (3), and only order flow for more liquid assets (i.e., index stocks, on-the-run corporate bonds and off-the-run Treasury bonds) is assumed to exhibit cross-market effects. In particular, on the Treasury bond market, off-the-run bonds are more liquid than on-the-run bonds; therefore, the order flow for off-the-run Treasury bonds is included in equations (4) and (5). After the lagged effect of all variables is removed as mentioned before, the estimation results of this new three-market model, equations (4) to (6), are shown in Table 5.

Within-market Effect of Order Flow

The within-market information content of order flow differs substantially between high and low-liquidity assets (Table 5). On the stock market, order flow for both the SS180 index and the non-SS180 index stocks significantly affects overall stock market returns, but a Wald test (not reported here) rejects the null hypothesis of "$a_1 = a_4$" at the significance level of 1%. The effect of a unit standard deviation change in order flow for the non-SS180 index portfolio is (four times) larger than that for the SS180 index portfolio. These results on the relative information content of index and non-index stocks are the opposite of what Harford and Kaul (2005) and Underwood (2009) find on mature markets. However, our results are closely related to the nature and preference of participants in the Chinese stock market and in line with the findings of Bailey *et al.* (2009), who show that in China the marginal explanation of order flow on stock returns is higher for individual investors than for institutional or proprietary investors.[23]

On the corporate bond market, only order flow for high-liquidity on-the-run bonds significantly affects market returns, while such an effect is insignificant for off-the-run bonds. On the Treasury bond market, while order flow for both on-the-run and off-the run bonds significantly affects market returns, a Wald test (not reported here) rejects the null hypothesis of "$c_3 = c_4$" at the significance level of 1%. Order flow on off-the-run bonds dominates order flow on on-the-run bonds in driving Treasury bond market movements.

Our results concerning the within-market effect of order flow provide evidence supporting the findings of Chordia and Swaminathan (2000), Harford and Kaul (2005), and Goyenko *et al.* (2008), who show that assets with different liquidity may have a different efficiency of price discovery.

[23] Indeed, as shown above, individual investors predominate on the Chinese stock market. Compared with institutional investors, individual investors have a lower ability to manage risk, and are more prone to speculate and less conscious of risk. They prefer small-cap or non-index stocks with higher expected returns. This explains our finding that order flow for non-index stocks presents higher information content of order flow.

Cross-market Effect of Order Flow

The results of equation (4) show that, after controlling for the within-market effects of order flow, order flow for highly-liquid off-the-run Treasury bonds (i.e., $OF_t^{T,off}$) is negatively correlated with stock market returns. Moreover, order flow for highly-liquid index stocks (i.e., OF_t^{index}) is also negatively correlated with Treasury bond market returns (equation (6)). Such results indicate jointly that, between the stock and Treasury bond markets, a rise in order flow on one market is accompanied by a fall in returns on the other market. In line with Underwood (2009), as aggregate order flow reveals information on preferences, endowments and the projection of news by market participants, the negative effect of order flow on returns shown in Table 5 implies significant cross-market portfolio rebalancing between the stock and Treasury bond markets.

By contrast with the evidence supporting the presence of cross-market portfolio rebalancing between the stock and Treasury bond markets, order flow for highly-liquid (on-the-run) corporate bonds does not have a significant effect on stock returns, nor does stock market order flow influence corporate bond returns. While all corporate bonds also have high quality and can be viewed as quasi-Treasury bonds, our results show that the stock market is less linked with the corporate than with the Treasury bond market.

A rise in order flow for highly-liquid (off-the-run) Treasury bonds (i.e., $OF_t^{T,off}$) is associated with a fall in corporate bond market returns; at the same time, a rise in order flow for highly-liquid (on-the-run) corporate bonds (i.e., $OF_t^{C,on}$) is associated with a fall in Treasury bond market returns.[24] This indicates that the two bond markets are well linked, and portfolio rebalancing between them is also important.

