Policy Interventions and Liquidity in Segmented Chinese Credit Bond Markets*

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Abstract

This paper documents the effects of policy interventions on liquidity in the Chinese interbank and exchange corporate bond markets. First, liquidity responded strongly to the central bank's liberalization policies on foreign investors in the interbank market and on domestic investors in the exchange market. Second, liquidity effects are priced in credit bond yields, and are more pronounced during crisis and liberalized periods. Third, bond yield spreads are more sensitive to liquidity effects for bonds approaching maturity, issued by credit-constrained firms, and rated by private credit rating agencies.

Keywords: credit bonds; yield spread; liquidity; policy shocks; China.
JEL classification: G01, G12, G15, G18

1 Introduction

China's financial sector is dominated by the state-controlled banking industry and the government-backed securities markets, and is, therefore, fundamentally different from the free economy structure of the financial sector in the U.S., Western Europe, and other large market economies. At the end of 2017, Chinese marketable financial assets had a total market capitalization of 20.8 trillion U.S. dollars, with the proportions of the three main constituent financial assets being 57%, 37% and 6%, for bonds, stocks and mutual funds, respectively.[1] However, this should not be surprising, as the fixed income market is mostly composed of debt securities issued by the central government and various local government entities, including state-owned enterprises.[2] While the equity market in China has approximately doubled in market capitalization over the past decade, the fixed income market has grown six-fold during the same period. Market analysts forecast that the size of China's fixed income market could potentially become quadruple the size of its equity market by 2025.[3] These developments have made the Chinese bond markets the dominant segment of the domestic financial market, while remaining much more under-researched than the stock market. Our contribution here is an attempt to address this lacuna.

All credit bonds in China are traded in the secondary market of the interbank and the exchange market. Due to the severe segmentation between the two markets, the extent to which each market is open to foreign investment differs, and varies over time. Though opened earlier to foreign investors, the exchange market accounts for only a small percentage of trading volume of bonds and market capitalization, while the more mainstream interbank market has experienced a liberalization process at a glacial pace. Despite the announcement of a series of liberalization policies over the past decade, such as the admission of more foreign investors, the simplification of approval procedures, and the gradual augmentation of investment quota limits, the percentage of foreign investors' holdings in the interbank bond market was merely 1.1% in June 2017. A year after the initiation of the *Bond Connect* trading platform, linking Shanghai and Hong Kong, in July 2017, this figure increased to 1.9%, although still remaining quite small. The fact that the exchange market was opened to foreign investment in the early 2000s, while the interbank market was not, provides a *quasi-natural* experimental setting to examine whether the liberalization process in the interbank market, though slow, has significantly affected the levels of liquidity, as well as the pricing of liquidity and clientele effects into credit bond yield spreads. Moreover, as the domestic Chinese

[1] These numbers do not include wealth management products, loans, peer-to-peer lending, etc. Federal Reserve System (2018) provides more detailed statistics.
[2] The fixed income market in China comprises of approximately 75% bonds and 25% wealth management products in 2018, according to a study by the Federal Reserve System (2018).
[3] See Gail Fosler Group (2018) for details.

economy gradually opened up to foreign investors and its financial markets became more integrated with global markets; the central government's ability to stabilize the financial markets through targeted measures was bound to diminish. It is, thus, of great importance to study how government policies affected the credit bond markets in the past, from which valuable lessons can be learned to forecast the impact of future policy shocks.

In this paper, we use a unique dataset spanning a twelve-year period, from January 2006 to December 2017, and employ an aggregate liquidity measure to examine the impact of liquidity effects on credit bond pricing over different phases of liberalization and changing economic conditions. Along with other major economies, China adopted a stimulus program in response to the 2008 global financial crisis to revive its economy, with a particular focus on the fixed income market, which was hitherto often disproportionally affected during economic downturns. It is, thus, essential to quantify the magnitude of changes in liquidity effects during recessions and crisis periods. In addition, due to the structural differences between the two markets along various dimensions, credit bonds with different maturities, issued by different firms and rated by different rating agencies, may exhibit significant variations in the pricing of liquidity effects across the two markets, even after controlling for the independent variables that are known to affect their yields to maturity. Therefore, it is also of interest to investigate the variation in the pricing of liquidity effects into credit bond yield spreads across maturities, firm ratings, rating agencies, etc.

Our findings are novel for a variety of reasons. First, we find that the levels of liquidity, measured by the principal component of a wide range of liquidity proxies, of different credit bond segments are unequal across the two trading venues. Second, we show that government policies exerted a profound influence on the levels of liquidity, during the various phases of liberalization in the interbank market, and domestic innovation in the exchange market. In particular, we observe significant changes in liquidity immediately after major policy announcements, even while the impact on credit bond yields due to each policy differs. These findings contain important policy implications and help the government discover the type of liberalization policy that improves liquidity the most. Third, unlike in the U.S. and Europe, where liquidity effects are pronounced during more stressful economic conditions, the impact of the economic cycle on the two markets in China differs dramatically. In the interbank market, we show that liquidity effects were the strongest during crises and much weaker during normal periods and recessions. However, in the exchange market, liquidity effects were the weakest during crises and much stronger during normal periods and recessions. This could largely be due to trades in the exchange market being driven by speculative retail traders. Fourth, we find that liquidity effects are stronger for bonds with shorter time-to-maturities, for bonds issued by more credit-constrained firms, and for bonds rated by private credit rating agencies.

The remainder of this paper is organized as follows. In section 2, we present a literature survey of the research relevant to our study. Section 3 discusses the institutional background of this paper. Section 4 motivates and states the testable hypotheses in this paper. Section 5 explains, in detail, the composition of our dataset, reports the descriptive statistics of the key variables, and introduces our aggregate liquidity measure. Section 6 presents our discussion of the empirical results on the levels of liquidity in response to policy shocks and on liquidity as a priced factor. Section 7 presents our discussion of liquidity effects in bond pricing. Section 8 concludes the paper.

2 Literature Survey

There is a vast literature on liquidity effects in bond pricing, especially in the U.S. market and, to a lesser extent, the European market. Amihud and Mendelson (1986) are the first to study the impact of illiquidity on asset pricing by analyzing a model of investors with different trading horizons. To test their model, Amihud and Mendelson (1991) demonstrate empirically that a negative relationship exists between illiquidity and asset pricing, and argue for the economic importance of liquidity even in an efficient market. Amihud (2002) also suggests that the illiquidity premium may partly explain the expected stock return, and that stock returns correlate negatively with contemporaneous unexpected illiquidity. Numerous researchers have later expanded and elaborated upon this work in a variety of markets around the world.[4]

Since the inception of the Trade Reporting and Compliance Engine (TRACE) database disseminated by the Financial Industry Regulatory Authority (FINRA) for the U.S. corporate bond market in 2002, a growing number of studies has emerged as researchers are now able to analyze liquidity effects on bond yields and bond price information, following post-trade transparency. Edwards, Harris and Piwowar (2007) are among the first to document that bid-ask spreads reduced significantly after transaction prices became available. Mahanti *et al.* (2008) propose a novel liquidity measure, known as "latent liquidity," defined as the weighted average of bond turnovers of investors, and find that the new measure is suitable for bond markets with sparse transactions. Bao, Pan and Wang (2011) propose a liquidity measure, the *gamma estimator*, and show that movements in bond prices can explain a large variation of yield spreads, a transitory component that is captured by the gamma estimator.

In the over-the-counter (OTC) market environment, Jankowitsch, Nashikkar and Subrahmanyam (2011) model price dispersion effects in OTC markets, and demonstrate that

[4] See Amihud, Mendelson and Pedersen (2013) for a survey of this literature.

transaction prices deviate from the market-wide valuation in the presence of inventory and search costs. They also document that their measure fits the data well in the U.S. corporate bond market. Duffie, Garleanu and Pedersen (2007) also show that illiquidity discounts are higher when it is difficult to find counterparties, sellers have less bargaining power, and there is a paucity of qualified owners. The dataset that we use in this paper for the Chinese market is broadly similar to a restricted version of the TRACE dataset in the U.S. market, and we next discuss it in detail in Section 5 below.

Liquidity has always been of primary concern during periods of crises, especially in the case of bond markets, which are relatively illiquid even in normal times. Some of the first papers to investigate this after the 2008 financial crisis are by Bao, Pan and Wang (2011), Friewald, Jankowitsch and Subrahmanyam (2012), and Dick-Nielsen, Feldhutter and Lando (2012). These authors show that trading costs peak during financial crises and largely affect yield spreads, especially for bonds with low credit quality. Friewald, Jankowitsch and Subrahmanyam (2012) also find that liquidity effects account for a large proportion of the total variation of corporate bond yield spread changes, and that the impact of liquidity effects on bond prices is much larger in times of financial distress. In this paper, we show that liquidity effects in the interbank market tend to be the most pronounced during crises, while in the exchange market they are the most pronounced during recessions. We also add depth to the broad statement relating to such effects by highlighting their differential effects in the two markets and in different credit bond segments in China.

Our paper also examines the impact of government policies on the levels of liquidity in the Chinese credit bond markets, a topic that has been studied in the U.S. context. For example, Duffie (2012) shows that restrictions imposed by regulators through the Volcker rule on the U.S. corporate bond market significantly affected the magnitude of bid-ask spreads. Bao, O'Hara and Zhou (2016) find that stressed bonds become more illiquid as market liquidity provisions by dealers affected by the inception of the Volcker rule weakened. The difference between this literature and our paper is that, rather than examining this issue from a micro-economic perspective, we investigate the issue in the Chinese bond markets from a broader macro-economic perspective. We do so by studying how liquidity effects change as the central government gradually opened the interbank market to more qualified institutional investors.

The earlier literature on the Chinese corporate bond market was hampered by the lack of high quality data. Notwithstanding this handicap, a few recent studies provide a good qualitative description of the Chinese bond markets. At a general level, Amstad and He (2018) provide a comprehensive introduction to Chinese bond market, while Hu, Pan and Wang (2018) present an empirical overview of the Chinese capital market, including the bond market. Chen *et al.* (2019a) also provide a more detailed discussion of the Chinese credit bond markets.

In recent years, researchers find that supply and demand effects are key determinants in bond pricing. On the theory side, Vayanos and Vila (2009) are among the first to present a model the term structure of interest rates, which results from the interaction between preferred-habitat investors and risk-averse arbitrageurs in a one-market setting. In the absence of arbitrage, they show that demand and supply effects influence bond prices. Mo (2019) develops a cross-market preferred-habitat model that is applicable to a much larger set of multiple-market settings and studies how exogenous supply and demand shocks from one market affect the term structure in the other market as the shocks are transmitted to the other market through a cross-market arbitrager. Empirically, Chen *et al.* (2019b) find that clientele effects in Malaysian bonds cause Islamic sovereign bond investors to enjoy 4.8 bps higher in yield than do conventional bond investors, after controlling for bond characteristics and liquidity. In the Chinese market context, Liu *et al.* (2019) find that enterprise bonds in the exchange market that receive more demand from retail investors are more expensive than those traded by institutional investors in the interbank market. However, they ignore the fact that the exchange market is not homogenous in terms of retail investors, due to the presence of institutional investors, who also can access the interbank market.

Our study employs a wide range of liquidity measures, to be introduced in Section 5.4, that have been proven useful for the U.S. and European bond markets. Friewald, Jankowitsch and Subrahmanyam (2012) are the first to apply a range of commonly utilized liquidity measures to study the yield spreads of corporate bonds. However, we focus only on the low-frequency measures in our research in the paper, due to the constraints of intra-day data availability and quality.

Our paper can be distinguished from the prior literature on Chinese bond markets along several important dimensions. First, we employ a much larger transaction dataset for all credit bond segments than any previous paper on Chinese credit bond markets, which typically focus only on a certain sub-segment of these markets. Second, our paper is related to the literature on the liquidity effects on bond pricing. Most of the existent liquidity measures are tested in the context of well-developed corporate and sovereign bond markets, such as in the U.S. and Europe, while we test them in the credit bond markets in the world's second largest economy. We also develop an aggregate liquidity measure, based on the aforementioned liquidity proxies, which adapts better to the highly illiquid Chinese bond markets. Third, our dataset spans a twelve-year period and covers most major policy announcements by the central government, regarding interbank liberalization policies and regulations, and exchange market domestic innovation. A sequence of such policies allows us to identify the changes in the levels of liquidity and the evolution of liquidity effects in credit bond pricing over various phases of liberalization and dynamic economic conditions.

3 Institutional Background

In this section, we provide a brief description of the Chinese interbank and exchange bond markets, as well as the five types of credit bonds traded across the two markets.[5] We also discuss the three different phases of foreign liberalization between 2006 and 2017, as well as the domestic innovation in the exchange market in 2015.

3.1 The interbank OTC market and the exchange market

The two trading venues for Chinese credit bonds differ from each other along various dimensions, of which the following six are the major ones: regulatory structure, market participants, trading instruments, trading mechanism, trading rules, and collateral policy.[6] In particular, for collateral policy, the interbank market has strict restrictions on instruments that can be pledged as collateral. During normal times, both government bonds and credit bonds with a triple-A rating can be pledged as collateral, while during crises, only "interest rate securities" are accepted as collateral.[7] In the exchange market, however, most high-quality credit bonds can be pledged as collateral at a certain discount rate ("haircut") at all times.[8] Of course, the haircut would vary over time and across credit bond segments. For instance, the classes of 'AAA', 'AA+' and 'AA' enterprise bonds can generally be pledged as collateral in the exchange market. On December 8, 2014, however, the exchange market suspended the repo eligibility of both classes of 'AA+' and 'AA' enterprise bonds. Chen *et al.* (2018) study how bond prices changed across markets and rating classes around this event.

3.2 Credit bonds in China

In this paper, we study five credit bond segments in China: (1) enterprise bonds and (2) corporate bonds in the exchange market, and (3) enterprise bonds, (4) medium-term notes and (5) commercial paper in the interbank market.[9] Figure 1 shows the parallel structure of

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[5] For more detailed information on the Chinese bond markets and on the Chinese credit bond markets, see Amstad and He (2018) and Chen *et al.* (2019a).

[6] See Table A1 of the Internet Appendix for a detailed description of the six major differences.

[7] Interest rate securities refer to low-risk instruments, including financial bonds, government bonds, local government bonds, central bills, and policy bonds.

[8] Credit bonds are classified into eight collateral buckets, each with a different discount rate ("haircut") depending on the bond rating, and whether it is publicly or privately issued.

[9] See Item A1 of the Internet Appendix for a description of major differences between corporate bonds and enterprise bonds.

the two trading venues and the various instruments traded at these venues. Although all credit bonds are termed corporate bonds in the U.S. and in the European bond markets, they have different nomenclatures in China because of their respective issuers and regulatory bodies. Corporate bonds are not traded in the interbank market. According to industry convention, however, debt-financing instruments of non-financial corporates (DFINFCs) function as the corporate counterpart in the interbank market. DFINFCs contain two types of instruments: commercial paper and medium-term notes. At the other end of the maturity spectrum, commercial paper is issued by non-financial firms, and functions as a short-term financing tool, similar to commercial paper in the U.S., with a maturity of less than one year. Due to the short-term feature of commercial paper, we only consider medium-term notes as the interbank corporate counterpart in our empirical analyses.

[Insert Figure 1 Here]

3.3 *Limits to arbitrage*

Financial markets in China are well known for the presence of strong regulations and frictions, the intrinsic reasons that contribute to their severe segmentation. Two bonds, one an interbank bond, and the other, an exchange bond, with the same risk characteristics and cash flows may be traded at completely different prices. What are the forces that drive these yield differentials over time, and prevent cross-market arbitrageurs from exploiting them? We discuss four major market frictions that have preserved the pricing differentials across the two trading venues over time.

First, only institutional investors can invest in both markets. While on the one hand, banks are prohibited from trading in the exchange market, on the other hand, retail investors do not have access to the interbank market. As mentioned before, retail investors are known to conduct speculative trades and provide immediacy in the exchange market. The lack of arbitrageurs has made it difficult to perform cross-market arbitrage and eliminate price differentials. Second, a very small subset of credit bonds, dual-listed enterprise bonds, can be traded across the two markets. Though each pair of dual-listed enterprise bonds are assigned distinct trading codes across markets, they are regarded as the same bond as an investor can purchase one dual-listed enterprise bond in one market and sell it in the other, through a transfer of custody. While about 79% of enterprise bonds are dual-listed in our sample, the remaining 21% were issued only in the interbank market. Third, short-selling of credit bonds in the conventional sense is prohibited, which makes it impossible for cross-market arbitragers to profit from the pricing differentials in a timely manner.[10] The last friction, and perhaps the most important one that prevents arbitrage, is the length of the settlement process. As pointed out in Chen *et al.* (2018), it takes at least five working days for an investor

[10] In China, only interest rate securities are permitted for short-selling, so that strict arbitrage is impossible.

to sell a bond in the interbank market, and buy another bond in the exchange market. Trades in the opposite direction, though quicker, still take at least two working days.

[Insert Figure 2 here]

3.4 Liberalization: foreign and domestic investors

China has gradually opened its bond markets to foreign institutional investors over the past decade, which witnessed a series of announcements regarding how regulators planned to reform the bond markets. It is, thus, important to identify which announcements had the greatest impact on the changes in the fundamental characteristics of the bond market. Figure 2 presents the timeline of the major policy announcements to be included in the empirical section. In particular, we define the following three subperiods of foreign liberalization in the interbank market:

Phase 1 – limited foreign institutional investors' participation (prior to March 2012)
Phase 2 – foreign central banks' participation (March 2012 ~ May 2016)
Phase 3 – expansion to most foreign institutional investors (May 2016 ~ December 2017)

The two cutoff policy dates, March 2012 and May 2016, are selected because liquidity levels significantly altered around these two dates, as shown in the empirical analyses in Section 7.

