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We construct a daily liquidity index of the China government bond market using transaction data from the national interbank market over the past twenty years. The index is a composite of popular price-based and quantity-based metrics of liquidity. The composite indexes, obtained by averaging across different metrics or by applying principal component analysis, both point to a better liquidity condition after 2010. Market liquidity swings appear to be highly correlated with domestic funding liquidity and financial market volatility, but display less correlation to global macrofinancial indicators. Our findings suggest that further deepening of the bond market would support domestic financial stability and monetary operations down the road.

Keywords: China government bond, Bond liquidity, Principal component analysis, Regime switching model

JEL Classification: G12

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1. Introduction

Investors are increasingly attracted to the rapidly growing Chinese bond market. Following more than two decades of reforms aimed at developing the market and improving investor access, China's bond market has become the second largest fixed income market in the world in 2020.[5] Among all debt instruments in China, China government bonds and government-backed policy bank bonds (or agency bonds) have the largest market capitalization and trading volume.[6] They serve as benchmarks for the pricing of credit bonds and play a critical role in facilitating monetary policy transmission. They are used by institutional investors as collateral in repurchase transactions and are purchased by foreign investors for diversification benefits.

Despite the importance of China's government bond market, no studies have provided a comprehensive measure of its liquidity, which is a key determinant of price efficiency, policy transmission and market development.[7] Mo and Subrahmanyam (2020) propose a liquidity mesasure but their focus is on China's corporate bond market. Other similar studies focus mostly on advanced economies and a few emerging markets.[8]

In this paper, we construct a composite daily liquidity index of China's government bond market over 2001-2019. We exploit rich daily trading information recorded by China Central Depository & Clear Corporation (CCDC). We focus on popular price-based measures including bid-ask spread, the Amihud ratio, price dispersion, and high-low price spread, as well as some quantity-based measures, such as quote numbers, trade numbers and turnover ratio. To obtain the best quality of data on liquidity, we extract the *on-the-run* government bonds and agency bonds separately on each trading day and for each available maturity that reflect the most active trading

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[5] China's bond market capitalization reached USD14 trillion in mid-2020. Market size has grown by about 36 times from 2000 to 2020, compared with a 16-fold growth in the equity market capitalization during the same time.

[6] China's bond market is a complex ecosystem made up of three underlying sub-sectors - onshore RMB-denominated bonds (CNY), offshore RMB-denominated bonds (CNH) and offshore US dollar-denominated bonds, each with fundamentally different characteristics. Our study is on onshore RMB-denominated treasury bonds and policy bank bonds (CNY).

[7] In the whole paper, we use the term "government bond market" to refer to "government and agency bond market".

[8] For example, see Adrian et al. (2017) on the US treasury market liquidity, Anderson and Lavoie (2004) on the liquidity in market for Canadian government bonds, Hoyos et al. (2020) on the Mexican government bond market, and Hameed et al. (2019) on the Malaysian corporate bond market.

of the day.[9] On-the-run government and agency bonds are often the most in demand by institutional investors due to their high liquidity (when new benchmark bonds are issued, often the older "off-the-run" bonds are less traded). We combine all the different measures of liquidity to construct our composite liquidity indexes, as any single liquidity measure may only capture one dimension of the market (as in Hameed et al. (2019) and Adrian et al. (2017)). We do this either by averaging across different dimensions or by applying principal component analysis (PCA), which has the benefit of accounting for correlations of liquidity measures.

We find that market liquidity has steadily improved since 2010 and is currently high by historical standards. Before 2010, several domestic and global events (i.e. the SARS epidemic in 2003, the global financial crisis (GFC) in 2008 and the European debt crisis in 2009) were partly associated with low levels of market liquidity and significant liquidity swings. Market liquidity recovered notably and stabilized in the few years following the GFC, as China's large-scale rescue packages kicked in. However, during 2013-2015 the liquidity condition slightly deteriorated as authorities embarked on financial deleveraging to contain financial risk. Since then it remained relatively stable until the outbreak of the global COVID-19 pandemic in 2020.