The Effect of Liquidity and Common Factors

Results in Table 5 also imply that liquidity affects asset returns. Stock market liquidity ($Spread_t^S$) and corporate bond market liquidity ($Spread_t^C$) are significantly negatively correlated with their own market returns. Because the residual series of the VAR (5) model with liquidity variables on the three markets are used to estimate our three-market model, $Spread_t^K$ ($K = S, C, T$) should be interpreted as representing unexpected liquidity. In line with the findings of Amihud (2002) and Acharya and Pedersen (2005), our result, that unexpected liquidity (relative spread) innovations are negatively correlated with asset returns, indicates the presence of a significant liquidity premium both on the stock and corporate bond markets. However, the effect of the liquidity factor on the Treasury bond market is insignificant.

[24] The correlations between order flow in one market and returns in another market (Table 3) turn from positive to negative just because the effects of within-market order flow and other common factors are controlled in the regressions.

As far as the effect of common factors is concerned, due to the results of Principal Component Analysis, in particular the uniformly negative loadings in the eigen-vector, the common factor for returns r_t^{Common} is negatively correlated with returns on all three markets. In addition, results in Table 5 show that stock market returns are positively correlated with the repo rate, which is another common factor. The latter evidence supports the findings of Fan and Zhang (2007) who document a positive relationship between investment demand on the stock market and repo rates.

So far, our results show that, after the lead-lag relationships and the effects of market liquidity and common factors are controlled, order flow has a significant negative cross-market effect on returns both between the stock and Treasury bond markets and between the corporate and Treasury bond markets. The fact that a rise in order flow on one market is accompanied by a fall in returns on another market provides direct evidence of cross-market portfolio rebalancing.

3.2 Market Uncertainty and Substitution Effects

While general portfolio rebalancing, such as the “noise trading” or “liquidity trading”, for reasons located outside the stock market as shown by Admati and Pfleiderer (1998), can occur under normal conditions, flight-to-quality or flight-to-liquidity usually refer to the changes of interrelationship under extreme market conditions. We now examine the relationship between the information content of order flow and market uncertainty. This is necessary to provide direct evidence on whether activities such as flight-to-quality or flight-to-liquidity under extreme market conditions explain the cross-market effects of order flow. Furthermore, because the Treasury bond market in China is small, it should show large price changes during investors’ portfolio rebalancing between the stock and Treasury bond markets. Thus, during a fall in returns on the stock or Treasury bond market, corporate bonds may substitute Treasury bonds due to the rise in the costs of Treasury-bond trading and the high quality of corporate bonds.

Accordingly, we estimate equations (4) to (6) under the following alternative market conditions: 1) sharp rises or sharp falls on the stock market; 2) rises or falls on the bond market. First, during sharp rises or sharp falls on the stock market, the Treasury bond market may not be able to bear a huge demand for safe assets (from the stock market) or provide a huge supply of investment funds (to the stock market). Thus, high-quality corporate bonds may be able to replace Treasury bonds as safe assets under these market conditions. Second, bond market conditions also affect investors’ portfolio rebalancing and their preference between corporate and Treasury bonds. As shown in Table 5, Treasury bonds rather than corporate bonds are viewed as the main alternative safe assets under normal conditions, thus corporate bonds may substitute Treasury bonds as safe assets only when the Treasury bond market falls.

Table 6 provides the estimation results of equations (4) to (6) conditional on extreme falls and rises on the stock market. The extreme falls and rises are defined as events associated with the highest and lowest deciles of stock market returns. The mean and maximum daily market returns during extreme stock falls are respectively -3.04% and -1.44%, and the mean and minimum returns during extreme rises are respectively 2.81% and 1.46%. Under extreme stock market conditions, order flow for *both* corporate and Treasury bonds has significant and higher effects on stock returns (Table 6),[25] compared with the unconditional results reported in Table 5. This means that under such extreme conditions buying or selling activities on both the corporate and Treasury bond markets provide important information on stock market movements.[26] In China, corporate bonds replace Treasury bonds as the safe "haven" for stock market investors, either when the demand for safe assets rises during a sharp fall in the stock market or when the demand for funds rises during a sharp rise in the stock market. Furthermore, when the stock market rises sharply, the constant term in the Treasury bond equation (c_0) is significantly negative (b_0 is also weakly significantly negative), and when the stock market falls sharply, c_0 is (weakly) significantly positive (Table 6). That is, the stock and bond markets depart from each other under extreme stock market conditions. While these results support the findings of Underwood (2009) that the cross-market effect of order flow is stronger during a volatile stock market, we show that flight-to-quality and flight-to-liquidity that occur particularly under extreme market conditions are responsible for the cross-market effect of order flow.