Despite the sequence of regulatory changes relating to foreign investors in Figure 2, they held only 1.1% of bonds in the interbank market by June 2017. In July 2017, however, *Bond Connect*, a trading platform that allows offshore investors and mainland China investors to invest in each other's bond markets, was established in Hong Kong. The *northbound* link of this channel, allowing offshore investors to invest in the domestic interbank bond market, was opened on July 3, 2017.[11] One year later, we observe an increase in foreign investors' holdings to 1.9%, a substantial increase of 70%.[12]

Although it was opened much earlier to foreign investors, the exchange market accounts for a small percentage of trading volume, and is often ignored in academic research. However, a sequence of liberalization policy changes in the interbank bond market also pushed forward the development of the exchange counterpart. *The Corporate Bond Issuance and Trading Regulations, File No. 113*, a major policy announcement in January 2015, largely increased the issuance of corporate bonds in the exchange market.[13] Moreover, not only did

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[11] The *southbound* link, which allows mainland China investors to invest in overseas bond markets, however, is yet to be explored, and may be opened at a later stage.

[12] See Figure A1 of the Internet Appendix for the issuance statistics of interbank credit bonds. We observe a steady increase in both the number and amount of credit bonds issued before 2017. The issuance of commercial paper dominates that of medium-term notes and enterprise bonds.

[13] See Figure A1 of the Internet Appendix for the issuance statistics of exchange credit bonds. Before 2015, the issuance of enterprise bonds accounted for almost 90% of the total exchange market issuance. However, after 2015,

it lower restrictions on issuers, offering methods and offering periods for corporate bonds, it simplified issuance approval procedures. More importantly, *unlisted* firms were allowed to issue corporate bonds in the exchange market, which substantially lowered their financing cost and shortened their approval process. We take into account this structural change by defining the following two subperiods in the exchange market, separated by May 2015:[14]

Before 2015 – only listed companies could issue corporate bonds (before May 2015)
After 2015 – unlisted firms could also issue corporate bonds (May 2015 ~ December 2017)

Despite the announcement that unlisted firms would be allowed to issue corporate bonds after January 2015, the first corporate bond issued by an unlisted firm did not occur until May 2015, which defines our break date.[15]

3.5 Subperiods of economic environments

We are interested in how the explanatory power of the independent variables and the statistical significance of the coefficients of these variables change under various phases of liberalization defined in the previous subsection. In addition, we compare the pricing of liquidity effects into credit bond yield spreads during regular market conditions, recession periods and crisis periods, across both markets. We adopt the Organization of Economic Cooperation and Development (OECD) recession indicators for the Chinese economy to define the three recession periods between 2006 and 2017.[16] During our sample period, the Chinese economy also witnessed two major financial crises, the 2008 global financial crisis and the 2015 Chinese stock market crash, which we further classify as crisis periods. Regular market periods are defined as the complement of the joint recession periods. We anticipate liquidity effects to be more pronounced during crises and recessions than during regular market conditions.

4 Hypotheses

In this section, we present an overview of the research questions that we pose, and the hypotheses that we test in our empirical research. In particular, we examine the validity of

we observe a drastic increase in the issuance of corporate bonds, doubling that of enterprise bonds, which became a less favored financing vehicle by private companies.

[14] See Chen *et al.* (2019a) for a detailed description of the major policy announcements in the exchange market.

[15] Zhoushan Port (Group) Co., Ltd. issued corporate bond "15 舟港债" on May 22, 2015, as the first unlisted firm in the exchange market. The bond has an issuance amount of 700 million RMB and a maturity of five years.

[16] The first recession period covers December 2007 to February 2009, the second recession period covers August 2011 to November 2012, and the third recession period covers January 2014 to September 2016.

specific arguments regarding the levels of liquidity of different credit bond segments and the impact of these liquidity effects on bond yield spreads.

Hypothesis 1: *The level of liquidity in the exchange credit bond market is higher than in its interbank counterpart. These levels were altered significantly by major policy announcements in the two markets.*

The Chinese credit bond markets are illiquid and largely segmented, which makes it interesting to explore whether the levels of liquidity in the various credit bond segments respond significantly to major policy shocks. If they do, particularly in the interbank market, it would show that government policies can significantly affect the levels of liquidity in the Chinese credit bond markets, despite the fact that the interbank market has been experiencing liberalization at a very gradual pace, and has a relatively small percentage of foreign institutional holdings. Moreover, we conjecture that the level of liquidity in the exchange credit bond market is higher, due to the speculative nature of its market participants, who are mostly retail investors.

Hypothesis 2: *Liquidity effects are priced more strongly into bond yield spreads in the exchange credit bond segments than in their interbank counterparts.*

Investors with different trading horizons have different expected returns, after taking into account the transactions costs over their respective horizons. This phenomenon translates into a clientele effect whereby less liquid assets are held by long-term investors, and are cheaper than more liquid ones, due to the liquidity premium reflected in their bond yields, as argued by Amihud and Mendelson (1986). It is also documented in the literature that market frictions such as search costs, inventory holding costs, and the relative bargaining power of buyers and sellers are reflected in equilibrium bond prices, whereby liquid bonds earn a lower expected return than illiquid bonds, after controlling for other factors known to affect bond yield spreads (see Duffie, Garleanu, and Pedersen (2007) and Jankowitsch, Nashikkar, and Subrahmanyam (2011)).

The Chinese credit bond market is especially interesting in this regard, as severe market segmentation drives the large variation in the levels of liquidity, and the differences in the pricing of liquidity effects across individual bonds also seem to be rather pronounced. Indeed, the trading frequency of credit bonds in China is low, as compared to the U.S. corporate bond market, and a large proportion of credit bonds is seldom traded. In addition, trading in the Chinese credit bond markets involves much higher costs due to greater trading frictions, compared to the corporate bond market in the U.S., as described in Section 3.3. Thus, we would expect a significant liquidity premium, as argued in Amihud and Mendelson (1986), and also that our aggregate liquidity measure can explain a significant portion of credit bond yield spreads. Our aim is to quantify these liquidity effects as a price factor and examine their variation across distinct credit bond segments. Following *Hypothesis 1*, we further conjecture that liquidity effects are stronger in the exchange credit bond market than in the interbank counterpart, due to the presence of speculative retail investors.

Hypothesis 3: *Liquidity effects are more pronounced during more stressed market environments. In a similar vein, foreign liberalization and domestic innovation in the bond markets also improved the extent to which liquidity is priced into yield spreads.*

This hypothesis is motivated by the fact that capital constraints become more binding and search costs rise drastically during crisis periods, as documented by Friewald, Jankowitsch and Subrahmanyam (2012) in the United States. In particular, we analyze liquidity effects for three different economic environments, including regular periods, recession periods and crisis periods. We expect liquidity effects to be more pronounced during crises than during normal periods, and more pronounced during recessions than during expansionary periods. Moreover, even after the interbank bond market was opened to foreign investors, its constraints, such as complex approval procedures and limited investment quotas, have largely hindered the participation of foreign investors. Although foreign investors' participation in China may be modest compared to developed markets, it would still be interesting to examine whether the slow pace of liberalization, and the low percentage of foreign investment, have significantly affected the levels of liquidity. We expect that liberalization policies improved the pricing of liquidity effects into credit bond yields in China. We test this issue rigorously by conjecturing that liquidity is a significant pricing factor in the pricing of credit bond yield spreads. We speculate that the degree to which liquidity is priced into yield spreads varies during different phases of liberalization and cyclical economic conditions.

Hypothesis 4: *Liquidity effects are stronger for credit bonds with shorter time-to-maturities, those issued by firms with lower credit ratings, and those rated by private rating agencies.*

First, credit bonds nearing maturity are usually less frequently traded than those with longer remaining maturities, because investors tend to hold them to maturity. Therefore, we expect that credit bonds with shorter-term maturities would be less liquid. On the other hand, credit bonds with long maturities are often on-the-run bonds, and are more frequently traded than off-the-run bonds that are near maturity, which receive much less attention from investors, who, in turn, have less incentive to trade them. Second, bonds issued by more credit-constrained firms usually have lower liquidity due to smaller demand from investors. This makes it more costly to trade such bonds. Last, investors tend to believe that state-owned credit rating agencies are more trustworthy than private rating agencies. As a result, we expect investors to prefer credit bonds rated by state-owned rating agencies to those rated by private rating agencies. We expect it to be more costly to demand liquidity for credit bonds rated by private rating agencies.

5 Data

In this section, we present the unique dataset that we have assembled for this paper. Our dataset contains two major segments: the primary market segment, which covers the issuance statistics of all types of bonds issued in the interbank and the exchange primary markets; and, the secondary market segment, which covers all end-of-day transactions from all types of bonds in the interbank and the exchange secondary markets.[17] We focus on all credit bonds that are actively traded in the two venues: enterprise bonds, corporate bonds, medium-term notes, and commercial paper.[18] We also use the yields to maturity of government bonds, in both the exchange market and the interbank market, to bootstrap the zero-coupon rates (de-couponed rates) in each market, as a robustness check to the alternative use of coupon-implied government bond yields as the risk-free rates, an industry convention. Recall that the source of the dataset is CFETS, an arm of the PBOC, which functions in a manner similar to the FINRA-developed platform, TRACE, which has been instrumental in facilitating the mandatory reporting of secondary market transactions in the U.S.[19]

5.1 *Composition and Processing*

Our dataset contains two subsets and covers a period of 12 years, from January 2006 to December 2017. The first subset contains fundamental bond characteristic variables, many of which are frequently used as simple liquidity proxies in the literature. The second subset contains detailed information about all end-of-day bond transactions, including daily trading volume, highest and lowest traded prices (clean and dirty), opening and closing prices (clean and dirty), and yield to maturity based on the closing dirty price, all of which are widely utilized in the literature on bond market liquidity.

Due to the data regulations of the People's Bank of China (PBOC), CFETS is only permitted to provide end-of-day transaction data. In other words, whether a bond is traded once or more than once during a day, it appears only once as a bond-day observation in our data set. As a result, we only know which bonds are traded during a given day, but cannot discern how many times each bond was traded on that day. This restriction certainly poses some serious challenges to our study, such as constructing certain trade-based liquidity measures, since detailed trading information during each trading day of each traded bond is not available. However, these are the best data available for the Chinese bond market, and

[17] Our dataset includes data on government bonds, local-government bonds, credit bonds, financial bonds, etc., though we focus on credit bonds in this paper.

[18] Sovereign bonds will be examined in a companion paper. Note also that our categorization of corporate credit bonds can differ from that in other academic research. We will point out these differences, as appropriate.

[19] To the best of our knowledge, we are the first to receive formal authorization from CFETS to use this dataset for academic research.

we have to conduct our research in the presence of this constraint. We, therefore, employ a complex filtering procedure, which is described in Appendix A, to process the data, and ensure the soundness of our final dataset.

One of the key variables employed in our study is the yield to maturity. However, in the early years of our dataset between 2007 and 2009, quite a few data points for the yield to maturity are missing for all types of bonds. We fill in the missing data points of yield to maturity by following the instructions in the official document issued by the PBOC.[20] Moreover, the volume-weighted yield for each week is calculated as

$$y_{it} = \left(\sum\nolimits_k Q_{it}^k\right)^{-1} \sum\nolimits_k y_{it}^k \times Q_{it}^k$$

where y_{it} is the volume-weighted yield of bond k in week t, y_{it}^k is the yield corresponding to day k of bond k in week t, and Q_{it}^k is the volume of day k in week t. In our analysis, we bootstrap the coupon-implied policy bank bond yields and use the resulting rate as a proxy for the risk-free rate. We also apply the three-factor Nelson-Siegel model to generate the entire risk-free yield curve, so that credit bond yields at any maturity can be matched with the respective risk-free rate, to construct the corresponding bond yield spread.[21]

5.2 *Bond rating quantification*

Similar to bond ratings in the U.S., bonds with a higher default risk are given lower ratings, in principle.[22] Bonds in China are mostly rated by eight credit rating agencies: Shanghai Brilliance & S&P (上海新世纪资信评估投资服务有限公司), China Chengxin & Moody's (中诚信国际信用评级有限责任公司), China Linahe & Fitch (联合资信评级有限公司), Dagong Global (大公国际资信评估有限公司), China Chengxin (中诚信证券评估有限公司), China Orient (东方金诚国际信用评估有限公司), China Lianhe (联合资信评级有限公司), Pengyuan (鹏元资信评估有限公司). The first three credit rating agencies have global partnerships with S&P Global, Moody's Corporation and FitchRating, respectively. Their credit ratings are similar to those of Standard and Poor's (S&P).[23] In China, bonds with ratings below 'BBB' are considered as speculative-grade bonds, while bonds that have ratings equal to or above 'BBB' are considered as investment-grade bonds. To control for credit risk differentials, prior

[20] See Item A2 of the Internet Appendix for the details of completing missing data points of yield-to-maturity.
[21] See Item A3 and Item A4 of the Internet Appendix for details of "de-couponing" government bond yields and generating zero curves.
[22] See Table A2 of the Internet Appendix for the summary statistics of distribution of ratings for the five credit bonds combined, including credit migration during a bond's life span.
[23] Although the nomenclature of the ratings appears similar to those of the major U.S. (international) credit rating agencies – S&P, Moody's, and Fitch – the credit risk implied by the ratings is quite different. In general, the Chinese ratings imply greater credit risk than their U.S. counterparts, for each rating category.

researchers such as Friewald, Jankowitsch and Subrahmanyam (2012) quantify the ratings by creating a measure called "Rating Number", being multiples of 1, i.e., AAA = 1, AAA- = 2, AA+ = 3, etc. This, however, is valid if and only if we assume that: (1) all rating agencies have the same rating criteria (i.e., if a bond is given a rating x by rating agency 1, it receives the same rating x from all other rating agencies); and (2) the credit differential between two adjacent ratings is approximately equal. To circumvent this problem, we create a dummy variable for each rating. For instance, an indicator measure for "AAA" is assigned one if the bond is rated "AAA," and zero otherwise. This approach gives us the most degrees of freedom to map from ratings to explanatory variables and eases the concern that assigning a specific number to each credit rating with linearized rating differences may be too restrictive. In addition to controlling for bond credit ratings in the empirical analyses, we also include dummy variables for rating agencies, to control for rating agency-specific effects, and for credit enhancement, to control for the variation between issuers' ratings and the ratings of their respective bond issuance.

[Insert Figure 3 here]

Figure 3 displays graphically the distribution of ratings for the five types of credit bonds in the two markets, after the filtering procedure described in Appendix A. We observe that almost all traded bonds traded have a rating above or equal to 'AA-'. The total number of bonds traded in the interbank market is approximately six times larger than that in the exchange market, which again shows that the former is the dominant market of the two. We also observe a vast decrease in the number of bonds traded in the exchange market, with corporate bonds declining about 20% and enterprise bonds declining nearly 65%, due to early redemption before maturity in the exchange market. These bond transaction records are discarded through our filtering procedure.

5.3 *Explanatory variables*

Along the lines of Friewald, Jankowitsch and Subrahmanyam (2012), the explanatory variables in this paper are classified into three groups: *bond characteristic variables, trading activity variables,* and *liquidity metric variables.* In addition, we present the specifications of our panel data regressions to explore the time-series properties of our dataset.[24]

Bond characteristic variables include *coupon*, *duration*, *maturity*, and *age*. Although these are crude indicators of the liquidity levels of bonds, they do provide some intuitive sense of the information conveyed by basic bond features about potential liquidity. In general, we expect bonds with longer maturities to be less liquid because they are often purchased by "buy-and-hold" investors with medium- to long-term objectives, bonds with higher coupons

[24] See Table A3 of the Internet Appendix for the cross-sectional descriptive statistics of the explanatory variables.

to be more liquid due to demand from income-seeking investors, and on-the-run (recently issued) bonds to be more liquid than off-the-run bonds. However, these measures are mostly used for cross-sectional comparisons, as many of them exhibit little variation over a short period. Trading activity variables include *daily trading volume*, *trading interval*, *zero-return measure*, and *zero-trade measure*. They provide information about liquidity based on bond transaction details, with higher trading activity generally indicating greater liquidity. In addition to *daily trading volume*, which is provided in the raw data set, we create three additional variables: *trading interval*, *zero-return*, and *zero-trade*. For a particular bond, *trading interval* is defined as the number of days between two consecutive trades; if the bond is not traded on a given day, its trading interval on that day is assigned "NA". The *zero-return measure* for a bond on a given day is an indicator variable that is assigned one, if there is price variation on that day (the highest dirty price is different from the lowest dirty price), and is assigned zero, otherwise. The *zero-trade measure* for a bond in a week is defined as the number of days in the week that the bond is not traded divided by five, the number of trading days in most weeks. Liquidity measures used in this paper include the price-impact *Amihud ratio* in Amihud and Mendelson (1986), the search-based *price dispersion measure* in Jankowitsch, Nashikkar and Subrahmanyam (2011), the *high-low spread estimator* in Corwin and Schultz (2012), the *interquartile range estimator* in Han and Zhou (2007), and the *CHL estimator* in Abdi and Ranaldo (2017). Definitions of these liquidity proxies are provided in Appendix B.

5.4 *An aggregate liquidity measure and its validity*

We develop an aggregate liquidity measure, which we term as "*Liquidity PC*", defined as the first principal component of the aforementioned five liquidity proxies. The reasons for us to adopt this measure in the Chinese credit bond market are manifold. First, bond markets in China are still in a nascent state, with trading rules and regulations that continue to be refined. This renders some liquidity measures that were proven to work well in more liquid markets unable to deliver the expected results in the Chinese context, which is usually characterized by low trading frequency, despite the large size of the market, in terms of outstanding amounts. Second, the transaction data that we obtain from CFETS are not tick-by-tick, which means that some of the intra-day trading information is not captured by our dataset. This inevitably generates noise in our end-of-day transaction records, even after we aggregate them on a weekly basis. Third, while every single liquidity measure captures a certain dimension of liquidity, no single liquidity measure is able to capture the overall level of liquidity in a particular bond market. In other words, the information that one liquidity measure can reflect in the market is largely limited, especially when the market, such as the Chinese bond markets, is extremely illiquid. It is entirely possible that a subset of liquidity proxies works well to capture liquidity variation for one particular type of credit bond, while another subset of liquidity proxies works better to capture liquidity variation for another type of credit bond. Extracting the first principal component, thus, enables us to obtain as much information from the *set* of liquidity proxies as possible, while avoiding the inclusion of noisy information when all individual liquidity proxies are individually included in the model.