We then use our liquidity indexes to examine what factors are associated with market liquidity in normal times and in times of extreme liquidity shortage. Using an event study, we show that domestic macro events and monetary policy changes have caused noticeable liquidity shocks. We complement the event study with formal and systematic econometric analysis, and find that the liquidity index is highly and consistently correlated with domestic funding liquidity and bond market volatility, but displays less correlation to global macrofinancial indicators. Using a regime-switching framework, we show that the correlation between market liquidity and the global factors becomes even weaker when we constrain our focus to periods of extreme liquidity freeze only.

Our study contributes to the policy discussion on the relationship between market size and market liquidity. Prior research on advanced countries' bond markets suggests

[9] This is similar to Hoyos et al. (2020), in which a liquidity index is formed using the on-the-run bond for each maturity on each trading day, instead of averaging across all trades and all maturities of the trading day.

that market size matters for market liquidity and vice versa (for example McCauley and Remolona (2000)).[10] The size of the whole market matters for liquidity because of economies of scale in market-making, i.e. in extracting information from quotes and positions taking. In turn, market liquidity can boost transactions by lowering trading costs, while market illiquidity may hamper the issuer's access to debt financing in the primary market and limit turnover in the secondary market. Our findings suggest that China's government bond market liquidity has increased steadily with its market size. However, liquidity may still be hindered by some constraints, as in the case of other less-developed financial markets.[11] Among these constraints is the prevalent role of domestic banks with their traditionally conservative trading strategy (Schipke et al (2019)). These constraints can be likely overcome if the increase in foreign participation experienced in recent years is sustained in the future. Foreign ownership of Chinese government bonds has increased notably from only 2% in 2010 to about 7.5% in the third quarter of 2020.[12] The recent inclusion in major global bond indexes will further boost foreign participation of local currency debt toward a more diversified investor base, and improve bond market liquidity.[13,14] Our liquidity index is useful for monitoring such changes and measuring the effects of future policy reforms and economic conditions.

The rest of the paper is organised as follows. Section 2 overviews the government bond market and explains the reasons for our focus on the national interbank market. Section 3 describes the data and constructs the bond liquidity composite index. Section

[10] McCauley and Remolona (2000) show that the larger the outstanding stock of publicly issued central government debt, generally the higher the turnover ratio in cash and futures trading for a group of 11 advanced economies using 1997 data.

[11] Typical constraints that affect liquidity in less-developed financial markets include holdings by government accounts, investors who do not trade actively, the trading microstructure, taxes, arrangements for repurchase, and clearing and settlement practices. Due to these factors market liquidity and market size may not always move proportionally (see for example Committee on the Global Financial System - BIS (1999) and Arvai and Heenan (2008)).

[12] According to https://asianbondsonline.adb.org/data-portal/, as of September 2020, foreign ownership of RMB-denominated Chinese government bonds rose to a record high with 22 months continuous inflow. In particular, foreign holdings of treasury rose to RMB 1.68 trillion, foreign holdings of policy bank bonds reached 0.54 RMB trillion based on data from CCDC.

[13] It also complements the Chinese yuan as a reserve currency in the special drawing rights (SDR) basket.

[14] In October 2020, China government bonds and policy bank bonds for the first time were added into the Bloomberg Barclays Global Aggregate Index. The index inclusion will eventually take China's weight in the index to 6.03% - the 4th largest in the index and the only one from emerging markets. FTSE announced that their FTSE World Government Bond Index will also include China government bonds starting from October 2021.

4 examines the effects of major macro and monetary events on liquidity movements, followed by Section 5 with an econometric analysis linking market liquidity to domestic and global financial and macro indicators. Sections 6 discusses policy implications, and Section 7 concludes.