In subsamples (Table 7), corporate (Treasury) bond order flow significantly negatively affects stock returns when its own market rises or when the Treasury (corporate) bond market falls. Moreover, in the two bond market equations (i.e., b_0 and c_0), when one intercept is positive the other is always negative. Estimates conditional on bond market conditions (Table 7) confirm the following results:

1) cross-market portfolio rebalancing is the main factor behind the cross-market effects of order flow, since a fall in stock market returns is not only accompanied by a rise in order flow but also a rise in returns on bond markets. That is, when a bond (either corporate or Treasury) market rises, a fall in stock market returns is accompanied by a rise in bond market order flow, but such a relationship disappears when the bond market falls.

[25] For example, the effect of Treasury bond order flow on stock returns (i.e, a_3) is stronger under extreme stock conditions. First, a_3 is about two (four) times larger when the stock market falls (rises) sharply than that under normal conditions. Second, if we interpreted a_3 as implying that a one-unit standard deviation change in Treasury bond order flow is accompanied by a a_3-unit standard deviation change in stock returns, then results in Table 5 and Table 6 show that: a 1 billion rise in T-bond order flow is accompanied by a fall in stock returns of 6.7 basis points (0.0075*0.016/0.18=0.00067); (here 0.016 and 0.18 are respectively the standard deviation of stock returns and T-bond order flow in 100 million), whereas the figures are respectively 7.1 and 17.1 basis points when the stock market falls and rises sharply.

[26] However, under extreme stock market conditions, the effect of stock-market order flow on the bond market becomes insignificant. This is reasonable as individual investors predominate on the stock market, and investment may come from or leave for other places than the bond markets under extreme stock market conditions. Actually, most individual investors in China undertake asset allocation between the stock market and bank accounts but not between the stock and bond markets. Therefore, stock order flow may present weak effects on bond returns due to the entry or exit of individual investors.

2) corporate and Treasury bonds substitute each other in the role of safe “haven”, since, between the two bond markets, when one market falls, the other market will have interactions with the stock market (i.e., present negative cross-market effects of order flow on returns). However, the Treasury bond market plays a more dominant role than the corporate bond market in stock-bond portfolio rebalancing, since stock order flow is always (significantly) negatively correlated with Treasury bond returns.

3) portfolio rebalancing between the two bond markets is also significant and should not be ignored, since returns on the two bond markets depart from each other when either market is rising or falling (i.e., among b_0 and c_0, when one is positive the other is always negative).

Using a CCC (Constant Conditional Correlation, Bollerslev, 1990) Multi-variate GARCH model, we also estimate equations (4) to (6) conditional on high market volatility on each of the three markets. Our results, not reported here, show that when volatility on the stock or Treasury market is high, order flow for both corporate and Treasury bonds exhibits significant (negative) effects on stock returns. These results reinforce the presence of substitution effects between corporate and Treasury bonds in China.

4. Conclusions

This paper has established both the within-market and cross-market information content of order flow on the Chinese stock, Treasury and corporate bond markets. We studied how the information content of order flow varies with asset liquidity and market conditions. Three main messages can be drawn from the results.

Firstly, order flow has important within-market effects on returns both on the stock and bond markets. On the stock market, aggregate market order flow is highly correlated with market returns. However, by contrast with the stock markets in developed countries, the effect of order flow for index (SS180) stocks is weaker than that for non-index stocks. On the bond markets, the order flow for high-liquidity bonds provides more information on bond market returns than order flow for low-liquidity bonds.

Secondly, we find a negative cross-market effect of order flow on returns both between the stock and corporate bond markets and between the corporate and Treasury bond markets. That is, a rise in order flow on one market means a fall in returns on the other market. In line with e.g. Connolly *et al.* (2005, 2007), Underwood (2009), our results provide evidence for Chinese markets of cross-market portfolio rebalancing both between stocks and bonds and between corporate and Treasury bonds. While the Treasury bond market serves more for hedging activities of stock market investors than the corporate bond market, hedging between corporate and Treasury bond markets is also essential. In addition, not only cross-market portfolio rebalancing under general market conditions, but also flight-to-quality or flight-to-liquidity, which occurs particularly under extreme market conditions, is responsible for the cross-market effects of order flow.