Table 1 presents the correlations between the variables of interest and *Liquidity PC*. First, we observe consistent negative correlations between *Trading PC* and *Liquidity PC*, with the correlations in the exchange market being consistently lower than those in the interbank market. Second, we are also interested in how each principal component correlates with each of its constituents. *Trading PC* has the anticipated negative signs of correlation with its constituents, *Zero-return*, *Zero-trade* and *Interval*, except for its negative correlations with the *Volume* variable in the exchange market, although relatively small. This can be largely explained by the much more volatile, speculative, and noisier trading behavior of retail investors in the exchange market. We confirm that *Liquidity PC* can be used as a proxy for liquidity by checking that it has negative correlations with its constituents, *Amihud*, *Price dispersion*, *HL-spread*, *IQR*, and *CHL*, which are well-known illiquidity measures. Indeed, *Liquidity PC* does have consistent negative signs of correlation with its constituents for all credit bond segments. The above findings justify the use of *Trading PC* and *Liquidity PC* as appropriate measures of trading activities and liquidity.

[Insert Table 1 Here]

5.5 *Data-based yields to maturity*

Before proceeding to the empirical results, we compute the weekly volume-weighted yields to maturity for each type of bond in the two markets. We also compare the difference in the yields to maturity between enterprise bonds in the interbank market and the comparable bonds in the exchange market, by pooling the daily observations in the two markets into 13 fixed maturity buckets.[25] Table 2 presents the cross-sectional descriptive statistics of the mean, standard deviation, minimum, maximum, median value, and 25th and 75th percentile for the yields to maturity of each bucket. Since the traded bonds in our dataset include less than 1% of all bonds with maturities longer than 10 years, we omit them from the summary statistics, and present the descriptive statistics of bonds with maturities less than or equal to 10 years. For bonds with multiple trades in one week, we estimate the yields from individual daily transactions by computing a volume-weighted average for that week. For each bucket, we calculate the cross-sectional descriptive statistics for each week, and report the time-series average of each statistic.

[Insert Table 2 Here]

[25] The 13 maturity buckets have mean maturities (in years) of 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, 8, 9, and 10. See Figure A2 of the Internet Appendix for plots of volume-weighted yields to maturity by rating categories for each credit bond.

In the interbank market, for medium-term notes, the average yields increase with maturity monotonically from 4.77% to 5.20%, although the annual increments are small. However, for enterprise bonds, yields peak at medium-term maturities (up to 6.16%), and then gradually decrease to 5.6%. In the exchange market, yields again peak at medium-term maturities for both enterprise bonds and corporate bonds. A cross-market comparison of enterprise bonds indicates a lower average yield for maturities less than five years, and a higher average yield for maturities of six years or more. A cross-market comparison of corporate bonds indicates that there exists a virtually uniform yield difference between the two markets, with the exchange-traded corporate bonds having a consistently higher average yield than their counterparts do, except for the last two buckets.

6 Empirical Design and Results: Part I

This section outlines the examination of *Hypothesis 1* and *Hypothesis 2*. First, we explore the time-series properties of the levels of liquidity. We then present our empirical design to explore how the levels of liquidity respond to various government interventions, including foreign liberalization and domestic regulation in the interbank market, and domestic innovation in the exchange market, followed by our empirical results. Second, we present our empirical design to study liquidity effects as a price factor, again followed by the respective empirical results.

6.1 Levels of liquidity

Figure 4 displays the levels of liquidity of the five credit bond segments in the Chinese markets. For exchange-traded corporate bonds, we observe a strong increase in the overall level of liquidity since 2014, preceded by a gradual decrease in liquidity since 2009. The former improvement is attributed to the policy announcement that allowed unlisted companies to issue corporate bonds in the exchange market in January 2015, which also led to a sharp increase in the number of bonds traded in 2015 (Chen *et al.*, 2019a). There has been no major policy announcement targeted at enterprise bonds in recent years and, indeed, we observe no perceptible change in their level of liquidity, except for a slight increase since 2016. We ascribe this improvement to a liquidity spillover from the vast increase in the trading activity of corporate bonds within the exchange market into the interbank market. In the interbank market, we observe a steady increase in liquidity for both enterprise bonds and medium-term notes, immediately after the 2008 financial crisis, due to the stimulus program from the Chinese government to boost the economy in its aftermath. Immediately following the introduction of 18 RMB-qualified foreign institutional investors (RQFIIs) in March 2012 (*purple bar*), the removal of quota limits and approval procedures for foreign central banks (*orange bar*) and the allowance of almost all foreign institutional investors to join (*red bar*), we observe a slight increase in the levels of liquidity of enterprise bonds and medium-term notes.

6.2 *Levels of liquidity around government interventions*

To test this formally, we perform a panel regression to analyze how the levels of liquidity in each credit bond segment change after several major policy shocks in the Chinese credit bond market. For interbank market policy announcements, we consider three foreign liberalization shocks (March 2012, July 2015 and May 2016)[26]. For exchange market policy announcements, we consider one domestic innovation shock (January 2015). Considering the illiquid nature of the Chinese credit bond markets, we select a two-month window frame, one month before and one month after the policy date, in this regression. The dependent variable is the first principal component of liquidity measures, and the independent variable is the dummy variable that is assigned one, if the observation comes from post policy data, and zero, otherwise:

$$(\text{Post Policy})_{i,t} = \begin{cases} 1 & t > \text{policy date} \\ 0 & t \leq \text{policy date} \end{cases} \tag{1}$$

We now investigate whether the levels of liquidity have significantly altered after each policy announcement by performing the regression:

$$(\text{Liquidity PC})_{i,t} = a_0 + a_1(\text{Post Policy})_{i,t} + \varepsilon_{i,t} \tag{2}$$

We control for bond fixed effects and monthly fixed effects. The bond rating, rating agency and credit enhancement dummies are included as independent variables.

Table 3 displays the empirical outputs for the six policy shocks in the two markets. First, the coefficient of *Post Policy Dummy* for medium-term notes is positive and significant for all three foreign liberalization shocks in the interbank market, indicating that liquidity did improve immediately after the announcements. However, the coefficient of *Post Policy Dummy* for enterprise bonds exhibits significant variation, and is only significant and positive for the last liberalization shock. We even observe a large short-term decline in liquidity for 0.120 unit after the March-2012 policy. This shows that this initial liberalization policy had the opposite impact on the levels of liquidity in the interbank market. The interbank enterprise bonds segment, much smaller compared to medium-term notes segment, was negatively affected when large RQFIIs entered the Chinese bond markets. For each shock, the level of liquidity of medium-term notes improved more than that of enterprise bonds, even

[26] See Figure 2 for the details of each policy announcement in the interbank market.

though the improvement in the levels of liquidity for both credit bond segments improved over the three shocks.

Second, for the domestic innovations in the exchange market, not only do we observe a significant improvement in the level of liquidity of 0.122 unit in the corporate bond segment, but also we observe an even stronger liquidity improvement of 0.155 unit in the enterprise bond segment. Despite the long-term decline in the enterprise bond trading volume, the short-term increase immediately after the policy shock was potentially caused by the massive sell-off of enterprise bonds as speculative exchange market investors anticipate that corporate bonds would gain favor in the near future. This dramatically improved the liquidity of enterprise bonds in the exchange market. Interestingly, interbank liquidity has also improved significantly after the shock, indicating a strong liquidity spillover from the exchange market to the interbank, as large institutional investors reacted quickly to such crucial innovations.

[Insert Table 3 here]

As a robustness check, we also perform the *sup-F* test to detect endogenously the break date by letting the data to speak for themselves. Briefly, this test corresponds roughly to a modified Chow (1960) test, with changing break points and sub-periods. In other words, while in the Chow test, the date of structural change break is pre-specified, the *sup-F* test leaves the structural break date unknown, *a priori*, and endogenously detects the date that is most likely to constitute a structural change in liquidity. This date is identified as the date with the largest Chow test-statistic, and the presence of a structural break is tested by comparing that date's test statistic with a non-standard distribution. More specifically, this *sup-F* test performs a Chow test for the relation in the above regression equation for each week in the data sample. If the null hypothesis of "no-structural-break" can be rejected, the date with the largest Chow test statistic is selected as the structural break date. To implement this test, for each policy announcement, we divide the overall sample period into two sub-periods: the first one covers a one-year period before the announcement date, and the second one covers a one-year period after the announcement date. Ideally, we expect to see a structural change in liquidity level around, slightly before, or after the announcement date.

We regress liquidity on time and verify that the structural changes in liquidity did indeed occur around the six policy announcement dates. As expected, all of the detected structural break dates are significant at the 1% level. These dates are identified purely based on the statistical evidence, and the dates with the highest Chow test statistics either coincide exactly with, or are very close to, the actual policy dates. Our evidence suggests that policy announcements in the credit bond markets do significantly alter the levels of liquidity.[27]

[27] See Figure A3 of the Internet Appendix for the results of the structural break test in the interbank market around the three foreign liberalization shocks.

6.3 *Liquidity as a priced factor*

We next rely on a panel data regression approach to analyze bond yield spreads. Our panel consists of the pooled time-series of bond yield spreads as the dependent variable and bond characteristic variables, the first principal component of liquidity measures, the VIX measure, a macro risk metric, and a group of control variables as independent variables. The set of control variables include *Trading PC* and the dummy variables: *economic condition*, *bond rating*, *rating agency* and *credit enhancement*. We also control for yearly fixed effects. To overcome the problem of heteroscedasticity and serial correlation, we apply a Newey-West correction to our model. We adopt two regression specifications, as shown in Table 5, which allow us to identify the incremental explanatory power of *Liquidity PC*. The full model is Model 3 and is performed in the following structure:

$$\begin{aligned}(\mathrm{YS})_k = a_0 + a_1\mathrm{Maturity}_k + a_2\mathrm{Maturity}_k^2 + a_3\mathrm{Age}_k + a_4\mathrm{Issuance}_k + a_5\mathrm{Coupon}_k \\ + a_6\mathrm{VIX}_k + a_7(\mathrm{Liquidity\ PC})_k + \boldsymbol{a_8}\cdot(\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k\end{aligned} \tag{3}$$

Subscript k denotes the k^{th} bond-week observation in our panel dataset, and superscript s varies from one to S, where S is the number of distinct credit ratings. The variable of interest here is *Liquidity PC*. A significant positive (negative) coefficient of *Liquidity PC* would indicate that greater (lower) liquidity should be compensated by a lower (higher) bond yield spread. We also examine the roles of the relative increase and the absolute increase in the model explanatory power, measured by *R-squared*, by comparing the specification in equation (3) with the specification in equation (4), with the exclusion of *Liquidity PC* during different market conditions.

$$\begin{aligned}(\mathrm{YS})_k = a_0 + a_1\mathrm{Maturity}_k + a_2\mathrm{Maturity}_k^2 + a_3\mathrm{Age}_k + a_4\mathrm{Issuance}_k + a_5\mathrm{Coupon}_k \\ + a_6\mathrm{VIX}_k + \boldsymbol{a_7}\cdot(\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k\end{aligned} \tag{4}$$

Table 4 presents the panel regression results of regression equation (3). Each panel contains two empirical specifications. Model 4 includes only bond characteristic variables and controls, and is a baseline case used to compare Model 3 against, and to explore the increase in explanatory power after including *Liquidity PC*. All the coefficients of *Liquidity PC* are negative and statistically significant at the 1% level, indicating that higher liquidity in the market is indeed compensated for with lower yield spreads. For the exchange enterprise segment, a one standard deviation increase in liquidity leads to a decline of 12.35 bps in the yield spread, which is more than triple that of the corresponding 3.54 bps decline in the interbank enterprise segment. For exchange-traded corporate bonds, a one-unit increase in liquidity leads to a decline of 22.09 bps in the yield spread, which is five times that of the 3.88 bps decline for medium-term notes. Thus, a cross-market comparison tells that liquidity effects are more strongly priced into the yields of exchange credit bonds than interbank credit bonds. This shows that yield spreads are more sensitive to liquidity effects in the exchange market than in the interbank markets. Moreover, a within-market comparison shows that liquidity effects are priced more strongly into the corporate bond yield spreads than in the enterprise counterpart. This shows that corporate bond yield spreads are more sensitive to changes in liquidity than enterprise bond yield spreads in both markets.

In terms of *R-squared*, as we move from Model 4 to Model 3, we find a relative improvement of 1.27% and 2.63%, respectively, for the two credit bonds in the exchange market. For enterprise bonds and medium-term notes in the interbank, the relative improvements are 0.17% and 0.42%, respectively. This shows that liquidity effects explain a much larger variation in bond yield spreads in the exchange market than in the interbank market, and complies with the above findings. Within each market, the impact of liquidity effects of corporate bonds also dominates that of enterprise bonds. This is understandable as the corporate segment always dominates the enterprise segment in both markets, in terms of both trading volume and the number of bonds traded. Overall, liquidity is an important priced factor driving yield spread variation in the Chinese credit bond markets. Liquidity effects explain a fair proportion of the bond yield spreads in levels.

[Insert Table 4 Here]

Table 5 compares the explanatory power (*R*-squared) of Model 3 and Model 4 under different economic conditions, where we assess the incremental explanatory power of liquidity effects in yield spreads. For the interbank market, it is clear that both the absolute increase and the relative increase in *R*-squared are much higher during crises than during regular market conditions and recessions. On the other hand, liquidity effects are the most pronounced during recessions for exchange credit bonds, while they are the most pronounced during crises for interbank credit bonds.

[Insert Table 5 Here]

7 Empirical Design and Results: Part II

This section outlines the examination of *Hypothesis 3* and *Hypothesis 4*. We present our empirical design to address each hypothesis, followed by the respective regression outputs.

7.1 Market liberalization

In this section, we explore the first part of *Hypothesis 3,* and study how liquidity effects change during *Phase 1*, *Phase 2*, and *Phase 3* of the liberalization process in the interbank market, and before and after May 2015 in the exchange market. We conjecture that liquidity became a more significantly priced factor after more foreign investment took place in the interbank market, and after unlisted firms were allowed to issue exchange-traded corporate bonds after May 2015 in the exchange market. To test this hypothesis, for interbank credit bonds, we run the specification in equation (5), and for exchange credit bonds, we run the specification in equation (6).

$$\begin{aligned}(\mathrm{YS})_k = {} & a_0 + a_1\mathrm{Maturity}_k + a_2\mathrm{Maturity}_k^2 + a_3\mathrm{Age}_k + a_4\mathrm{Issuance}_k + a_5\mathrm{Coupon}_k \\ & + a_6\mathrm{VIX}_k + a_7(\mathrm{Liquidity\ PC})_k + a_8(\mathrm{P2})_k + a_9(\mathrm{P2})_k \times (\mathrm{Liquidity\ PC})_k \\ & + a_{10}(\mathrm{P3})_k + a_{11}(\mathrm{P3})_k \times (\mathrm{Liquidity\ PC})_k + \boldsymbol{a_{12}} \cdot (\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k \end{aligned} \tag{5}$$

$$\begin{aligned}(\mathrm{YS})_k = {} & a_0 + a_1\mathrm{Maturity}_k + a_2\mathrm{Maturity}_k^2 + a_3\mathrm{Age}_k + a_4\mathrm{Issuance}_k + a_5\mathrm{Coupon}_k \\ & + a_6\mathrm{VIX}_k + a_7(\mathrm{Liquidity\ PC})_k + a_8(\mathrm{Post\ 2015})_k \\ & + a_9(\mathrm{Post\ 2015})_k \times (\mathrm{Liquidity\ PC})_k + \boldsymbol{a_{10}} \cdot (\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k \end{aligned} \tag{6}$$

In Model 5, *P2* (*P3*) is a dummy variable that is equal to one, if the observation comes from *Phase 2* (*Phase 3*), and is equal to zero, otherwise. Our aim here is to quantify the relative change in the pricing of liquidity of interbank credit bonds during *Phase 2* and *Phase 3*, compared to *Phase 1*, by examining the coefficients of (*Phase 2*) × (*Liquidity PC*) and (*Phase 3*) × (*Liquidity PC*). In Model 6, *Post 2015* is a dummy variable that is equal to one, if the observation falls after May 25, 2015, and is equal to zero, if it falls before that date. A similar aim applies to Model 6.

[Insert Table 6 Here]

Table 6 presents the regression outputs from these specifications. In the interbank market, the coefficients of (*Liquidity PC*) × (*Phase 2*), −0.018 and −0.038, are negative and statistically significant at the 1% critical level for both credit bond segments, showing that liquidity effects are priced more strongly into interbank credit bond yield spreads during more liberalized regimes. In other words, the impact of a one standard deviation change in liquidity on yield spreads was stronger during *Phase 2* than during *Phase 1*. Moreover, the coefficients of (*Liquidity PC*) × (*Phase 3*), −0.018 and −0.049, are significant for both credit bond segments, showing an increase in the sensitivity of yield spreads to liquidity effects, after medium to small foreign institutional investors entered the interbank market. The fact that the coefficient of (*Liquidity PC*) × (*Phase 3*) is only significant at the 10% level, and is roughly equal to the coefficient of (*Liquidity PC*) × (*Phase 2*) for enterprise bonds, shows no significant improvement in the pricing of liquidity effects. In addition, the two coefficients for medium-term notes are larger in magnitude and statistical significance than those of enterprise bonds, showing that it became more costly to demand liquidity in the corporate segment than in the enterprise counterpart. In the exchange market, the coefficients of (*Liquidity PC*) × (*Post 2015*), −0.218 and −0.066, are negative and statistically significant at the 1% level for both enterprise and corporate bonds, showing that liquidity effects became more pronounced after the domestic innovation shock in the exchange primary market. The fact that the coefficient of (*Liquidity PC*) × (*Post 2015*) for enterprise bonds has a magnitude of 0.218, triple that of the coefficient, 0.066, for corporate bonds, indicates that the liquidity effects are much higher for enterprise bonds than for corporate bonds, for a one standard deviation of change in liquidity.