2. Government bond market in China

China's government bonds (CGB) or treasury bonds have been issued by the Ministry of Finance since 1964. Initially issued as a way of financing fiscal expenses, the treasury bonds are now the key instruments deployed by the People's Bank of China (PBoC) to implement monetary policy through repos and reverse repos. Government-backed agency bonds are quasi-sovereign bonds issued by China's three policy banks: China Development Bank, Export-Import Bank of China, and Agricultural Development Bank of China, who are government-backed entities. Agency bonds were introduced in 1994, and since then had become one of the largest segments in China's bond market. To a certain extent, agency bonds enjoy even higher secondary market liquidity and are de facto (credit-) quasi-sovereign benchmark in practice.

Despite many new developments in the bond market since mid-2000 (such as the introduction of Negotiable CDs in 2013 and the permission of issuance of local government bonds in 2015), treasury and agency bonds are still by far the largest constituent in China's bond market in terms of both market capitalization and trading volumes. Figure 1 shows that, though with a declining trend, government and agency bonds still account for more than 30% of the total bonds outstanding during the past three years on average. They are the largest single constituent followed by local government bonds which account for 20% of bond market capitalization. Figure 2 shows that agency bonds alone are one of the most actively traded constituents in the last decade.[15] The increasing market capitalization of government bonds over time is associated with an increasing trading volume, and declining price spread, as indicated by Figures 3-4.

[15] Local government bonds are also called municipal bonds and are issued by local governments mainly to finance the local government infrastructure projects. The market had been slowly trending up since 2008 before taking a dramatic surge in 2014. The category "Others" in Figure 2 includes central bank bills, ABS, PPN, Financial bonds, and Convertible bonds etc.