In China, corporate bonds can replace Treasury bonds as the safe “haven” of stock market investors, either when the demand for safe assets or investment funds rises during a sharp rise or sharp fall in the stock market or when the cost of portfolio rebalancing into Treasury bonds rises during a fall in the Treasury bond market.

At a more general level, two implications of our results stand out. First, each market plays its own role for investors; therefore, no market should be ignored in investigating cross-market portfolio rebalancing, and restricting the analysis to only two markets (as in previous studies) may bias results. The second point is that asset characteristics (e.g., asset liquidity), market conditions (e.g., rises or falls), and even the nature and preferences of market participants (e.g., predominance of individual or institutional investors) strongly affect the information content of order flow. Thus, in China the order flow for high-liquidity assets tends to have higher cross-market effects, but it does not necessarily have higher within-market effects. For example, the less-liquid non-index stocks held mostly by individual investors provide more information on stock market movements but less information on bond market movements than the more-liquid index stocks.

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Table 1. Trading and Liquidity for the Stock and Bond Portfolios

Here, statistics about the daily trading activity and liquidity for different portfolios are provided, including the average daily trading volume in value, relative spread, and Amihud's (2002) *illiquidity* measure. We not only provide the mean of these variables over the whole sample, but also the *difference in mean* and its p-value for two specified portfolios in a particular market; *** denotes that the *difference in mean* is significantly different between the two relative within-market portfolios.

Portfolios	Mean of daily trading volume in value (Million RMB)	Mean of daily relative Spread ($\times 10^{-3}$)	Mean of daily Amihud's *illiquidity* measure ($\times 10^{-3}$)
On the stock market			
(1) SS180 index stocks	45.46	2.31	1.14
(2) Non-SS180 index stocks	11.66	3.33	1.36
Difference: (1)-(2)	33.80***	-1.02***	-0.22***
On the corporate bond market			
(3) On-the-run bonds	3.31	4.87	0.18
(4) Off-the-run bonds	1.32	6.61	0.23
Difference: (3)-(4)	1.99***	-1.74***	-0.05***
On the Treasury bond market			
(5) On-the-run bonds	32.36	1.33	0.11
(6) Off-the-run bonds	40.03	0.82	0.08
Difference: (5)-(6)	-8.33	0.51***	0.03***

Table 2. Descriptive Statistics of Market Returns and Order Flow

Here, r^S and OF^S are the daily average returns and aggregate order flow on the Shanghai stock market; r^T (r^C) and OF^T (OF^C) are the daily average returns and aggregate order flow (100 million) for all Treasury (corporate) bonds on SHSE; the Standardized returns are defined as mean returns over standard deviation.

	Returns			Order flow (100 Million)		
	r^S	r^C	r^T	OF^S	OF^C	OF^T
Mean	0.019%	0.021%	0.011%	-1.6034	0.0033	0.0391
Median	0.120%	0.033%	0.019%	-1.7985	0.0003	0.0418
Maximum	7.528%	0.674%	0.905%	49.3227	0.1887	0.8639
Minimum	-7.778%	-1.052%	-1.176%	-66.4052	-0.3830	-1.0245
Std. Dev.	1.674%	0.155%	0.145%	10.4230	0.0267	0.2016
Skewness	-0.2784	-1.2135	-1.2547	-0.2513	-3.2468	-0.1558
Kurtosis	4.8407	10.6447	15.7876	8.0769	71.2155	4.6448
Standardized returns	0.0113	0.1364	0.0777	--	--	--

Table 3. Unconditional Correlation of Order Flow and Returns among the Three Markets

Here, r^S, r^C and r^T are respectively daily average returns on the stock, corporate and Treasury bond markets; $\ln OF^S$, $\ln OF^C$ and $\ln OF^T$ are respectively daily aggregate order flow on the three markets; the p-value of unconditional correlations are computed by bootstrapping; *, ** and *** respectively represent significance at the 10%, 5% and 1% levels.

	r^S	r^C	r^T	$\ln OF^S$	$\ln OF^C$	$\ln OF^T$
r^S	1.0000	0.0500 *	0.0399			
r^C		1.0000	0.5055***			
r^T			1.0000			
$\ln OF^S$	0.7869***	0.0419	0.0461*	1.0000	-0.0796	0.0779**
$\ln OF^C$	-0.0081	0.1351***	0.0144		1.0000	-0.0331
$\ln OF^T$	0.0372	0.2040***	0.4755***			1.0000