7.2 The Changing Economic environment

We now explore whether liquidity effects are stronger during periods of recession and financial distress, conjectured in *Hypothesis 3*. We perform this investigation by considering different economic environments in China, including regular economic periods, recession periods and crisis periods, as defined in Section 3.6, and run the specification in equation (7).

$$\begin{aligned}(\text{YS})_k = {} & a_0 + a_1\text{Maturity}_k + a_2\text{Maturity}_k^2 + a_3\text{Age}_k + a_4\text{Issuance}_k + a_5\text{Coupon}_k \\ & + a_6\text{VIX}_k + a_7(\text{Liquidity PC})_k + a_8(\text{Recess})_k + a_9(\text{Recess})_k \times (\text{Liquidity PC})_k \\ & + a_{10}(\text{Crisis})_k + a_{11}(\text{Crisis})_k \times (\text{Liquidity PC})_k + \boldsymbol{a_{12}} \cdot (\textbf{Controls})_{\boldsymbol{k}} + \varepsilon_k \qquad (7)\end{aligned}$$

We expect to observe more pronounced liquidity effects during recessions and crisis periods, as was found in the literature on the U.S. and the European bond markets.[28] In Model 7, *Recession* (*Crisis*) is a dummy variable that is equal to one, if the observation comes from the recession periods (crisis periods), and zero, otherwise. Our aim here is to quantify the relative change in the pricing of liquidity among credit bonds during recessions and crises, compared to regular market periods, by examining the coefficients of (*Recess*) × (*Liquidity PC*) and (*Crisis*) × (*Liquidity PC*).

[Insert Table 7 Here]

Table 7 displays the regression outputs. The coefficients of (*Liquidity PC*) × *Recession* and (*Liquidity PC*) × *Crisis* are negative and statistically significant in all credit bond segments, except for the exchange enterprise segment. This shows that, in general, liquidity effects are more pronounced during recessions than during regular market periods, and during crises periods then during recessions. Moreover, the coefficient of (*Liquidity PC*) × *Crisis* is uniformly larger in magnitude than that of the corresponding recession cross-term, indicating that yield spreads are more sensitive to liquidity effects during crises than during recessions. The exchange enterprise segment, being the smallest of the four, was left almost unaffected during economic downturns, as indicated by the small and insignificant coefficients of the two interaction terms. Again, a within-market comparison tells us that liquidity effects are stronger in the two corporate bond segments than for their respective enterprise counterpart, for a one standard deviation of change in liquidity. This analysis

[28] See, for example, Friewald, Jankowitsch and Subrahmanyam, (2012) for details.

shows that corporate bond yield spreads became more sensitive to liquidity than enterprise bond yield spreads, during more stressful economic conditions.

7.3 *Time-to-maturity*

In this section, we explore the first conjecture of *Hypothesis 4* and study how the pricing of liquidity effects changes as the time-to-maturity of bonds varies. To test this hypothesis, we divide bonds into three time-to-maturity buckets: (1) zero to three years, (2) three to seven years, and (3) seven to ten years. We run the specification in equation (8).

$$
\begin{aligned}
(\mathrm{YS})_k = a_0 &+ a_1 \mathrm{Maturity}_k + a_2 \mathrm{Maturity}_k^2 + a_3 \mathrm{Age}_k + a_4 \mathrm{Issuance}_k + a_5 \mathrm{Coupon}_k \\
&+ a_6 \mathrm{VIX}_k + a_7 (\mathrm{Liquidity\ PC})_k + a_8 (\mathrm{Medium})_k + a_9 (\mathrm{Medium})_k \times (\mathrm{Liquidity\ PC})_k \\
&+ a_6 \mathrm{VIX}_k + a_7 (\mathrm{Liquidity\ PC})_k + a_8 (\mathrm{Medium})_k + a_9 (\mathrm{Medium})_k \times (\mathrm{Liquidity\ PC})_k \\
&+ a_{10} (\mathrm{Long})_k + a_{11} (\mathrm{Long})_k \times (\mathrm{Liquidity\ PC})_k + \boldsymbol{a_{12}} \cdot (\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k \qquad (8)
\end{aligned}
$$

Intuitively, *on-the-run* bonds are traded more frequently than *off-the-run* bonds. Thus, the pricing of liquidity effects into yield spreads for *on-the-run* bonds should be less pronounced than for *off-the-run* bonds. Hence, *Age* has a positive effect on the yield spread, since more recently issued bonds tend to be more expensive, due to their greater liquidity. On the other hand, investors tend to hold bonds that are near maturity to the end, while bonds with longer times-to-maturity are more frequently traded. In Model 8, *Medium-TTM* (*Long-TTM*) is a dummy variable that is equal to one, if the credit bond observation has time-to-maturity between three years and seven years (seven years and ten years), and is equal to zero, otherwise. Our aim here is to quantify the relative change in the pricing of liquidity among credit bond groups with medium and long time-to-maturities, compared to shorter ones, by examining the coefficients of (*Medium*) × (*Liquidity PC*) and (*Long*) × (*Liquidity PC*).

[Insert Table 8 Here]

Table 8 displays the regression outputs. The coefficients of (*Liquidity PC*) × *Medium* and (*Liquidity PC*) × *Long* are mostly positive and statistically significant at the 1% level, except for the negative coefficient of (*Liquidity PC*) × *Medium* in the exchange corporate segment. Moreover, the coefficient of (*Liquidity PC*) × *Long* is larger than that of (*Liquidity PC*) × *Medium,* in all four segments. These findings conform to our conjecture that liquidity effects are less pronounced for bonds with a longer time-to-maturity than those with a shorter time-to-maturity. The only exception is the negative coefficient of (*Liquidity PC*) × *Medium* of corporate bonds, −0.041, which shows that yield spreads are the most sensitive to liquidity effects for corporate bonds with a medium time-to-maturity. A within-market comparison shows that enterprise bond yield spreads respond more strongly to liquidity than do corporate bond yield spreads as the time-to-maturity increases, adjusting for a one standard deviation of change in liquidity. Meanwhile, a cross-market comparison indicates that the yield spreads of exchange market credit bonds are more sensitive to a one standard deviation change in liquidity than are those in the interbank market.

7.4 Issuers' credit quality

In this section, we explore the second conjecture of *Hypothesis 4,* and study how the credit constraints of bond issuers affect the pricing of liquidity effects into yield spreads. To examine this, we interact firm credit ratings with *Liquidity PC,* and examine how the coefficients of the interaction terms vary. We run the specification in equation (9):

$$\begin{aligned}(\mathrm{YS})_k = {} & a_0 + a_1\mathrm{Maturity}_k + a_2\mathrm{Maturity}_k^2 + a_3\mathrm{Age}_k + a_4\mathrm{Issuance}_k + a_5\mathrm{Coupon}_k \\ & + a_6\mathrm{VIX}_k + a_7(\mathrm{Liquidity\ PC})_k \\ & + \sum\nolimits_{(j,\mathrm{FR})\}\in\{(1,AA+),(2,AA),(3,AA-)\}} a_{7+j}(\mathrm{FR})_k \times (\mathrm{Liquidity\ PC})_k \\ & + \sum\nolimits_{(j,\mathrm{FR})\}\in\{(4,AA+),(5,AA),(6,AA-)\}} a_{7+j}(\mathrm{FR})_k + \boldsymbol{a_{14}} \cdot (\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k \end{aligned} \tag{9}$$

Intuitively, investors would prefer credit bonds issued by firms with higher credit ratings (less stringent credit constraints), indicating that the yield spreads of bonds issued by firms with higher credit quality should be less sensitive to liquidity effects. In other words, we should expect yield spreads of bonds issued by firms with lower credit ratings to react more strongly to liquidity. In Model 9, *FR* ∈ {AA+, AA, and AA-} is a dummy variable for the firm credit rating. *FR* takes the value one, if the issuer of the bond has firm rating *FR.* and is equal to zero otherwise. Our aim here is to quantify the *relative* change in the pricing of liquidity among groups of credit bonds issued by firms with firm ratings of 'AA+', 'AA', and 'AA-', compared to 'AAA' firms, by examining the coefficients of (*AA*+) × (*Liquidity PC*), (*AA*) × (*Liquidity PC*), and (*AA*-) × (*Liquidity PC*).

[Insert Table 9 Here]

Table 9 displays the regression output. The coefficient of (*Liquidity PC*) × *FR* becomes more negative as firms become more credit-constrained in almost all cases, except for the coefficient of (*Liquidity PC*) × (*AA*-) in the exchange enterprise segment, which is insignificant. This is due to the fact that the exchange enterprise bond segment is the smallest of the four bond groups in that market , and only a small number of bonds traded in that segment are issued by 'AA-' firms. Thus, we have verified the conjecture that liquidity effects are stronger for credit bonds issued by more credit-constrained firms. Our findings are consistent with the findings in Friewald, Jankowitsch and Subrahmanyam (2012) that speculative grade (higher credit risk) bonds respond more strongly to changes in liquidity.

7.5 *Rating agencies*

In this section, we explore the last conjecture of *Hypothesis 4*, and study how the pricing of liquidity effects into yield spreads is affected by the ownership of credit rating agencies (CRAs). To do so, we interact dummies for the CRA ownership type with *Liquidity PC* and examine how the coefficients of the interaction terms vary. We run the specification in equation (10).

$$\begin{aligned}(\mathrm{YS})_k = {} & a_0 + a_1\mathrm{Maturity}_k + a_2\mathrm{Maturity}_k^2 + a_3\mathrm{Age}_k + a_4\mathrm{Issuance}_k + a_5\mathrm{Coupon}_k \\ & + a_6\mathrm{VIX}_k + a_7(\mathrm{Liquidity\ PC})_k + a_8(\mathrm{Private})_k + a_9(\mathrm{Private})_k \times (\mathrm{Liquidity\ PC})_k \\ & + \boldsymbol{a_{10}} \cdot (\mathbf{Controls})_{\boldsymbol{k}} + \varepsilon_k \qquad (10)\end{aligned}$$

Intuitively, investors would prefer credit bonds rated by government-owned CRAs to bonds rated by private CRAs, as the former are usually considered more independent, and hence more reliable. We, thus, expect credit bonds rated by private CRAs to have lower liquidity. In other words, we should expect it to be more costly to demand liquidity for credit bonds rated by private CRAs. In Model 10, *Private* is a dummy variable of ownership type of rating agencies. It is assigned one, if the traded credit bond is rated by a private CRA, and is equal to zero, otherwise. Our aim here is to quantify the difference in the pricing of liquidity effects between credit bonds rated by government-owned CRAs, and those rated by private CRAs by examining the coefficient of (*Private*) × (*Liquidity PC*).

[Insert Table 10 Here]

Table 10 displays the regression outputs. The coefficient of (*Liquidity PC*) × (*Private*) is uniformly negative and statistically significant at the 1% critical level, for all credit bond segments. This confirms our expectation that bonds rated by private CRAs are less liquid and, hence, their yield spreads are more sensitive to liquidity effects. Interestingly, the coefficient of the interaction term of corporate bonds, −0.042, is half that of enterprise bonds, −0.084, in the exchange market, and so this supposition is also true in the interbank market (MTNs: −0.015 vs. enterprise: −0.03). This shows that, in both markets, the yield spreads of enterprise bonds rated by private CRAs are about twice as sensitive to liquidity effects as those of their corporate counterparts, adjusting for a one standard deviation change in liquidity. A cross-market comparison tells us that liquidity effects of both enterprise bonds and corporate bonds rated by private CRAs in the exchange market bonds are more pronounced than their respective counterparts in the interbank market, adjusting for a one standard deviation change in liquidity. To be specific, investors in the interbank market earn 4.43 bps and 1.82 bps more for enterprise bonds and medium-term notes rated by private CRAs, respectively, while exchange investors are paid 10.17 bps and 5.27 bps more for enterprise bonds and corporate bonds rated by private CRAs, respectively.

8 Conclusion

Over the past two decades, the pricing of liquidity effects into bond yields has received increasing attention from both academic researchers and industry practitioners. This is less true of Chinese bond markets, which have experienced a sequence of policy changes towards liberalization to facilitate foreign investment, and have become the second largest bond market in the world. In this paper, our analyses, based on the most complete dataset on the Chinese credit bond markets currently available, provide a comprehensive description and analysis of liquidity-related issues relating to credit bonds, traded in the two active venues, the interbank market and the exchange market. The primary challenge in studying bond markets in China is that they are less liquid than bond markets in the U.S. and, of course, the corresponding equity markets. In addition, data limitations make constructing more accurate liquidity proxies in the Chinese bond market challenging, particularly since only a very small proportion of credit bonds in China is traded even every few days. Moreover, a substantial proportion of the trading volume occurs in the interbank market, and not in the exchange market, and the most reliable dataset consists only of end-of-day transactions, which may be noisy. To overcome potential biases from individual trading activity variables and liquidity measures, we extract the first principal component from the set of trading activity variables and the first principal component from a set of liquidity measures, which we then examine and verify for their validity as measures of trading activity and liquidity.

Our empirical analyses explore the time-series aspects of the levels of liquidity, the pricing of liquidity, and clientele effects in bond yield spreads. We find that the levels of liquidity and the impact of liquidity effects on bond pricing vary across different categories of credit bonds, and change significantly before and after important foreign liberalization announcements. We find that liquidity responded most strongly to liberalization policies regarding admitting new foreign investors, but only mildly to policies regarding simplifying approval procedures. To confirm our definitions of the sub-periods, a structural break test is also applied to detect endogenously the break dates in each scenario to ensure robustness.

Regarding the pricing of liquidity effects, we find that *Liquidity PC* accounts for up 2.63% of credit yield spreads across the two markets. We also find that liquidity effects became stronger as the interbank market became more liberalized over the past decade, such as bringing in more foreign investors, simplifying approval procedures and increasing investment quotas, and as the exchange market permitted unlisted firms to issue corporate bonds since early 2015. Moreover, we find that the impact of liquidity effects on credit bond prices became stronger during more stressed market conditions. Liquidity effects were the strongest during recessions for the exchange market and during crisis periods for the interbank market. We confirm this finding by exploring the improvement in our models' explanatory power before and after including *Liquidity PC*. Furthermore, after interacting *Liquidity PC* with some dummy variables of interest and including them in the main regression, we find that yield spreads are more sensitive to liquidity effects for bonds with shorter time-to-maturities, for bonds issued by more credit-constrained firms, and for bonds rated by private credit rating agencies.

In light of the analysis in this study, our empirical results are useful for many practical applications in the Chinese credit markets, especially for regulatory policy, risk management, and the pricing of liquidity effects. Most importantly, they provide a broad understanding of the Chinese credit bond markets for bond market asset managers and help advance the global practice of investment management. Since the Chinese credit bond markets are still in a nascent stage of development, and more detailed and robust findings await better data and further research, conclusions drawn from this paper should be interpreted with caution when extended to a broader setting (for example, with regard to financial bonds and government bonds in the two markets). However, the findings in this paper represent a first step towards fully elucidating how the impact of trading behavior and liquidity effects on the pricing of credit bonds in China during the various stages of policy development with respect to liberalization for foreign investors, domestic innovation and regulation, and under different macroeconomic conditions.

References

Abdi, Farshid, and Angelo Ranaldo, 2017, A simple estimation of bid-ask spreads from daily close, high, and low prices, *The Review of Financial Studies* 30 (12), 4437-4480.

Amstad, Marlene, and Zhiguo He, 2018, Handbook on Chinese financial system, Working paper, Chicago Booth.

Amihud, Yakov, 2002, Illiquidity and stock returns: cross-section and time-series effects, *Journal of Financial Markets* 5, 31-56.

Amihud, Yakov, and Haim Mendelson, 1986, Asset pricing and the bid-ask spread, *Journal of Financial Economics* 17, 223-249.

Amihud, Yakov, and Haim Mendelson, 1991, Liquidity, maturity, and the yields on US Treasury securities, *The Journal of Finance* 46, 1411-1425.

Amihud, Yakov, Haim Mendelson, and Lasse Heje Pedersen, 2013, Market liquidity: Asset pricing, risk, and crises, *Cambridge: Cambridge University Press,* 277 p.

Bao, Jack, Maureen O'Hara, and Xing Zhou, 2018, The Volcker rule and corporate bond market making in times of stress, *Journal of Financial Economics* 130 (1), 95-113.

Bao, Jack, Jun Pan, and Jiang Wang, 2011, The illiquidity of corporate bonds, *The Journal of Finance* 66, 911-946.

Corwin, Shane A., and Paul Schultz, 2012, A simple way to estimate bid-ask spreads from daily high and low prices, *The Journal of Finance* 67, 719-760.

Chen, Hui, Zhuo Chen, Zhiguo He, Jinyu Liu, and Rengmin Xie, 2018, Pledgeability and asset prices: Evidence from the Chinese corporate bond markets, Working paper, Chicago Booth.

Chen, Minxia, Joseph Cherian, Jingyuan Mo, Marti G. Subrahmanyam, 2019a, China's credit bond markets: Development and policy issues, Working paper, NYU Stern.

Chen, Minxia, Joseph Cherian, Yuping Shao, Marti G. Subrahmanyam, 2019b, Clientele effects in sovereign bonds: Evidence from the Malaysian cash and repo markets, Working paper, NUS.

Dick-Nielsen, Jens, Peter Feldhütter, and David Lando, 2012, Corporate bond liquidity before and after the onset of the subprime crisis, *Journal of Financial Economics* 103, 471-492.

Diebold, Francis X., and Canlin Li, 2006, Forecasting the term structure of government bond yields, *Journal of Econometrics*, 130, 337-364.

Duffie, Darrell, 2012, Market making under the proposed Volcker rule, Rock Center for Corporate Governance at Stanford University Working Paper, No. 106.

Duffie, Darrell, Nicolae Garleanu, and Lasse Heje Pedersen, 2007, Valuation in over-the-counter markets, *The Review of Financial Studies* 20, 1865-1900.

Duffie, Darrell, and Kenneth J. Singleton, 2012, Credit risk: pricing, measurement, and management, Princeton University Press.