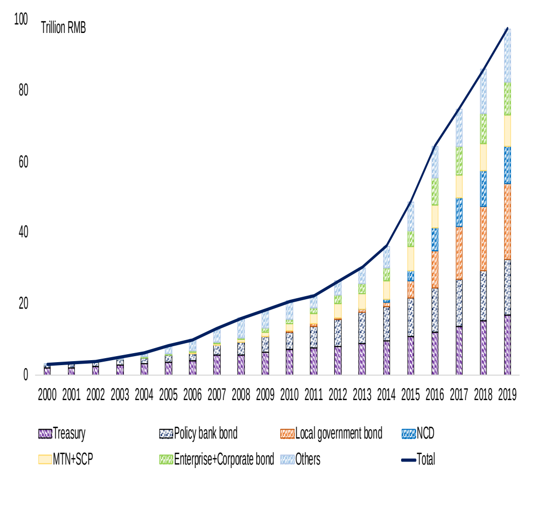
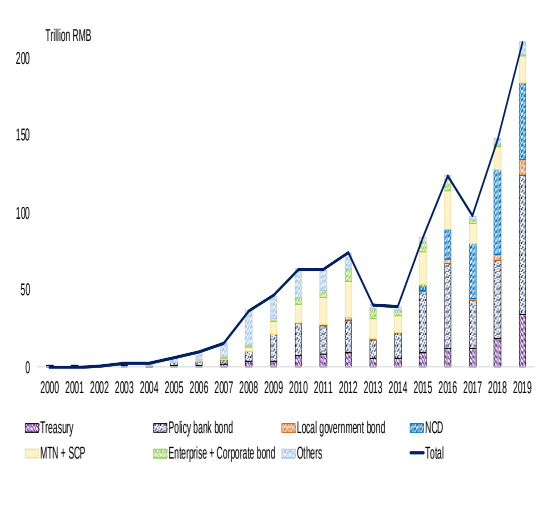
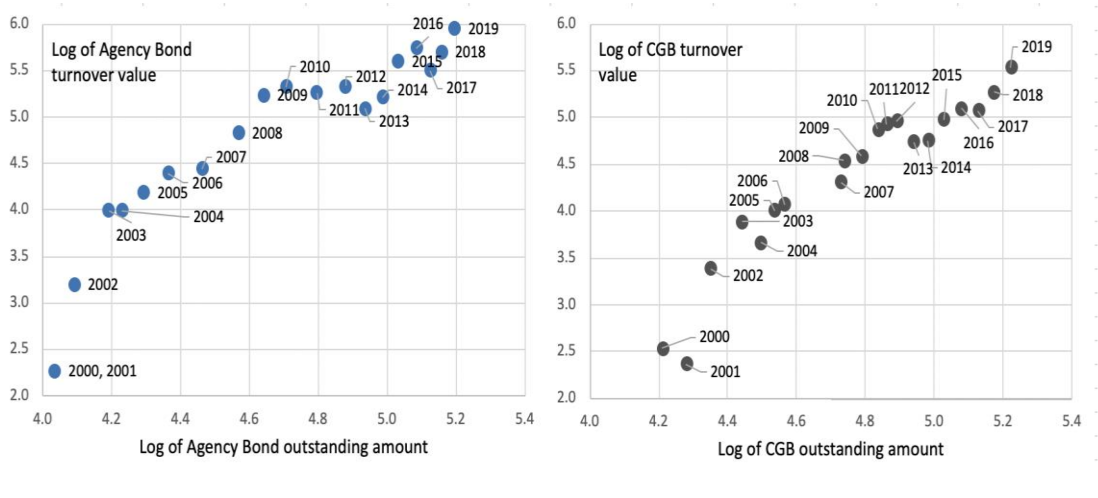
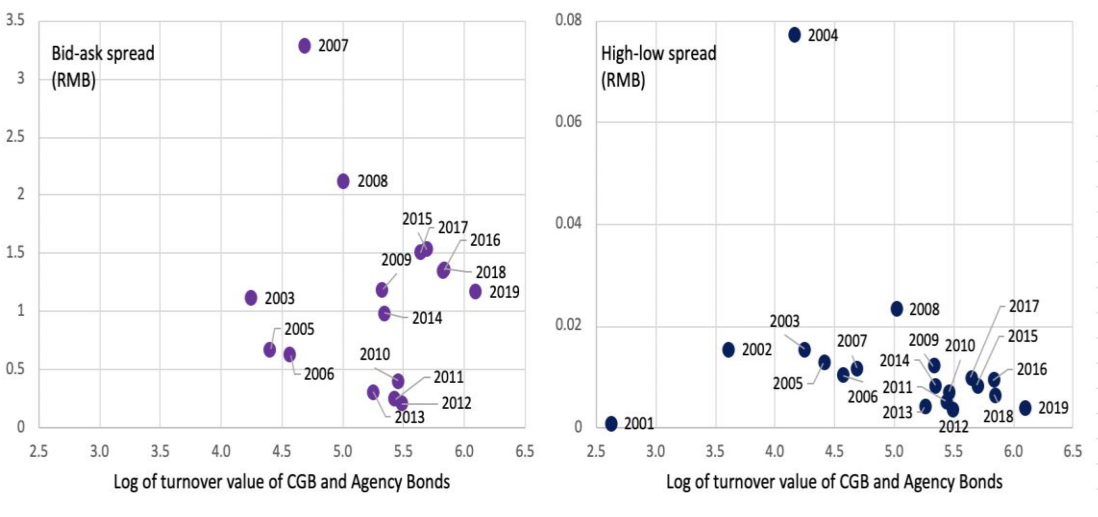
Figure 1: Market capitalization of China's debt instruments	Figure 2: Trading volume of China's debt instruments
	