Table 4. Correlations of Returns among the Stock, Corporate and Treasury Bond Markets

In Table 4, r^S , r^C and r^T are respectively the weighted average returns on the stock, corporate and Treasury bond markets. For correlations between market *i* and *j* returns, we split the whole sample into 5 subsamples by returns on each market, then correlations and their p-value in these subsamples are computed. For example, with respect to return correlations between the stock and corporate bond markets, $cor\left(r_t^S, r_t^C\right)$, we firstly split the whole sample respectively by the 20%, 40%, 60% and 80% quantiles of stock market returns r_t^S and corporate bond market returns r_t^C, and then we compute $cor\left(r_t^S, r_t^C\right)$ and its significance level (p-value) by bootstrapping in these subsamples. There are about 145 observations in each subsample; Pctl is the quantile of returns on each market; *, ** and *** respectively represent significance at the 10%, 5% and 1% levels.

	Cor(r^S , r^T)		Cor(r^S , r^C)		Cor(r^C , r^T)	
Variables	r^S	r^T	r^S	r^C	r^C	r^T
All	0.0404	0.0404	0.0500*	0.0500*	0.5055***	0.5055***
0-20th pctl	0.0479	0.1334**	0.0869	0.1110**	0.4462***	0.6823***
20-40th pctl	0.0557	0.1026**	0.1395**	0.0890	0.0809	0.2050***
40-60th pctl	0.1862***	0.0288	-0.0043	0.0814	-0.0632	-0.0048
60-80th pctl	0.0267	-0.0034	0.0213	0.0048	0.1457*	0.0596
80-100th pctl	-0.0316	-0.1726***	-0.1123**	0.0014	0.2102***	0.2597***

Table 5. Estimation Results of the Three-market Model

Here, estimation results are shown in this table for the following model,

$$r_t^S = a_0 + a_1 OF_t^{index} + a_2 OF_t^{C,on} + a_3 OF_t^{T,off} + a_4 OF_t^{non-Index} + a_5 Spread_t^S + a_6 r_t^{Common} + +a_7 Repo_t + \varepsilon_t^S$$

$$r_t^C = b_0 + b_1 OF_t^{index} + b_2 OF_t^{C,on} + b_3 OF_t^{T,off} + b_4 OF_t^{C,off} + b_5 Spread_t^C + b_6 r_t^{Common} + +b_7 Repo_t + \varepsilon_t^C$$

$$r_t^T = c_0 + c_1 OF_t^{index} + c_2 OF_t^{C,on} + c_3 OF_t^{T,off} + c_4 OF_t^{T,on} + c_5 Spread_t^T + c_6 r_t^{Common} + c_7 Repo_t + \varepsilon_t^T$$

$$E\left[\varepsilon_t^S\right] = 0\ ,\ E\left[\varepsilon_t^C\right] = 0\ ,\ E\left[\varepsilon_t^T\right] = 0\ ,\ E\left[\varepsilon_t^K \cdot \varepsilon_s^M\right] = \begin{cases} \sigma & \text{If } t = s \\ 0 & \text{Otherwise} \end{cases}\ ,\ K, M = S, C, T$$

where r_t^K ($K = S,C,T$) are equally-weighted returns for the Shanghai stock, corporate and Treasury bond market on day t; OF_t^J ($J = index, C-on, T-off \ldots$) are aggregate order flow (in 100 million) for high-liquidity portfolios in each market on day t; $OF_t^{K,Low-L}$ ($K = S,C,T$) are order flow (in 100 million) for low-liquidity portfolio in each market, i.e., non-index stock, off-the-run corporate bond, and on-the-run Treasury bond portfolios; $Spread_t^K$ ($K = S,C,T$) are equally-weighted liquidity (relative spreads) for the three markets; r_t^{Common} is the principal component decomposed by the sample correlation matrix for market return series vector (r_t^S, r_t^C, r_t^T); $Repo_t$ is the 7-day repo rate of Treasury bonds. Returns, and liquidity are equally-weighted, and order flow is aggregated for the three markets or all asset portfolios. Before model estimation, we run a vector autoregressive model of VAR (5) model respectively on the vectors of endogenous variables (r_t^S, r_t^C, r_t^T), $(Spread_t^S, Spread_t^C, Spread_t^T)$, $(OF_t^{index}, OF_t^{non-index})$, $(OF_t^{C,on}, OF_t^{C,off})$ and $(OF_t^{T,on}, OF_t^{T,off})$ in turn to remove the strong autocorrelation and lead-lag relationship for all endogenous and exogenous variables.