Edwards, Amy K., Lawrence E. Harris, and Michael S. Piwowar, 2007, Corporate bond market transaction costs and transparency, *The Journal of Finance* 62, 1421-1451.

Friewald, Nils, Rainer Jankowitsch, and Marti G. Subrahmanyam, 2012, Illiquidity or credit deterioration: A study of liquidity in the US corporate bond market during financial crises, *Journal of Financial Economics* 105, 18-36.

Friewald, Nils, Rainer Jankowitsch, and Marti G. Subrahmanyam, 2014, Transparency and liquidity in the structured product market, *The Review of Asset Pricing Studies* 7, 316-348.

Han, Song, and Hao Zhou, 2007, Nondefault bond spread and market trading liquidity, Working Paper, Federal Reserve Board.

Hu, Grace Xing, Jun Pan and Jiang Wang, 2018, Chinese capital market: an empirical overview, NBER Working Paper.

Jankowitsch, Rainer, Amrut Nashikkar, and Marti G. Subrahmanyam, 2011, Price dispersion in OTC markets: A new measure of liquidity, *Journal of Banking and Finance* 35, 343-357.

Jiang, Xianfeng, and Frank Packer, 2017, Credit ratings of domestic and global agencies: What drives the differences in China and how are they priced? *BIS Working Papers*.

Livingston, Miles, Winnie P.H. Poon, and Lei Zhou, 2018, Are Chinese credit ratings relevant? A study of the Chinese bond market and credit rating industry, *Journal of Banking and Finance* 87, 216-232.

Liu, Clark, Shujing Wang, K.C. John Wei, and Ninghua Zhong, 2019, The demand effect of yield-chasing retail investors: Evidence from the Chinese enterprise bond market, *Journal of Empirical Finance* 50, 57-77.

Mahanti, Sriketan, Amrut Nashikkar, Marti G. Subrahmanyam, George Chacko, and Gaurav Mallick, 2008, Latent liquidity: A new measure of liquidity, with an application to corporate bonds, *Journal of Financial Economics* 88, 272-298.

Mo, Jingyuan, 2019, Cross-market arbitrage and optimal integration. Working paper, NYU Stern.

Nelson, Charles R., and Andrew F. Siegel, 1987, Parsimonious modeling of yield curves, *The Journal of Business* 60 (04), 473-489.

Vayanos, Dimitri and Jean-Luc Vila, 2009, A preferred-habitat model of the term structure of interest rates, Working Paper, LSE.

Appendix

A Data filters

To ensure that our price/yield estimation is as accurate as possible, we discard suspicious data observations by adopting the following data filtering procedures.

Early redemption filter: Some enterprise bonds and corporate bonds in the exchange market can be partially redeemed prior to maturity. These prices and other transaction information bias our empirical estimation and have to be discarded. We remove the transaction records of a bond if its name contains "PR", which indicates that early redemption of the bond has been initiated.

Extreme information filter: We winsorize the data by removing outliers of dirty price, yield to maturity, and daily trading volume which are below the 0.5^{th} percentile and above the 99.5^{th} percentile of all observations.

Maturity information filter: We remove all bonds with time to maturity less than one month and longer than 10 years.

Trading information filter: We define the trading span of a bond to be the period from the first day of its recorded transaction to the last day of its recorded transaction. We remove the transaction records of a bond if its trading span is shorter than one month. We also remove the transaction records of a bond if the total number of its trading days is less than 10 during its trading span.

Liquidity information filter: For newly constructed liquidity measures that have missing entries, we remove the whole observation.

B Liquidity proxies

The Amihud ratio measures the price impact of trades and is an illiquidity measure, measured on a daily basis in this paper. Note that only daily total trading volume is available, rather than per-trade trading volume. The former is used to compute the Amihud measure, given by $|r_t|/V_t$. A low Amihud measure would indicate high liquidity. To compute the Amihud measure on a weekly basis, for each end-of-day transaction, we divide the absolute value of the daily return r_j, measured in basis points, by the daily trading volume V_j, measured in dollar terms, and take the average of all observations over a week t with $N_{i,t}$ observed trading days:

$$(\text{Amihud})_{i,t} = \frac{1}{N_{i,t}} \sum_{j=1}^{N_{i,t}} \frac{|r_j|}{V_j}$$

The interquartile range estimator is another measure that we use, in which a low interquartile range estimator indicates high liquidity. The interquartile estimator, for a given bond i on day t, measured on a daily basis, is calculated as half of the spread between the highest trading price $H_{i,t}$ and the lowest price $L_{i,t}$, divided by the weighted average of price on that day:

$$(\text{IQ})_{i,t} = \frac{H_{i,t} - L_{i,t}}{2WA_{i,t}}$$

The price dispersion measure introduced in Jankowitsch, Nashikkar and Subrahmanyam (2011) measures how transaction prices deviate from the market-wide valuation, and can be considered as the transaction cost of a trade. Since market-wide valuation is not available in our data, we instead use the weighted average of daily transaction prices within a week, $vwap_t$. A low price dispersion measure indicates that transaction prices are close to the market-wide valuation and transaction costs are low, which corresponds to high liquidity. The weekly price dispersion measure, for bond I, is defined as the root-mean of the average of squared deviations of end-of-day j transaction prices $P_{i,j}$ from $vwap_{i,t}$, weighted by the daily trading volume V_j:

$$(\text{price dispersion})_{i,t} = \sqrt{\frac{1}{\sum_j V_j} \sum_j \left(P_{i,j} - vwap_{i,t}\right)^2 V_j}$$

The high-low spread estimator is introduced in Corwin and Schultz (2012). A high HL-spread estimator indicates high liquidity and low discrepancy between the highest and the lowest transaction prices across the two-day period. Assuming that the highest trading price H_t and the lowest trading price L_t during a day t are from the buy side and the sell side, respectively, the ratio of the two prices is assumed to reflect the information asymmetry of the two sides. For a given bond i, the high low spread measure is defined as:

$$(\text{HL spread})_{i,t} = \frac{2(\exp(\alpha) - 1)}{\exp(\alpha) + 1}$$

where

$$\alpha = \frac{\sqrt{2\beta} - \sqrt{\beta}}{3 - 2\sqrt{2}} - \sqrt{\frac{\gamma}{3 - 2\sqrt{2}}}, \beta = \left[\log\left(\frac{H_t}{L_t}\right)\right]^2 + \left[\log\left(\frac{H_{t+1}}{L_{t+1}}\right)\right]^2, \gamma = \left[\log\left(\frac{\max\{H_t, H_{t+1}\}}{\max\{L_t, L_{t+1}\}}\right)\right]^2$$

The last liquidity measure that we use is the CHL estimator, introduced in Abdi and Ranaldo (2017). They propose a new method to estimate the bid-ask spread for less liquid stocks when quote data are not available. This fits perfectly to our setting, because trading frequency of bonds in China is quite low and quote data, although available, are largely incomplete. The daily CHL measure for bond *i* is given by:

$$(\mathrm{CHL})_{i,t} = 2\sqrt{\max\left\{\left(\log P_t - \log\left(\frac{H_t + L_t}{2}\right)\right)\left(\log P_t - \log\left(\frac{H_{t+1} + L_{t+1}}{2}\right)\right), 0\right\}}$$

and the weekly CHL measure is simply

$$(\mathrm{CHL})_t = \frac{1}{N_{i,t}}\sum_{t=1}^{N_{i,t}}(\mathrm{CHL})_{i,t}$$

where $N_{i,t}$ is the number of days that bond *i* is traded in week.

Figure 1. Parallel structure of the Chinese secondary bond markets.

This figure displays the parallel structure of the Chinese interbank and exchange secondary bond markets. Financial bonds, government bonds, and credit bonds are examples of commonly traded bonds across both markets. In this paper, we focus on the credit bond segment. The interbank credit bond segment comprises of enterprise bonds and debt financing instruments for non-financial corporates (DFINFCs), which further contains medium-term notes and commercial paper, while the exchange credit bond segment comprises enterprise bonds and corporate bonds. The National Development Reform Commission (NDRC) regulates enterprise bonds in both markets, while DFINFCs and exchange corporate bonds are regulated by the National Association of Financial Markets Institutional Investors (NAFMII) and the Chinese Securities Regulatory Commission (CSRC), respectively.

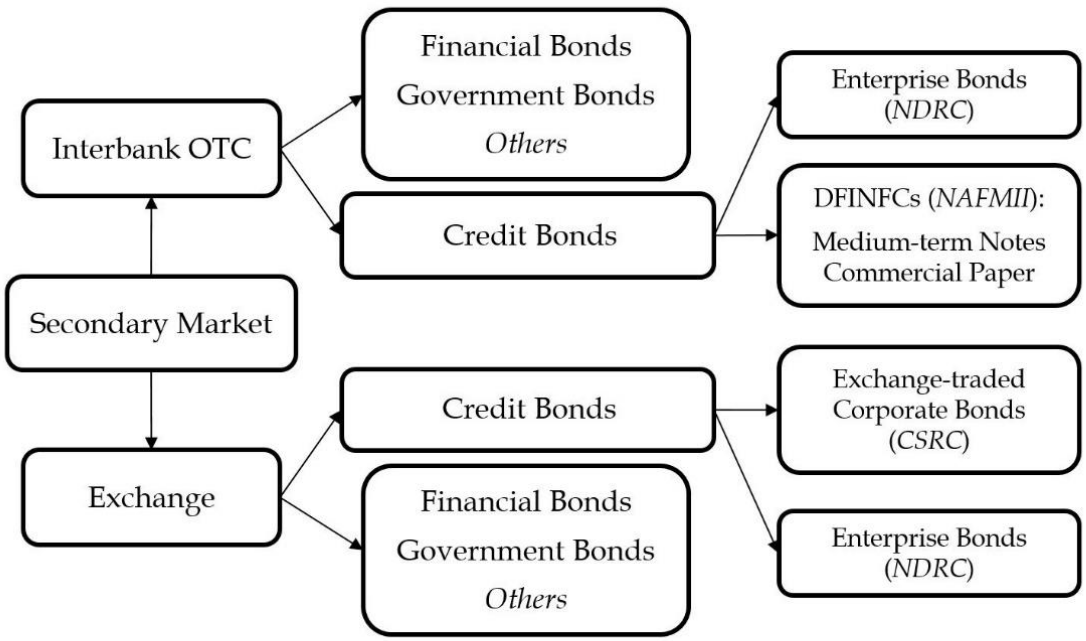


Figure 2. Timeline of major policy announcements in the interbank market.

This figure displays the timeline of major policy announcements regarding liberalization and regulation in the Chinese interbank bond market. It presents the three phases of liberalization: *Phase 1* lasts from early 2005 to March 2012, characterizing the early opening of the interbank bond market to Renminbi qualified foreign institutional investors (RQFIIs) with limited freedom of participation. *Phase 2* lasts from April 2012 to May 2016, characterizing the period of introducing qualified foreign institutional investors (QFIIs). *Phase 3* lasts from June 2016 to December 2017, characterizing the period of broad opening to virtually all foreign investors with medium- and long-term investment objectives.

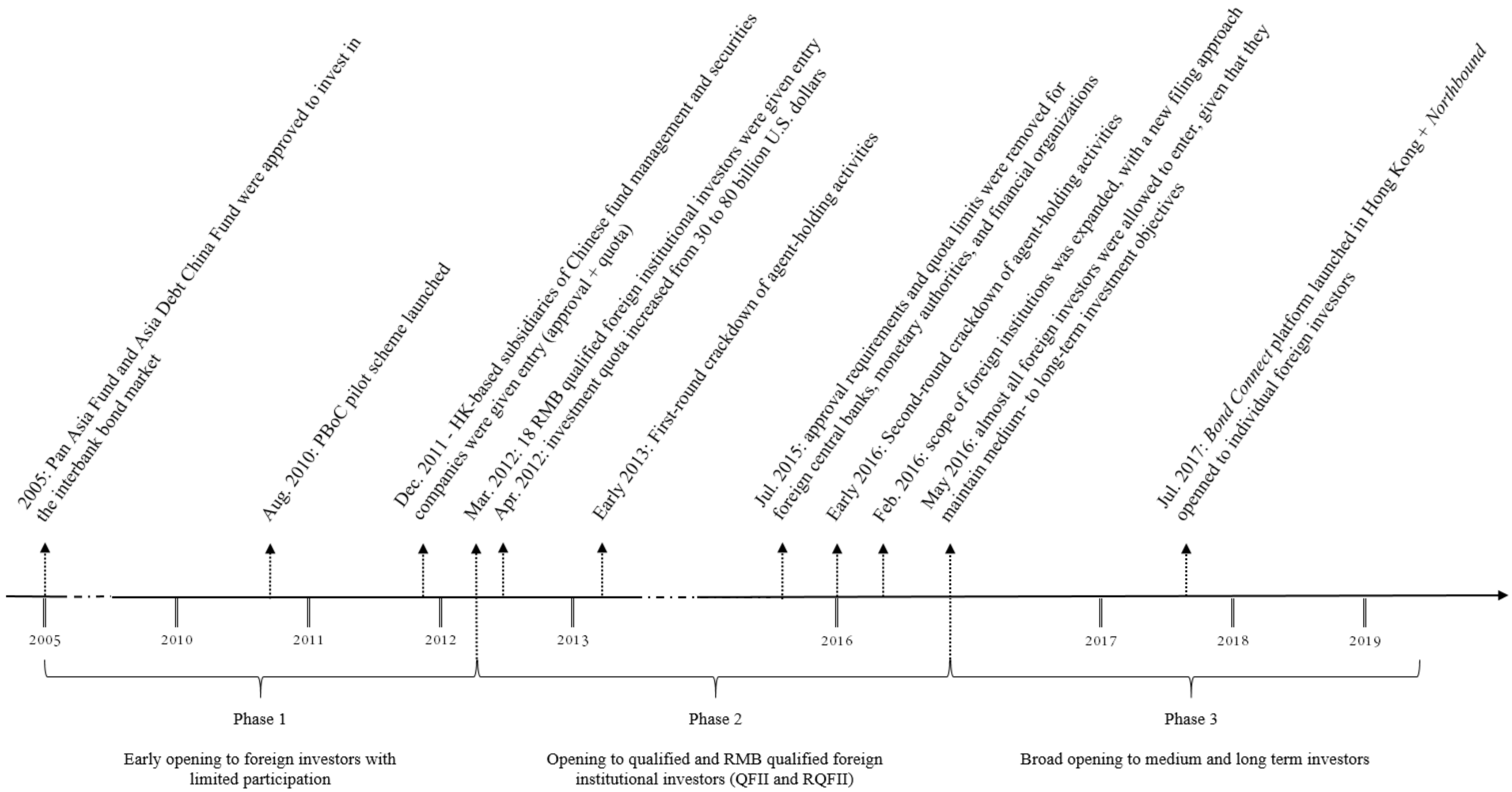
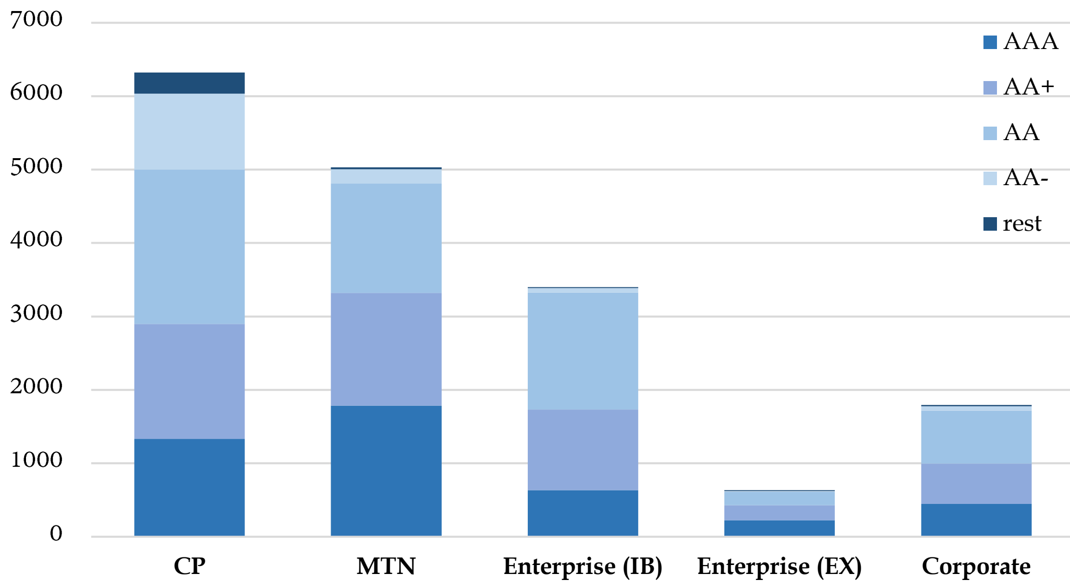


Figure 3. Traded corporate credit bonds by ratings and by year.

This figure displays the total number of bonds (after applying the data filtering procedure in Appendix A) traded of each of the four corporate credit bonds in the interbank market and the exchange market from 2006 to 2017, classified by ratings. They are enterprise bonds and medium-term notes (MTNs) traded in the interbank market, and enterprise bonds and corporate bonds traded in the exchange market. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.



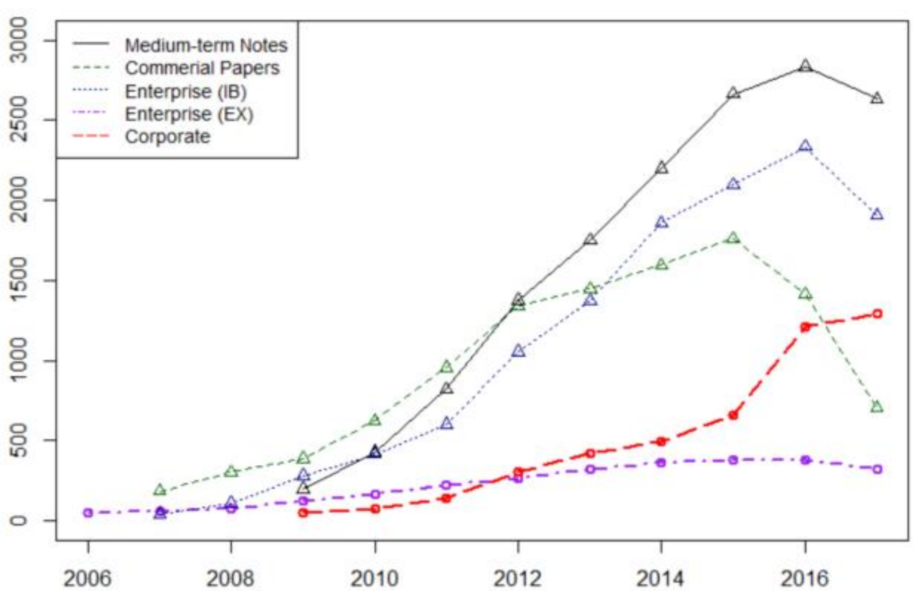


Figure 4. Levels of liquidity.