Source: WIND	Source: WIND

Figure 3: Bond market capitalization vs. turnover value



Source: WIND

Figure 4: Bond turnover value vs. price spread

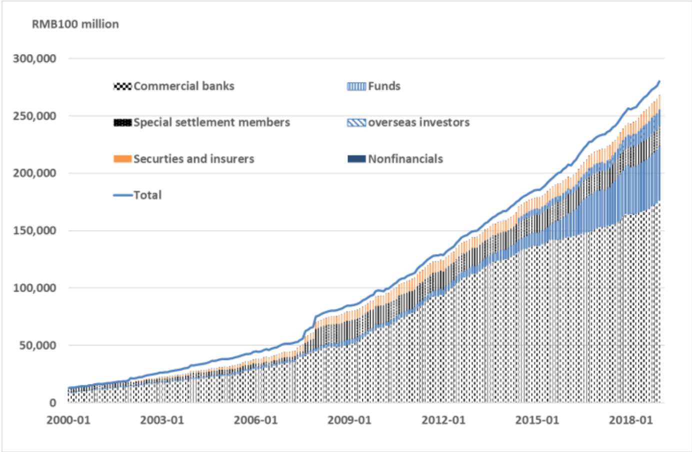


Source: WIND

Like many other dual-listed bonds, government and agency bonds are traded both on the exchange market (i.e., the Shanghai Stock Exchange) and on the interbank market (i.e., China Foreign Exchange Trade system). Although the exchange market was established earlier for bond trading, the market power started to shift to the interbank market after 2000, where large state banks and national joint-stock commercial banks are primary players (Figure 5).[16] Today government and agency bonds are far more traded in the interbank market than in the exchange market. In 2001, the cash bond trading volume in the interbank market was about twice the size of the exchange. In 2019, the cash bond trading reached RMB217.4 trillion in the interbank market, 25 times as large as that on the exchange. Meanwhile, government and agency bonds account for around 30% of the interbank bond (and note) trading, or about 29.8% of the total bond (and note) cash trading in the two markets. Given its prevalent status in bond trading, we apply the interbank bond data for our study.

[16] Commercial banks are not allowed to participate in the exchanges market. Such bond market segmentation is a special feature of China's bond market, in which two markets – interbank market and exchanges market – come under the oversight of different regulation bodies (see also Amstad and He (2019)). Historically the exchanges market was established for bond issuance in 1990, however due to scandals of banks' speculation in the stock market through bonds financing, a separate market – the interbank market – was established for banks in 1997 and gradually developed into a multi-participants market including banks, securities companies, insurance firms and mutual funds etc.

Figure 5: Investor structure in China's government bond market



Source: WIND

3. The bond liquidity index

In this section, we first describe the bond data, from which we construct seven bond liquidity measures and a bond liquidity composite index.

3.1 Bond dataset

Table 1: Summary statistics for government and agency bonds

Variable	Obs	Mean	Max	Min	Sd
Closing price	84788	101.4	147.5	65.4	4.4
Daily high price	84660	101.6	147.5	65.4	4.3
Daily low price	84669	101.2	146.6	3.1	4.6
Trading value	84788	1920	160000	0.1	5260
Number of deals	83965	13.9	381	1	31.0
Daily return (%)	84620	0.03	52.9	-32.7	1.2
Turnover ratio	74712	2.6	232.3	0.0	5.5
Best bid price	68876	101.0	226.6	76.6	4.4
Best ask price	69072	101.9	138.0	2.7	4.4
Number of quotes	84788	46.3	1440	0.0	77.9
Residual maturity	84772	8.3	50	0.1	7.5

Note: All the prices (in RMB) exclude accrued interest. The trading value is in the unit of 1 million RMB, and residual maturity is in the unit of year. Source: WIND

We obtain the bond transactions data from the China Central Depository & Clear Corporation through the data vendor WIND. Daily government and policy bank bond transaction data covering the period from 2001-June 2020 in the national interbank market are used. There are 475 government bonds in total and 2776 policy bank bonds once or currently traded in the interbank market.[17] The original dataset keeps more than seven million daily records of these bonds from the day when they were launched to their maturity dates (even though they are not traded every day). We drop the non-trading day records and from the pool of trading-days records, we keep the on-the-run bonds, i.e., the bonds with the highest trading value on each trading day and for each available maturity (in the unit of 0.1 year). This leaves us with 81300 valid observations. We select 11 transaction variables to construct 7 liquidity measures as shown below, which are further used to build the bond liquidity composite index. The summary statistics for the 11 transaction variables for on-the-run bonds are listed in Table 1. It shows that considerable differences exist among the sample of on-the-run bonds and that abnormal readings in daily prices and returns may also present.[18]