	C	OF_t^{index}	$OF_t^{C,on}$	$OF_t^{T,off}$	$OF_t^{K,Low-L}$	$Spread_t^k$	r_t^{Common}	$Repo_t$	$\bar{R}^2$
r_t^S	-1.06×10^{-4}	4.85×10^{-4}	-9.69×10^{-4}	-7.47×10^{-3}	2.01×10^{-3}	-6.3954	-5.57×10^{-4}	1.10×10^{-2}	0.6698
	(0.77)	(0.00)	(0.96)	(0.00)	(0.00)	(0.00)	(0.10)	(0.06)	
r_t^C	-7.28×10^{-6}	-8.48×10^{-6}	4.45×10^{-3}	-8.55×10^{-4}	1.65×10^{-3}	-1.18×10^{-2}	-8.83×10^{-4}	3.98×10^{-4}	0.5647
	(0.83)	(0.18)	(0.01)	(0.00)	(0.47)	(0.08)	(0.00)	(0.47)	
r_t^T	-3.35×10^{-6}	-1.77×10^{-5}	-2.41×10^{-3}	2.17×10^{-3}	8.41×10^{-4}	-1.72×10^{-3}	-7.07×10^{-4}	-3.21×10^{-4}	0.6228
	(0.91)	(0.00)	(0.09)	(0.00)	(0.01)	(0.91)	(0.00)	(0.50)	

Table 6. Three-market Model Conditional on Extreme Rises or Falls in the Stock Market

Here, estimation results of equations (4) to (6) conditional extreme stock market rising or falling are shown; the explained variables r_t^K ($K = S, C, T$) are returns for the three markets; OF_t^J ($J = index, C-on, T-off \ldots$) are aggregate order flow (in 100 million) for high-liquidity portfolios in each market on day t; $OF_t^{K,Low-L}$ are order flow (in 100 million)for low-liquidity portfolio in each market on day t; $Spread_t^K$ ($K = S, C, T$) are liquidity for the three markets; r_t^{Common} is the principal component of the three market-return vector (r_t^S, r_t^C, r_t^T); $Repo_t$ is the 7-day repo rate of Treasury bonds. Returns, order flow or liquidity are equally-weighted for the three markets and all portfolios. Before model estimation, we run a vector autoregressive model or VAR (5) model respectively on the vectors of endogenous variables (r_t^S, r_t^C, r_t^T), $(Spread_t^S, Spread_t^C, Spread_t^T)$, $(OF_t^{index}, OF_t^{non-index})$, $(OF_t^{C,on}, OF_t^{C,off})$ and $(OF_t^{T,on}, OF_t^{T,off})$ in turn to remove the strong autocorrelation and lead-lag relationships for all endogenous and exogenous variables. Table 7 provides the estimation results of equations (4) to (6) conditional on extreme stock market rises or falls, which are respectively defined as events with the highest and lowest 10% of stock market returns. The P-value of coefficient-estimation is shown in the parentheses.