This figure plots the levels of liquidity for each credit bond segment. The level of liquidity is measured by the first principal component of a set of liquidity proxies. The *green bar* corresponds to the announcement that non-listed companies were allowed to issue corporate bonds in the exchange market. The *purple bar* corresponds to the introduction of 18 QFIIs into the interbank market. The *orange bar* corresponds to removal of approval procedures and quota limits for foreign central banks and monetary authorities. The *red bar* corresponds to the policy that almost all foreign institutional investors can invest in the interbank market. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

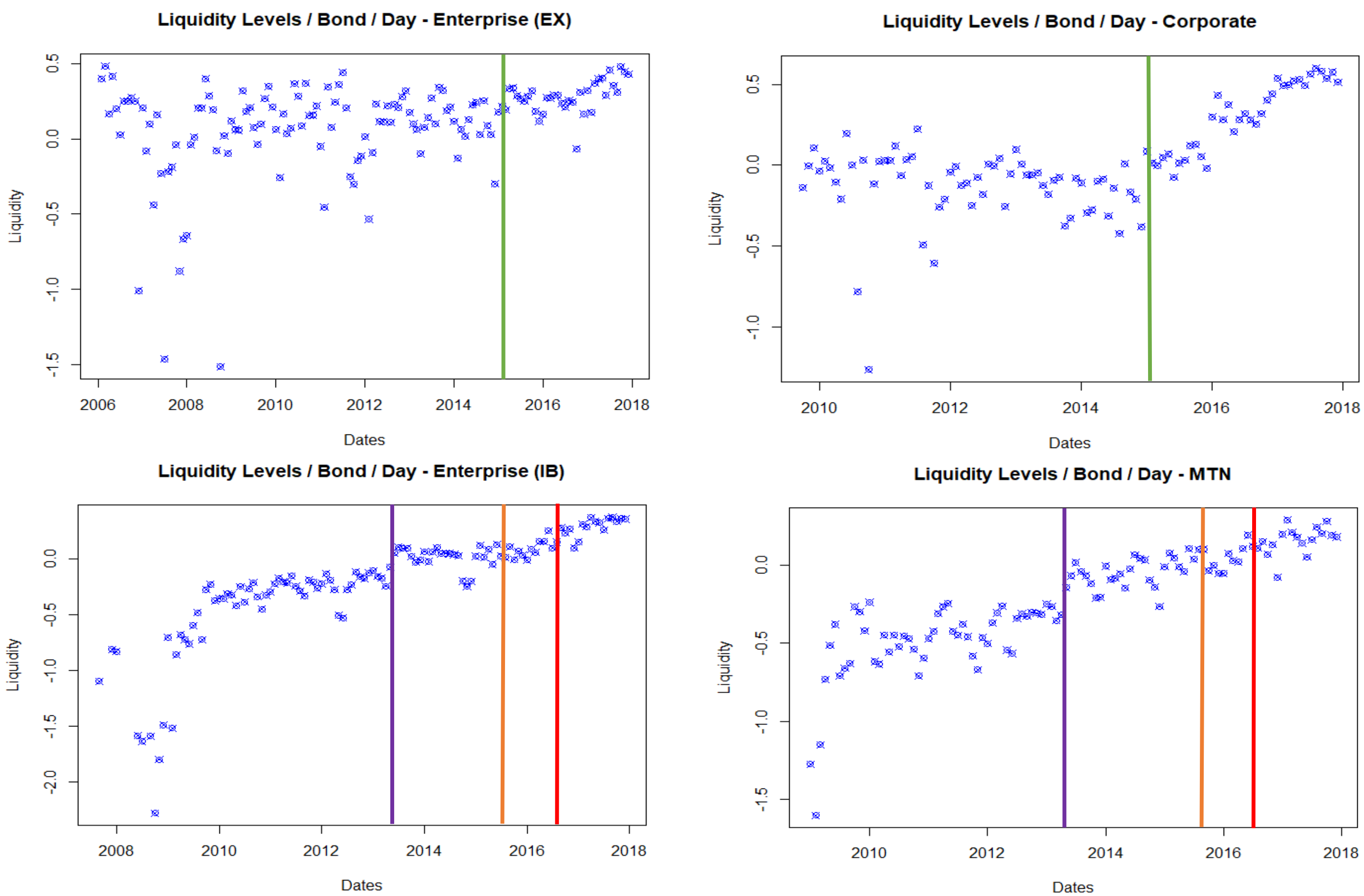


Table 1. Correlations between variables of interest.

This table presents the correlations between *Yield*, *Coupon*, *Age*, *Maturity*, *Duration*, *Volume*, *Zero-return*, *Zero-trade*, *Interval* and the two first principal components, *Trading PC* and *Liquidity PC*, for each of the four credit bonds across the interbank market and the exchange market. In addition, it reports the correlations between the two first principal components for each type of credit bond. Yield is the yield to maturity and is given in percentage points. The set of bond characteristic variables, including *Coupon*, *Age*, *Maturity* and *Duration*, and *Volume* are provided in the dataset. The remaining trading activity variables, including *Zero-return, Zero-trade* and *Interval,* and the liquidity proxies, including the *Amihud ratio,* the *Price dispersion measure,* the *Interquartile-range estimator* and the *CHL measure*, are not given in the original dataset and are constructed using the given variables. For bonds with multiple trades in a week, we calculate each statistic from individual trades by calculating a volume-weighted average of that statistic for the week. We then compute the correlations based on weekly aggregated variables. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. Summary statistics in this table are obtained after performing the filtering procedures in Appendix A.

	Exchange Market				**Interbank Market**			
	Enterprise bonds		Corporate bonds		Enterprise bonds		MTNs	
Variables	*Trading*	*Liquidity*	*Trading*	*Liquidity*	*Trading*	*Liquidity*	*Trading*	*Liquidity*
Yield	0.250	-0.013	0.216	-0.089	0.073	-0.118	-0.072	-0.066
Coupon	0.160	0.099	0.200	-0.049	-0.059	-0.047	-0.152	-0.044
Age	-0.080	-0.008	0.106	-0.132	-0.203	0.043	-0.140	0.006
Maturity	0.087	-0.144	-0.032	-0.129	0.213	-0.083	0.149	-0.115
Duration	0.078	-0.158	-0.045	-0.118	0.250	-0.114	0.155	-0.112
Volume	-0.127	0.056	-0.193	0.097	0.726	-0.158	0.659	-0.105
Zero-return	-0.402	0.003	-0.422	0.126	-0.398	0.169	-0.664	0.077
Zero-trade	-0.781	0.086	-0.795	0.170	-0.806	0.301	-0.798	0.322
Interval	-0.799	0.054	-0.804	0.099	-0.508	0.118	-0.449	0.158
Amihud	-0.006	-0.649	0.011	-0.461	-0.001	-0.181	-0.013	-0.606
Price dispersion	0.198	-0.756	0.206	-0.695	0.284	-0.681	0.263	-0.763
Interquartile range	-0.013	-0.151	0.036	-0.160	0.130	-0.628	0.310	-0.224
Corrected high-low	-0.033	-0.370	0.154	-0.510	0.137	-0.569	0.241	-0.510
Corr (*Trading, Liquidity*)	-0.093		-0.178		-0.291		-0.261	

Table 2. Data-based yields by maturity buckets.

This table reports the cross-sectional mean and standard deviation for the actual (data-based) yields for different maturities of the four types of credit bonds across the two trading venues, the interbank market and the exchange market. Note that commercial paper is not included due to its short maturity of less than one year. Yield is the yield to maturity and is given in percentage points. For bonds with multiple trades in one week, we estimate the yield from individual daily transactions by computing a volume-weighted average for that week. We pool the observations into fixed maturity buckets of 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, 8, 9, and 10 years to maturity. For each bucket, we calculate the descriptive statistics cross-sectional in each week and report the time series average of each statistic. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. Summary statistics in this table are obtained after performing the filtering procedures in Appendix A.

	Exchange Market				**Interbank Market**			
Bond Type	Enterprise		Corporate		Enterprise		MTNs	
Maturity	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.5	4.69	0.15	5.04	0.16	4.33	0.24	4.77	0.19
1	4.72	0.17	5.29	0.14	4.74	0.19	4.88	0.18
1.5	4.87	0.19	5.53	0.13	5.17	0.16	4.96	0.16
2	5.18	0.16	5.68	0.11	5.42	0.14	5.03	0.14
2.5	5.3	0.16	5.86	0.10	5.70	0.11	5.07	0.13
3	5.26	0.14	5.99	0.09	5.81	0.11	5.14	0.11
4	5.47	0.14	5.88	0.08	6.04	0.09	5.13	0.10
5	5.84	0.13	5.85	0.07	6.16	0.09	5.22	0.09
6	6.14	0.13	5.93	0.08	6.14	0.08	5.01	0.07
7	6.31	0.12	5.79	0.06	5.85	0.08	5.12	0.07
8	6.06	0.1	5.56	0.08	5.69	0.09	5.10	0.06
9	5.8	0.08	5.07	0.07	5.53	0.06	5.14	0.04
10	5.76	0.09	4.96	0.05	5.60	0.05	5.17	0.05

Table 3. Panel regression results around major policy shocks.

This table presents the results for the changes in liquidity levels around policy shocks, one month before and one month after, and the results for the relative changes in liquidity levels around policy shocks for the same type of credit bond across the interbank market and the exchange market. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	$(\text{Liquidity})_{i,t} = a_0 + a_1(\text{Post Policy})_{i,t} + e_{i,t}$			
	Interbank Market			**Exchange Market**
Shock Type	Foreign Liberalization			Domestic Innovation
Shock Source	*Interbank*	*Interbank*	*Interbank*	*Exchange*
Date	2012/03	2015/07	2016/05	2015/01
	Medium-term Notes			Corporate Bonds
Intercept	1.095	0.733	1.416	-1.748 ***
	(0.625)	(0.600)	(0.626)	(0.144)
Post Policy Dummy	0.056 **	0.063 ***	0.101 ***	0.122 ***
	(0.022)	(0.021)	(0.020)	(0.018)
Bond FE	Yes	Yes	Yes	Yes
R-squared	0.751	0.765	0.775	0.891
	Enterprise Bonds			Enterprise Bonds
Intercept	0.484	0.822	0.931	-0.510 **
	(0.729)	(0.707)	(0.571)	(0.201)
Post Policy Dummy	-0.120 ***	0.004	0.060 **	0.155 ***
	(0.033)	(0.022)	(0.025)	(0.028)
Bond FE	Yes	Yes	Yes	Yes
R-squared	0.611	0.549	0.468	0.823

Table 4. Panel regression results of liquidity effects – full period.

This table presents the results for the four panel regressions of the yield spread on a set of independent variables. Independent variables include maturity, maturity², age, amount issued, *Liquidity PC* and a group of control variables, including *Trading PC* and dummy variables of *Market Condition, Rating Agency, Bond Rating* and *Credit Enhancement*. The full model is Model 3 and includes all independent variables. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	Interbank Market				**Exchange Market**			
	Enterprise Bonds		Medium-term Notes		Enterprise Bonds		Corporate Bonds	
Variables	Model 4	Model 3	Model 4	Model 3	Model 4	Model 3	Model 4	Model 3
Intercept	2.033 ***	2.026 ***	1.918 ***	2.011 ***	2.906 ***	3.061 ***	1.864 ***	2.22 ***
	(0.112)	(0.111)	(0.084)	(0.086)	(0.098)	(0.100)	(0.119)	(0.116)
Maturity	-0.037 ***	-0.038 ***	-0.034 ***	-0.048 ***	0.077 ***	0.052 ***	0.051 ***	0
	(0.011)	(0.011)	(0.006)	(0.007)	(0.012)	(0.012)	(0.011)	(0.011)
Maturity²	0.005 ***	0.004 ***	0	0.001	-0.008 ***	-0.007 ***	-0.004 ***	-0.004 ***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Age	-0.082 ***	-0.083 ***	-0.057 ***	-0.068 ***	-0.041 ***	-0.057 ***	-0.091 ***	-0.17 ***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.003)	(0.004)	(0.004)
Amount Issued	-0.004 ***	-0.004 ***	-0.001 ***	-0.001 ***	-0.009 ***	-0.008 ***	-0.003 ***	-0.002 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Coupon	0.238 ***	0.237 ***	0.293 ***	0.285 ***	0.238 ***	0.235 ***	0.457 ***	0.431 ***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)
Liquidity PC		-0.024 ***		-0.032 ***		-0.102 ***		-0.176 ***
		(0.025)		(0.002)		(0.008)		(0.004)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yearly FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.572	0.573	0.474	0.476	0.552	0.559	0.571	0.586
# of Bonds	2777	2777	4020	4020	500	500	1232	1232
# of Observations	153852	153852	329655	329655	58778	58778	87704	87704

Table 5. Improvement in model explanatory power.

This table reports the values of *R-squared* of Model 3 and Model 4 listed below. Model 4 includes only the VIX, bond characteristic variables and control variables as independent variables, while Model 3 includes one additional independent variable, *Liquidity PC*. Yield spread is defined as the yield to maturity subtracted by the corresponding risk-free rate. Control variables include *Trading PC* and dummy variables of *Market Condition*, *Rating Agency*, *Bond Rating* and *Credit Enhancement*. The difference in *R-squared* allows us to identify the incremental explanatory power of liquidity effects in bond yield spreads. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

Model 3 –

$$\begin{aligned}(\text{yield spread})_k = a_0 &+ a_1\text{Maturity}_k + a_2\text{Maturity}_k^2 + a_3\text{Age}_k + a_4\text{Issuance}_k + a_5\text{Coupon}_k \\ &+ a_6\text{VIX}_k + a_7(\text{Liquidity PC})_k + \boldsymbol{a_8^s}\cdot(\textbf{Control})_k^s + \varepsilon_k\end{aligned}$$

Model 4 –

$$\begin{aligned}(\text{yield spread})_k = a_0 &+ a_1\text{Maturity}_k + a_2\text{Maturity}_k^2 + a_3\text{Age}_k + a_4\text{Issuance}_k + a_5\text{Coupon}_k \\ &+ a_6\text{VIX}_k + \boldsymbol{a_7^s}\cdot(\textbf{Control})_k^s + \varepsilon_k\end{aligned}$$

	Bond Type	Economy State	Model 4	Model 3	Relative Increase	Absolute Increase
Interbank Market	Enterprise	*Regular*	0.581	0.584	0.35%	0.60%
		Recession	0.589	0.592	0.30%	0.50%
		Crisis	0.331	0.341	1.01%	3.05%
	MTNs	*Regular*	0.481	0.483	0.18%	0.37%
		Recession	0.486	0.493	0.47%	0.97%
		Crisis	0.475	0.486	1.08%	2.28%
Exchange Market	Enterprise	*Regular*	0.555	0.580	2.48%	4.47%
		Recession	0.518	0.546	2.78%	5.37%
		Crisis	0.629	0.648	1.89%	3.00%
	Corporate	*Regular*	0.572	0.612	3.97%	6.94%
		Recession	0.539	0.577	3.78%	7.01%
		Crisis	0.602	0.634	3.16%	5.24%

Table 6. Panel regression results of liquidity effects – by liberalization phases.

This table presents the results of the four segments of credit bonds in the interbank and exchange markets for the full panel regression model of Model 5 and Model 6. Independent variables include the VIX, maturity, maturity-squared, age, amount issued, coupon rate, *Liquidity PC*, a set of control variables, and the interaction of *Liberalization Phase* dummies with *Liquidity PC*. Control variables include *Trading PC* and the dummy variables of *Market Condition, Rating Agency, Bond Rating* and *Credit Enhancement*. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level.

	Interbank Market		**Exchange Market**	
	Enterprise	MTNs	Enterprise	Corporate
Variables	Model 5	Model 5	Model 6	Model 6
Intercept	1.924 *** (0.096)	1.95 *** (0.082)	3.135 *** (0.093)	2.226 *** (0.109)
Characteristic Variables	Omitted	Omitted	Omitted	Omitted
Liquidity PC	-0.007 (0.005)	0.003 (0.004)	-0.038 *** (0.007)	-0.142 *** (0.005)
Phase 2 Dummy	-0.134 *** (0.068)	0.091 (0.066)		
Phase 3 Dummy	0.005 (0.055)	0.161 *** (0.059)		
(*Liquidity PC*) × (*Phase 2*)	-0.018 *** (0.006)	-0.038 *** (0.004)		
(*Liquidity PC*) × (*Phase 3*)	-0.018 * (0.011)	-0.049 *** (0.006)		
Post 2015 Dummy			0.201 *** (0.050)	0.135 *** (0.036)
(*Liquidity PC*) × (*Post 2015*)			-0.218 *** (0.012)	-0.066 *** (0.007)
Controls	Yes	Yes	Yes	Yes
Yearly FE	Yes	Yes	Yes	Yes
R-squared	0.587	0.486	0.573	0.590
# of Bonds	2777	4020	500	1232
# of Bonds (by stages)	629/2447/2277	841/3160/3084	432/417	504/1169
# of Observations	153852	176101	58778	87704
# of Observations (by stages)	21889/89549 /43220	24432/95777 /55892	43254/15524	41459/46245

Table 7. Panel regression results of liquidity effects – by economic environments.

This table presents the results for the full-panel regression model of the yield spread on a set of independent variables, during three different market conditions: normal, recession, and crisis periods. Independent variables include the VIX, maturity, maturity-squared, age, coupon rate, *Liquidity PC*, the interaction of *Market Condition* dummies with liquidity, and a set of control variables. Control variables include *Trading PC* and dummy variables of *Market Condition, Rating Agency, Bond Rating* and *Credit Enhancement*. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	Interbank Market		**Exchange Market**	
	Enterprise	MTNs	Enterprise	Corporate
Variables	Model 7	Model 7	Model 7	Model 7
Intercept	1.919 *** (0.096)	1.943 *** (0.083)	3.136 *** (0.094)	2.195 *** (0.000)
Characteristic Variables	Omitted	Omitted	Omitted	Omitted
Liquidity PC	-0.019 *** (0.006)	-0.014 *** (0.003)	-0.100 *** (0.013)	-0.148 *** (0.000)
Recession Dummy	0.230 *** (0.045)	0.176 *** (0.031)	0.495 *** (0.065)	0.271 *** (0.000)
Crisis Dummy	-0.148 *** (0.053)	-0.128 *** (0.037)	0.145 * (0.079)	-0.221 *** (0.000)
(*Liquidity PC*) × *Recession*	-0.014 * (0.008)	-0.023 *** (0.005)	-0.009 (0.015)	-0.038 *** (0.000)
(*Liquidity PC*) × *Crisis*	-0.060 *** (0.009)	-0.070 *** (0.006)	0.017 (0.021)	-0.062 *** (0.000)
Controls	Yes	Yes	Yes	Yes
Yearly FE	Yes	Yes	Yes	Yes
R-squared	0.587	0.486	0.567	0.590
# of Bonds	2777	4020	500	1232
# of Bonds (Boom, Recession, Crisis)	2754/2628 /2181	3970/3647 /2589	485/419/473	1224/1025/738
# of Observations	153852	176101	58778	87704
# of Observations (Boom, Recession, Crisis)	66329/67965 /20364	79016/75634 /21451	26256/24606 /7916	38199/38240 /11265

Table 8. Panel regression results of liquidity effects – by time-to-maturity.

This table presents the results of the four segments of credit bonds in the interbank and exchange markets for the full panel regression model of Model 8. Independent variables include the VIX, maturity, maturity-squared, age, amount issued, coupon rate, *Liquidity PC*, a set of control variables, and the interaction of *Time-to-maturity* dummies with liquidity. Control variables include *Trading PC* and the dummy variables of *Market Condition, Rating Agency, Bond Rating and Credit Enhancement*. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level.

	Interbank Market		**Exchange Market**	
	Enterprise	MTNs	Enterprise	Corporate
Variables	Model 8	Model 8	Model 8	Model 8
Intercept	1.802 *** (0.107)	2.002 *** (0.087)	3.206 *** (0.110)	2.233 *** (0.117)
Characteristic Variables	Omitted	Omitted	Omitted	Omitted
Liquidity PC	-0.075 *** (0.020)	-0.047 *** (0.004)	-0.148 *** (0.010)	-0.157 *** (0.005)
Medium-TTM Dummy	-0.344 *** (0.021)	-0.016 (0.011)	-0.042 ** (0.019)	0.019 (0.017)
Long-TTM Dummy	-0.654 *** (0.035)	0.224 *** (0.038)	0.145 *** (0.034)	0.189 *** (0.033)
(*Liquidity PC*) × (*Medium*)	0.049 *** (0.019)	0.012 *** (0.004)	0.061 *** (0.009)	-0.041 *** (0.006)
(*Liquidity PC*) × (*Long*)	0.086 *** (0.021)	0.031 *** (0.005)	0.130 *** (0.015)	0.058 *** (0.009)
Controls	Yes	Yes	Yes	Yes
Yearly FE	Yes	Yes	Yes	Yes
R-squared	0.581	0.475	0.563	0.587
# of Bonds	2777	4020	500	1232
# of Bonds (Short, Medium, Long)	898/2694 /356	3377/2352 /72	368/462 /121	742/1011 /75
# of Observations	153852	176101	58778	87704
# of Observations (Short, Medium, Long)	15723/126950 /11985	100624/73404 /2073	18885/33980 /5913	39334/46053 /2317

Table 9. Panel regression results of liquidity effects – by firm ratings.

This table presents the results of the four segments of credit bonds in the interbank and exchange markets for the full panel regression model of Model 9. Independent variables include the VIX, maturity, maturity-squared, age, amount issued, coupon rate, *Liquidity PC*, a set of control variables, and the interaction of *Firm Rating* dummies with liquidity. Control variables include *Trading PC* and the dummy variables of *Market Condition, Rating Agency, Bond Rating* and *Credit Enhancement*. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level.

	Interbank Market		**Exchange Market**	
	Enterprise	MTNs	Enterprise	Corporate
Variables	Model 9	Model 9	Model 9	Model 9
Intercept	1.624 ***	2.041 ***	2.967 ***	1.651 ***
	(0.123)	(0.086)	(0.104)	(0.103)
Characteristic Variables	Omitted	Omitted	Omitted	Omitted
Liquidity PC	0.051 ***	-0.014 ***	-0.082 ***	-0.132 ***
	(0.012)	(0.003)	(0.014)	(0.005)
AA+ Dummy	0.006	-0.271 ***	0.604 ***	-0.201 ***
	(0.035)	(0.030)	(0.046)	(0.012)
AA Dummy	0.204 ***	-0.074 ***	0.605 ***	’-0.145 ***
	(0.036)	(0.028)	(0.042)	(0.013)
AA- Dummy	0.460 ***		0.629 ***	
	(0.038)		(0.068)	
(*Liquidity PC*) × (*AA+*)	-0.055 ***	-0.021 ***	-0.063 ***	-0.012 **
	(0.011)	(0.003)	(0.013)	(0.006)
(*Liquidity PC*) × (*AA*)	-0.076 ***	-0.040 ***	-0.038 ***	-0.072 ***
	(0.012)	(0.004)	(0.014)	(0.007)
(*Liquidity PC*) × (*AA-*)	-0.092 ***		0.023	
	(0.012)		(0.018)	
Controls	Yes	Yes	Yes	Yes
Yearly FE	Yes	Yes	Yes	Yes
R-squared	0.576	0.478	0.58	0.58
# of Bonds	2777	4020	500	1232
# of Bonds (AAA, AA+, AA, AA-)	211/294 /1703/520	1240/1073 /1444	111/77 /221/78	294/276 /599
# of Observations	153852	176101	58778	87704
# of Observations (AAA,AA+, AA, AA-)	9806/16566 /93578/2270	61062/50850 /55454	13257/6016 /22401/13787	17199/17953 /43788

Table 10. Panel regression results of liquidity effects – by rating agency types.

This table presents the results of the four segments of credit bonds in the interbank and exchange markets for the full panel regression model of Model 10. Independent variables include the VIX, maturity, maturity-squared, age, amount issued, coupon rate, *Liquidity PC*, a set of control variables, and the interaction of a *Private Rating Agency* dummy with liquidity. Control variables include *Trading PC* and the dummy variables of *Market Condition, Bond Rating* and *Credit Enhancement*. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% level.

	Interbank Market		**Exchange Market**	
	Enterprise	MTNs	Enterprise	Corporate
Variables	Model 10	Model 10	Model 10	Model 10
Intercept	0.853 *** (0.092)	1.579 *** (0.084)	2.980 *** (0.099)	1.94 *** (0.111)
Characteristic Variables	Omitted	Omitted	Omitted	Omitted
Liquidity PC	-0.023 *** (0.008)	-0.030 *** (0.002)	-0.085 *** (0.009)	-0.176 *** (0.004)
Private CRA Dummy	-0.030 *** (0.005)	-0.011 *** (0.005)	-0.116 *** (0.013)	-0.112 *** (0.010)
(*Liquidity PC*) × (*Private CRA*)	-0.030 *** (0.007)	-0.015 *** (0.004)	-0.084 *** (0.013)	-0.042 *** (0.006)
Controls	No CRA	No CRA	No CRA	No CRA
Yearly FE	Yes	Yes	Yes	Yes
R-squared	0.573	0.474	0.537	0.582
# of Bonds	2777	4020	500	1232
# of Bonds (State-owned, Private)	2482/295	3337/683	455/45	1098/134
# of Observations	153852	176101	58778	87704
# of Observations (State-owned, Private)	137339/17319	150266/25835	53981/4797	7895/8748

Internet Appendix to

"Policy Interventions and Liquidity in Segment Chinese Credit Bond Markets"

Jingyuan Mo and Marti. G. Subrahmanyam

This internet appendix contains three sections. The first section, consisting of Items A1 to Item A4, provides more detailed descriptions of the institutional aspects of some of the points in the text. The second section, consisting of Figures A1 to A3, provides graphical representations of statistics on primary market issuance, secondary market trading activities, and the results to the structural break test. The third section, consisting of Tables A1 to A3, provides quantitative information on the institutional aspects, including descriptive and summary statistics, of the Chinese credit bond markets.

Item A1. Corporate bonds vs. enterprise bonds

Although both corporate bonds and enterprise bonds are issued by entities with corporate credit exposure, corporate bonds are mostly issued by limited liability, joint-stock companies (listed and unlisted), while enterprise bonds are mostly issued by state-owned enterprises and state-holding companies, both at the national and provincial level. The two types of bonds also differ according to their financing purposes: enterprise bonds are issued to finance projects approved by the central government or local governments, such as infrastructure projects, while the issuance of corporate bonds enjoys more flexibility, in terms of debt payment, long-term investment, and projects that benefit the future growth of the corporations. In addition, enterprise bonds are traded in both the interbank market and the exchange market, while corporate bonds are traded only on the exchange. As a result, issuers can choose to issue enterprise bonds in both markets and, therefore, approximately 90% of enterprise bonds became dual-listed in both markets since 2005, the year that the exchange market started to permit enterprise bond issuance. However, enterprise bonds issued by the same entity cannot be traded across the two markets; they are assigned different trading codes across the two markets and can be regarded as two distinct bonds, even if their terms are identical. This gives us a perfect setup to identify the pricing discrepancy across the two segmented markets.

Item A2. Completing missing data points of YTM

On each trading day, the dirty price is related to the clean price through the relation

$$\text{dirty price} = \text{clean price} + AI$$

where AI is the accrued interest and is computed as

$$AI = \frac{t}{365/f} \times C$$

where t is the number of days between the last coupon payment date and the trading date, f is the number of coupon payments per year, and c is the amount of the next coupon payment. The dirty price is related to the yield to maturity through the following equation:

$$PV = \frac{FV}{(1 + y/f\,)^{N-1+\frac{d}{(365/f)}}} + \sum\nolimits_{k=0}^{N-1} \frac{C_i/f}{(1 + y/f)^{k+\frac{d}{(365/f)}}}$$

where PV is the dirty price, y is the annualized yield to maturity, C_i is the coupon payment per period i, f is the frequency of coupon payments per year, d is the number of days between the trading date and the next coupon payment date, N is the total number of coupon payments, and FV is the notional face value of the bond. The yield to maturity y does not have a closed form solution, except if the trading date is within the final coupon payment period. In other words, if only one cash flow remains ($N = 1$), yield is found explicitly as:

$$y = \frac{365}{d} \times \left(\frac{C_N + FV}{PV} - 1\right)$$

Item A3. De-couponing government bond yields

In prior papers related to bond markets in China, researchers have adopted the convention of using the yields to maturity of the Chinese government bonds as a proxy for the risk-free rates of the relevant maturity, in line with industry practice. Since all government bonds in China have non-zero coupon payments, yields are all coupon-implied, i.e., yields to maturity with coupon payments considered. This, in particular, renders government bond yields as an inappropriate and incorrect proxy of the risk-free rate, due to the associated coupon effects. In this paper, we therefore "de-coupon" the original coupon-implied government yields to create the respective zero rates (i.e., "bootstrapping" the zero curves). The resultant zero rates can be more properly used as the correct proxy of the risk-free rates in China. In this paper, we consider both sets of yields – the coupon-implied yields and the zero rates – as proxies for the risk-free rates and investigate the differences between the resultant bond yield spreads, as a robustness check.

To the best of our knowledge, we are the first to point out this issue in the literature related to Chinese financial markets, and are also the first to explicitly compute the zero rates in the interbank market and the exchange market. Not surprisingly, for a given trading day, the correlation between the coupon-implied yield curve and the bootstrapped zero curve is very close to one, as the latter is obtained through de-couponing the former. In the exchange market, after winsorizing the time series at the 95% confidence interval, the correlation lies between 0.905 and 1, with a mean of 0.996. In the interbank market, after winsorizing the correlation time series at the 95% confidence interval, the correlation lies between 0.916 and 1, with a mean of 0.999.

Item A4. Generating the entire yield curve

The dependent variable in our regression analysis is the yield spread of a particular type of bond, which is defined as the difference between the yield to maturity of that bond and the zero rate corresponding to the same time to maturity on the same trading day. However, in most cases, the two sets of maturities do not match exactly. For instance, a bond that is traded on one trading day may have a time to maturity of 3.22 years, while there is no government bond traded on the same day with exactly the same time to maturity. Without knowing the corresponding zero rate, it would be impossible to calculate the yield spread for that bond on that day. In order to better capture the non-linear relationship between bond yields and time to maturities and to obtain zero rates of all possible maturities on a given trading day, we fit our daily data with a Nelson-Siegel three-factor model, as in Nelson and Siegel (1987) as modified by Diebold and Li (2006). The three-factor estimation for any given maturity τ is given by:

$$y_t(\tau) = \beta_{0t}X_{0t} + \beta_{1t}X_{1t} + \beta_{2t}X_{2t}$$

where

$$X_{0t} = 1, \qquad X_{1t} = \frac{1 - \exp(-\lambda_t \tau)}{\lambda_t \tau}, \qquad X_{2t} = \frac{1 - \exp(-\lambda_t \tau)}{\lambda_t \tau} - \exp(-\lambda_t \tau)$$

The three factors in the Nelson-Siegel model, the level factor β_{0t}, the slope factor β_{1t} and the curvature factor β_{2t}, are interpreted as latent dynamic factors. The λ_t parameter is the time-dependent decay factor that determines the level of contribution of $\beta_{0t,}$, β_{1t}, and β_{2t}. It should be noted that while λ_t is often taken to be time-invariant in many previous studies, we allow this decaying factor to be time-varying on a daily basis, similar to what was originally implemented in Nelson and Siegel (1987).

For each type of bond with a total number of N trading days, we generate an $N \times 1000$ grid, which contains a term structure of zero rates for each trading day, and for all maturities τ ranging from 0.01 year to 10 years, with an increment of 0.01 year. In this way, we can match a zero rate to the yield of every traded bond on each trading day until maturity.

Figure A1. Issuance statistics of credit bonds in the primary markets.

This figure displays the number of credit bonds issued and the amount of credit bonds issued in the interbank and exchange primary markets (before applying the data filtering procedure in Appendix A). They are enterprise bonds, medium-term notes and commercial paper traded in the interbank market, and enterprise bonds and corporate bonds traded in the exchange market. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

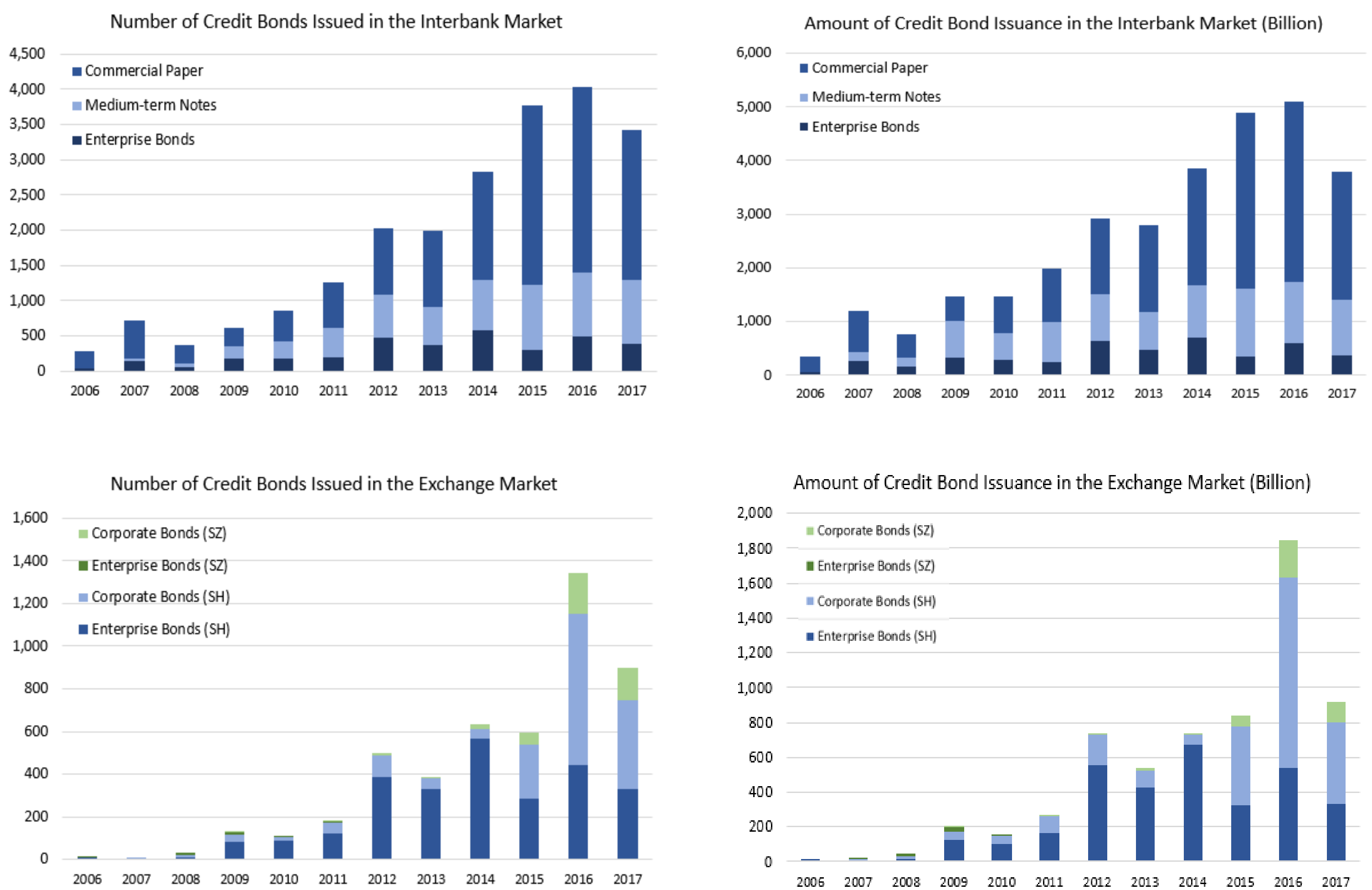


Figure A2. Volume-weighted yields to maturity by bond ratings.