	C	OF_t^{index}	$OF_t^{C,on}$	$OF_t^{T,off}$	$OF_t^{K,Low-L}$	$Spread_t^k$	r_t^{Common}	$Repo_t$	$\bar{R}^2$
Panel A: Estimation results conditional on EXTREME FALLS of stock market returns									
r_t^S	-2.29×10^{-2}	-3.66×10^{-6}	-1.39×10^{-1}	-1.43×10^{-2}	9.26×10^{-4}	-6.2732	-7.17×10^{-4}	1.85×10^{-2}	0.4004
	(0.00)	(0.99)	(0.06)	(0.04)	(0.01)	(0.04)	(0.45)	(0.29)	
r_t^C	-1.58×10^{-4}	-1.48×10^{-5}	1.32×10^{-2}	-6.43×10^{-4}	9.73×10^{-4}	-6.32×10^{-3}	-7.55×10^{-4}	-1.86×10^{-3}	0.6259
	(0.27)	(0.39)	(0.05)	(0.28)	(0.85)	(0.42)	(0.00)	(0.23)	
r_t^T	2.12×10^{-4}	-4.63×10^{-6}	-1.03×10^{-2}	1.24×10^{-3}	1.32×10^{-3}	4.55×10^{-1}	-9.05×10^{-4}	-3.90×10^{-5}	0.6770
	(0.17)	(0.80)	(0.14)	(0.06)	(0.10)	(0.02)	(0.00)	(0.98)	
Panel B: Estimation results conditional on EXTREME RISES of stock market returns									
r_t^S	1.95×10^{-2}	5.12×10^{-4}	-1.62×10^{-1}	-2.81×10^{-2}	6.16×10^{-4}	-1.5828	-1.25×10^{-3}	2.29×10^{-3}	0.4368
	(0.00)	(0.07)	(0.02)	(0.00)	(0.10)	(0.46)	(0.23)	(0.85)	
r_t^C	-2.92×10^{-4}	8.54×10^{-6}	7.70×10^{-3}	-7.30×10^{-4}	2.58×10^{-3}	-3.21×10^{-2}	-9.26×10^{-4}	2.08×10^{-4}	0.4575
	(0.13)	(0.69)	(0.40)	(0.46)	(0.60)	(0.46)	(0.00)	(0.89)	
r_t^T	-3.09×10^{-4}	6.05×10^{-6}	-1.81×10^{-3}	1.07×10^{-3}	1.36×10^{-3}	4.44×10^{-2}	-1.03×10^{-3}	-1.87×10^{-3}	0.6520
	(0.05)	(0.72)	(0.80)	(0.19)	(0.41)	(0.81)	(0.00)	(0.13)	

Table 7. The Three-market Model Conditional on HIGH or LOW BOND Market Returns

The estimation results of equations (4) to (6) conditional on high or low bond market returns are shown in this table; the explained variables r_t^K ($K = S,C,T$) are returns for the three markets; OF_t^J ($J = index, C-on, T-off ...$) are aggregate order flow (in 100 million) for high-liquidity portfolios in each market on day t ; $OF_t^{K,Low-L}$ are order flow (in 100 million) for low-liquidity portfolios in each market; $Spread_t^K$ ($K = S,C,T$) are liquidity for the three markets; r_t^{Common} is the principal component of the three market-return vector (r_t^S, r_t^C, r_t^T) ; $Repo_t$ is the 7-day repo rate of Treasury bonds. Returns, order flow or liquidity are equally-weighted for the three markets and all portfolios. Before model estimation, we run a vector autoregressive model, or VAR (5) model, respectively on the vectors of endogenous variables (r_t^S, r_t^C, r_t^T) , $(Spread_t^S, Spread_t^C, Spread_t^T)$, $(OF_t^{index}, OF_t^{non-index})$, $(OF_t^{C,on}, OF_t^{C,off})$ and $(OF_t^{T,on}, OF_t^{T,off})$ in turn to remove the strong autocorrelation and lead-lag relationships for all endogenous and exogenous variables. We split the whole sample into two subsamples with high and low returns either on the Treasury or corporate bond market based on the median of returns on each market. This table provides the estimation results of Equation (4) to (6) respectively on these subsamples. The P-value of coefficient estimation is shown in the parentheses.