The first four sub-figures plot the volume-weighted averages of yields to maturity of the thirteen different maturity buckets of each of the four credit bonds in the interbank and the exchange markets, classified by ratings. The last sub-figure plots the overall volume-weighted averages of yields to maturity of each of the five bonds. They are enterprise bonds and medium-term notes traded in the interbank market, and enterprise and corporate bonds traded in the exchange market. The thirteen maturity buckets are [0~0.5], [0.5~0.1], [0.1~1.5], [1.5~2], [2~2.5], [2.5~3], [3~4], [4~5], [5~6], [6~7], [7~8], [8~9] and [9~10], measured in years. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

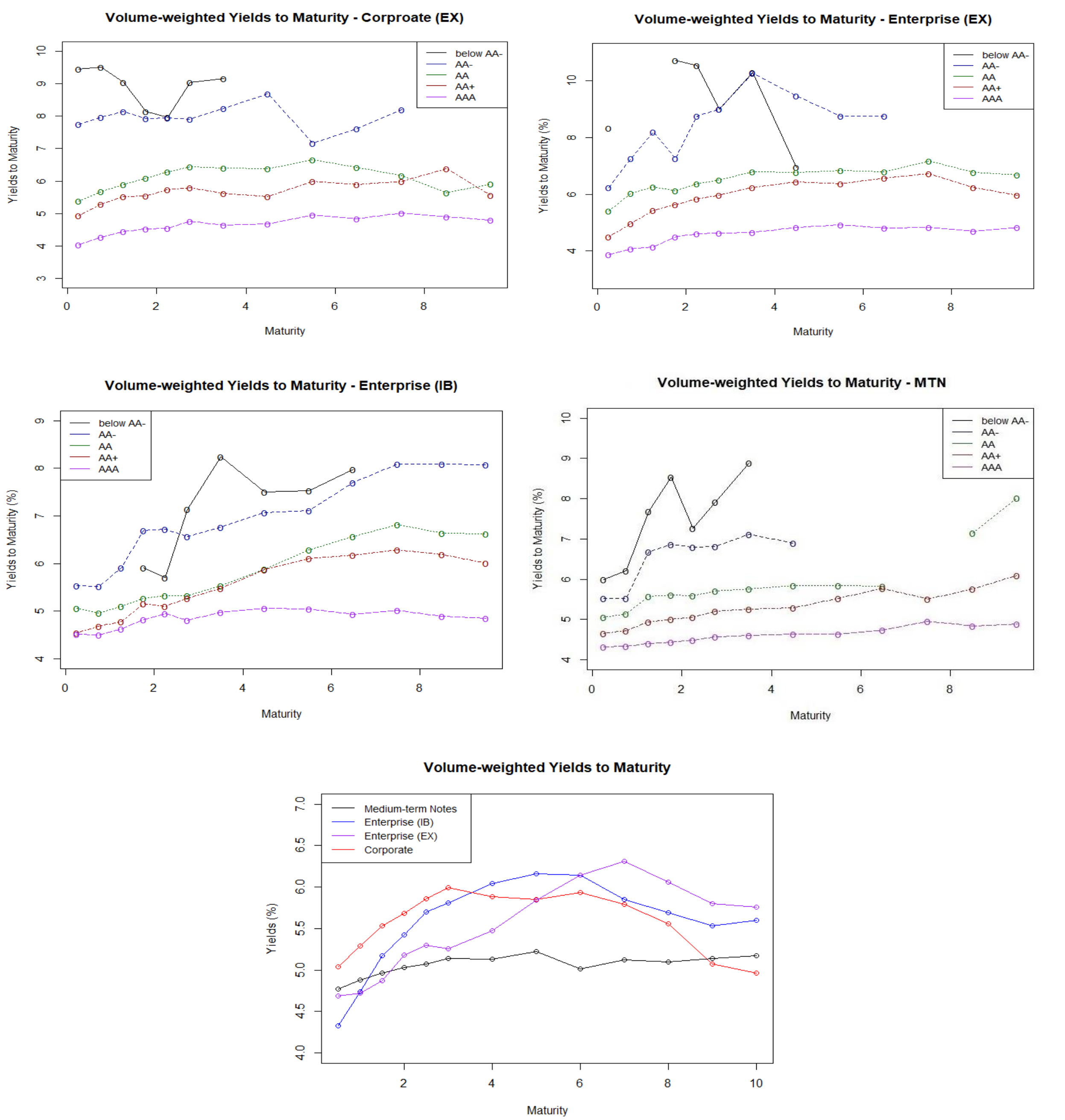


Figure A3. Structural break test on the levels of liquidity – interbank market.

This figure shows the *F*-test results for the Chow test for each week in our sample, excluding the first and last five weeks of observations, in the interbank market. The horizontal lines mark the 1% level of significance for the largest of the *F*-test values. The two policy shock ranges are: (1) [March – April, 2012] the allowance of 18 RQFIIs to enter the interbank market, with increased quota from 30 to 80 billion U.S. dollars, and (2) [July 2015 – May 2016] from the quota limits removal for foreign central banks to the inclusion of almost all foreign institutions. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

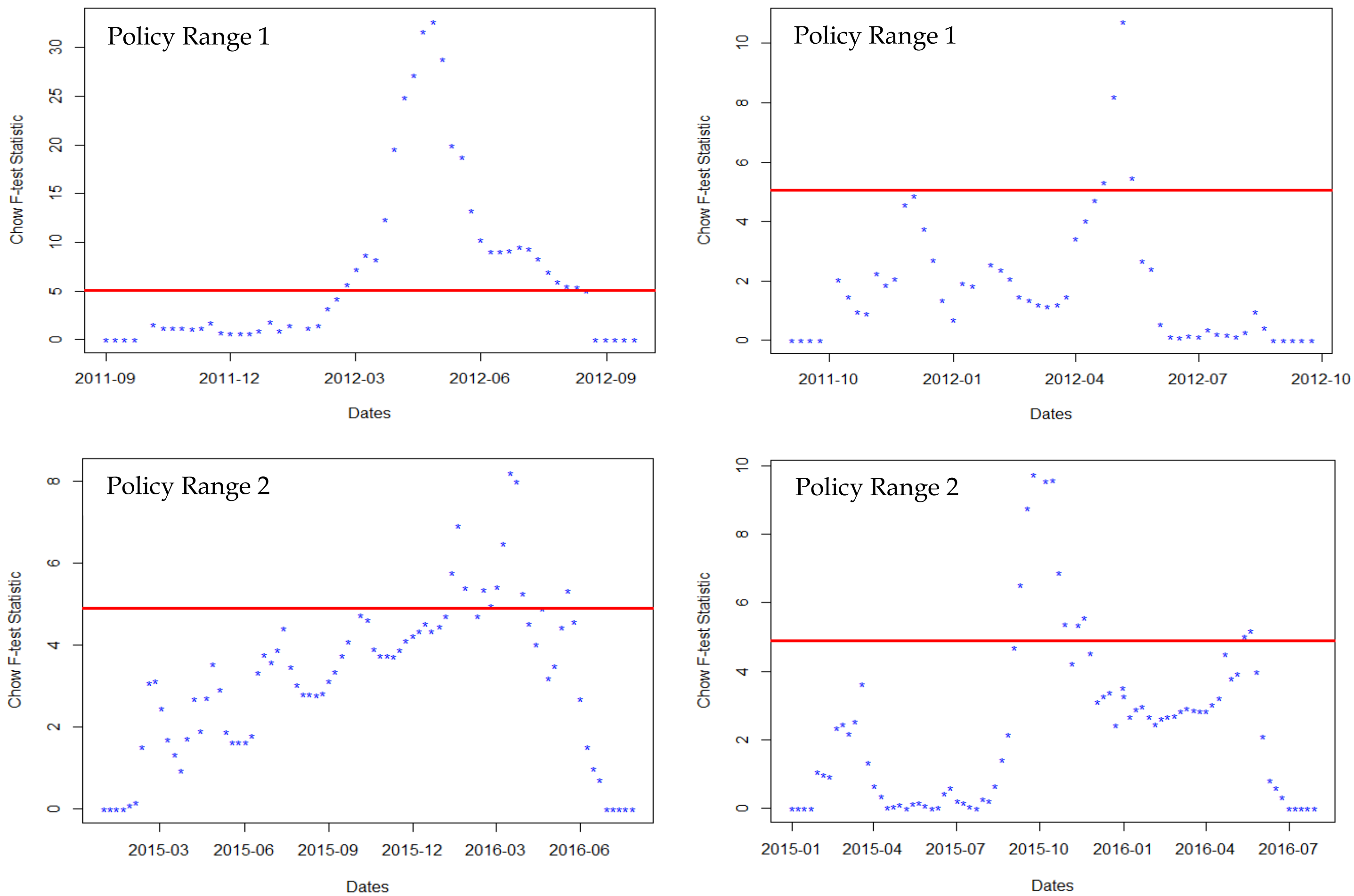


Table A1. Major differences across the two trading venues.

This table shows the major differences across the two parallel trading venues, the interbank OTC market and the exchange market. The six categories compared here are *regulators*, *trading platforms*, *market participants*, *trading mechanisms*, *trading rules*, and *collateral policies*.

	Interbank Market	**Exchange Market**
Regulator	People's Bank of China (PBoC)	China Securities Regulatory Commission (CSRC)
Trading platform	China Foreign Exchange Trade System (CFETS)	- Shanghai Stock Exchange - Shenzhen Stock Exchange
Market participants	- banks - all institutional investors	- medium and small institutional investors - retail/household investors
Trading mechanism	- decentralized trading - telephone market, OTC setting - with counterparty risk	- centralized trading - through clearinghouse (order-driven) - little counterparty risk
Trading rule	- trades based on inquiries - bilateral quotes by market makers	- trades matched through a centralized trading system - settled based on clean prices
Collateral policy	- strict restrictions on collaterals - 'AAA' bonds can be pledged in normal market periods, while only interest rate securities in crises	- less strict restrictions - 'AAA', 'AA+' and 'AA' bonds can be pledged (haircut) - only 'AAA' can be pledged after December 8, 2014

Table A2. Distribution of ratings.

This table displays the distribution of ratings by the number of bonds in each rating category, for the combined four types of credit bonds in the interbank market and the exchange market. The numbers of bonds assigned each credit rating, in each market, are listed in the diagonal entries of each sub-table. The numbers in the off-diagonal entries represent the number of bonds that shifted from one credit rating to the other, which could be either upgrades or downgrades during their respective trading periods. The ratings range cover AAA, AAA-, AA+, AA, AA-, A+, A, A-, BBB+, BBB, BBB-, BB+, BB-, B+, B, B-, CCC, CC and C. We quantify the ratings by creating a measure "Rating Number," in multiples of 1, i.e., AAA = 1, AAA- = 2, AA+ = 3, etc. The total number of bonds in the sample is also listed. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

The Chinese Corporate Credit Bond Market – All Five Credit Bonds Combined								
Ratings	AAA	AA+, AA, AA-	A+, A, A-	BBB+, BBB	BB+, BB	B+, B	CCC, CC, C	
AAA	5569	1032						
AA+, AA, AA-		13900	149					
A+, A, A-			525	7	8	2	3	
BBB+, BBB				23		2	1	
BB+, BB					13		2	
B+, B						3	0	
CCC, CC, C							30	Total
%	27.76%	69.28%	2.62%	0.11%	0.06%	0.01%	0.15%	20063

Table A3. Descriptive statistics.

This table reports the cross-sectional descriptive statistics (5th percentile, 25th percentile, median, 75th percentile, 95th percentile, mean and standard deviation) for the yield spread, bond characteristic variables, trading activity variables and liquidity measures. The yield spread is difference between the yield to maturity of each band and the corresponding risk-free rate, reported in percentage points. For bonds having multiple trades in a week, we estimate the yield from individual trades by calculating a volume-weighted average for the week. Bond characteristic variables include *Rating*, *Maturity*, *Age* and *Coupon*. Trading activity variables include *Trading interval*, *Trading intensity*, *Zero-return*, and *Zero-trade*. Liquidity measures include *Amihud ratio*, *Price dispersion measure*, *Interquartile range estimator*, *High-low spread measure* and *CHL measure*. We compute the descriptive statistics cross-sectional for each week, and report the time series average of each statistic. We obtain the dataset from the China Foreign Exchange and Trade System, covering the period from January 2006 to December 2017.

Interbank Market	**Enterprise Bonds**							**Median Term Notes**						
	5%	25%	50%	75%	95%	Mean	SD	5%	25%	50%	75%	95%	Mean	SD
Yield spread (%)	1.381	2.013	2.525	3.146	3.975	2.583	0.8	0.928	1.331	1.732	2.243	3.364	1.874	0.756
Rating	0.5	1	1.424	1.5	1.5	1.186	0.381	0.5	0.5	1	1.5	1.5	1.002	0.443
Coupon (%)	4.05	5.38	6.45	7.18	8.29	6.294	1.269	3.46	4.5	5.3	6	7.228	5.292	1.148
Time to maturity	3.414	5.115	5.823	6.421	8.496	5.784	1.345	1.428	2.139	3.041	4.111	5.558	3.217	1.419
Age	1.381	2.013	2.525	3.146	3.975	2.583	0.8	0.928	1.331	1.732	2.243	3.364	1.874	0.756
Volume (mln)	50	76.73	102.5	140.8	252	120.7	75.17	34.57	61	89.6	140	314.3	124.7	151
Trade interval (day)	0.01	0.022	0.038	0.069	0.206	0.066	0.108	0.01	0.026	0.048	0.088	0.205	0.07	0.075
Intensity	0.348	0.539	0.686	0.793	0.922	0.663	0.173	0.342	0.594	0.729	0.828	0.944	0.698	0.177
Zero return	0.06	0.169	0.277	0.399	0.617	0.299	0.173	0.066	0.221	0.357	0.522	0.764	0.381	0.212
Zero trade	0.239	0.317	0.414	0.581	0.796	0.458	0.176	0.228	0.288	0.361	0.493	0.812	0.417	0.176
Amihud (bp/mln)	0.015	0.041	0.07	0.103	0.165	0.077	0.049	0.01	0.022	0.04	0.066	0.12	0.049	0.038
Price disp. (bp)	0.007	0.085	0.174	0.28	0.457	0.195	0.144	0.002	0.031	0.093	0.171	0.316	0.117	0.111
IQR	0	0	0.001	0.002	0.004	0.002	0.002	0	0	0	0.001	0.002	0.001	0.001
High-low spread	0.132	0.226	0.294	0.602	0.69	0.375	0.203	0.073	0.138	0.184	0.231	0.284	0.183	0.075
CHL	0.001	0.011	0.026	0.039	0.063	0.028	0.022	0.001	0.003	0.011	0.023	0.04	0.015	0.014

Exchange Market	Enterprise Bonds							Corporate Bonds						
	5%	25%	50%	75%	95%	Mean	SD	5%	25%	50%	75%	95%	Mean	SD
Yield spread (%)	0.77	1.344	2.005	2.844	4.442	2.213	1.168	0.635	1.329	2.158	3.324	4.955	2.432	1.389
Rating	0.5	0.5	1	1.464	1.5	0.958	0.423	0.5	0.655	1	1.5	1.5	1.113	0.448
Coupon (%)	3.819	4.98	5.96	6.892	8.081	5.908	1.27	3.235	4.5	5.6	6.795	8	5.643	1.485
Time to maturity	1.476	2.993	4.05	5.37	7.524	4.227	1.827	1.422	2.273	3.648	4.237	6.211	3.489	1.536
Age	0.77	1.344	2.005	2.844	4.442	2.213	1.168	0.635	1.329	2.158	3.324	4.955	2.432	1.389
Volume (mln)	0.2	1.236	3.348	6.065	14.813	4.667	5.024	2.224	5.206	9.021	18.242	66.397	17.81	25.18
Trade interval (day)	1.825	3.285	9.49	28.835	80.665	24.455	47.45	0.006	0.014	0.029	0.058	0.148	0.047	0.057
Intensity	0.384	0.594	0.72	0.856	0.991	0.714	0.177	0.446	0.624	0.72	0.829	0.96	0.717	0.151
Zero return	0.013	0.159	0.354	0.59	0.966	0.396	0.286	0.058	0.337	0.585	0.885	1	0.585	0.311
Zero trade	0.223	0.351	0.507	0.716	0.905	0.534	0.215	0.24	0.331	0.43	0.577	0.85	0.471	0.183
Amihud (bp/mln)	0.056	0.417	1.063	2.469	9.992	2.62	6.128	0.025	0.08	0.267	0.967	4.269	1.161	3.902
Price disp. (bp)	0.004	0.042	0.1	0.192	0.483	0.154	0.188	0.004	0.026	0.065	0.148	0.358	0.109	0.131
IQR	0	0.001	0.002	0.003	0.008	0.003	0.004	0	0	0.001	0.002	0.004	0.001	0.002
High-low spread	0.141	0.269	0.381	0.509	0.702	0.4	0.181	0.077	0.142	0.211	0.352	0.515	0.253	0.146
CHL	0	0.03	0.056	0.088	0.139	0.062	0.043	0	0.001	0.018	0.041	0.088	0.027	0.03