	C	OF_t^{index}	$OF_t^{C,on}$	$OF_t^{T,off}$	$OF_t^{K,Low-L}$	$Spread_t^k$	r_t^{Common}	$Repo_t$	$\bar{R}^2$
Panel A: Estimation results conditional on LOW TREASURY bond market returns									
r_t^S	5.23×10^{-4}	5.97×10^{-4}	-7.18×10^{-2}	-4.00×10^{-3}	1.88×10^{-3}	-7.2762	-1.02×10^{-3}	1.08×10^{-2}	0.7109
	(0.39)	(0.00)	(0.03)	(0.28)	(0.00)	(0.00)	(0.03)	(0.14)	
r_t^C	2.18×10^{-5}	-1.43×10^{-5}	6.88×10^{-3}	-4.18×10^{-4}	-7.54×10^{-3}	-1.83×10^{-2}	-7.96×10^{-4}	-4.57×10^{-4}	0.5117
	(0.70)	(0.08)	(0.03)	(0.22)	(0.07)	(0.12)	(0.00)	(0.51)	
r_t^T	-4.62×10^{-4}	-1.47×10^{-5}	-9.52×10^{-4}	9.39×10^{-4}	3.61×10^{-4}	-4.03×10^{-3}	-6.43×10^{-4}	-3.54×10^{-5}	0.5809
	(0.00)	(0.01)	(0.67)	(0.00)	(0.31)	(0.77)	(0.00)	(0.94)	
Panel B: Estimation results conditional on HIGH TREASURY bond market returns									
r_t^S	4.34×10^{-4}	3.13×10^{-4}	2.70×10^{-2}	-1.11×10^{-2}	2.30×10^{-3}	-4.8308	-7.67×10^{-6}	8.21×10^{-3}	0.6287
	(0.48)	(0.10)	(0.20)	(0.01)	(0.00)	(0.00)	(0.99)	(0.40)	
r_t^C	-1.56×10^{-4}	5.40×10^{-7}	3.16×10^{-3}	-9.25×10^{-4}	5.20×10^{-3}	-9.05×10^{-3}	-1.05×10^{-3}	1.34×10^{-3}	0.5756
	(0.01)	(0.96)	(0.11)	(0.01)	(0.05)	(0.26)	(0.00)	(0.14)	
r_t^T	5.44×10^{-4}	-1.44×10^{-5}	-1.50×10^{-3}	1.50×10^{-3}	1.05×10^{-3}	1.42×10^{-2}	-4.13×10^{-4}	3.40×10^{-4}	0.3238
	(0.00)	(0.06)	(0.32)	(0.00)	(0.01)	(0.62)	(0.00)	(0.63)	

Table 7. Continued

Panel C: Estimation results conditional on LOW CORPORATE bond market returns									
r_t^S	9.48×10^{-4}	7.12×10^{-4}	3.84×10^{-2}	-7.86×10^{-3}	1.71×10^{-3}	-6.0583	-1.39×10^{-3}	9.14×10^{-3}	0.6858
	(0.12)	(0.00)	(0.08)	(0.03)	(0.00)	(0.00)	(0.01)	(0.30)	
r_t^C	-6.28×10^{-4}	-7.99×10^{-6}	2.80×10^{-3}	-1.16×10^{-3}	3.16×10^{-4}	-8.60×10^{-3}	-6.02×10^{-4}	-6.62×10^{-4}	0.4443
	(0.00)	(0.25)	(0.08)	(0.00)	(0.92)	(0.16)	(0.00)	(0.31)	
r_t^T	8.84×10^{-5}	-2.40×10^{-5}	-2.42×10^{-3}	2.32×10^{-3}	-2.29×10^{-5}	-1.25×10^{-2}	-7.28×10^{-4}	-2.06×10^{-4}	0.5453
	(0.10)	(0.00)	(0.19)	(0.00)	(0.96)	(0.48)	(0.00)	(0.79)	

Panel D: Estimation results conditional on HIGH CORPORATE bond market returns									
r_t^S	-1.48×10^{-4}	2.99×10^{-4}	-1.17×10^{-1}	-4.36×10^{-3}	2.37×10^{-3}	-6.1748	-6.56×10^{-5}	1.09×10^{-2}	0.6753
	(0.81)	(0.07)	(0.00)	(0.23)	(0.00)	(0.00)	(0.91)	(0.16)	
r_t^C	6.78×10^{-4}	-2.89×10^{-7}	1.52×10^{-3}	-2.97×10^{-4}	1.16×10^{-3}	2.29×10^{-3}	-4.95×10^{-4}	1.72×10^{-3}	0.2651
	(0.00)	(0.97)	(0.59)	(0.30)	(0.63)	(0.85)	(0.00)	(0.01)	
r_t^T	$-1.57\times10\text{-}^{4}$	-1.17×10^{-5}	-1.73×10^{-3}	1.99×10^{-3}	1.38×10^{-3}	3.64×10^{-2}	-8.26×10^{-4}	-5.24×10^{-4}	0.6205
	(0.00)	(0.10)	(0.51)	(0.00)	(0.00)	(0.21)	(0.00)	(0.38)	