3.2 Bond liquidity measures

Following Hameed et al. (2019) and Hoyos et al. (2020), we construct 7 liquidity measures, which include:

Price measures:

1. *Bid-ask spread:* Defined as the best ask price – the best bid price.
2. *Amihud ratio:* Calculated as the ratio of the absolute value of daily return to the trading value. A larger ratio is associated with a less liquid market.
3. *Price dispersion:* Defined as the trading value weighted variance of closing price relative to the trading value weighted average closing price, which can be simplified as $(\sum_i w_i p_i^2)/(\sum_i w_i p_i) - \sum_i w_i p_i$, where $\sum_i$ represents summation across observations, p_i is the observation of the closing price, and w_i is the weight for observation *i*. We use two-week rolling window to calculate the weighted variance.

[17] As a comparison, there are 465 government bonds and 38 policy bank bonds traded in the Shanghai Stock Exchange, 465 government bonds and 9 policy bank bonds traded in Shenzhen Stock Exchange, and 141 government bonds and 296 policy bank bonds traded in the OTC market.

[18] Nevertheless, we keep these observations in the sense that a large part of these outlier effects would be dropped in the process of index construction and aggregation.

4. *Daily price amplitude:* Defined as the daily high-low price spread relative to the average daily high and low prices.

Quantity measures:

5. *Turnover ratio:* We fill some missing values of the turnover ratio by using the ratio of trading value to the market capitalization of the relevant bonds.
6. *Trade number:* The initial number of deals of on-the-run bonds deflated by the market capitalization of the corresponding bonds.[19]
7. *Quote number:* The initial number of quotes of on-the-run bonds deflated by market capitalization of the corresponding bonds.[20]

At the first step, we simply calculate daily sub-measures at each maturity according to the above definition. Table 2 lists the mean of the 7 sub-measures for selected maturities with standard deviations in parentheses. It appears that bonds with short maturities (i.e., less than 10 years) are more liquid than bonds with long maturities (i.e., more than 10 years). In terms of quantity measures, the 10-year bonds become the most liquid ones among all the bonds.

Table 2: Mean of price- and quantity-liquidity sub-measures at major maturities

Variable	Y1	Y2	Y5	Y10	Y20	Y30
Bid-ask spread	0.19	0.39	1.20	0.61	0.66	3.68
	(0.08)	(0.21)	(0.70)	(0.87)	(0.31)	(2.18)
Amihud ratio	0.000	0.005	0.002	0.003	0.009	0.003
	(0.00)	(0.05)	(0.00)	(0.03)	(0.07)	(0.01)
Price dispersion	0.001	0.002	0.003	0.002	0.010	0.002
	(0.00)	(0.01)	(0.01)	(0.01)	(0.08)	(0.01)
Price amplitude	0.002	0.003	0.005	0.008	0.009	0.009
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Turnover ratio	7.62	7.55	6.80	14.66	6.68	10.00
	(14.03)	(17.05)	(16.04)	(22.76)	(13.49)	(17.45)
Trade number	0.045	0.05	0.052	0.154	0.05	0.075
	(0.081)	(0.126)	(0.103)	(0.221)	(0.099)	(0.11)
Quote number	0.131	0.278	0.075	0.161	0.014	0.019
	(0.227)	(0.846)	(0.109)	(0.338)	(0.022)	(0.062)

Note: Standard deviations in parentheses. Source: Authors' estimates

[19] We set *Trade number* to be missing if the initial number of deals is recorded as 0 in the dataset when constructing the composite liquidity index.

[20] We set *Quote number* to be missing if the initial number of quotes is recorded as 0 in the dataset when constructing the composite liquidity index.

At the second step, we take a simple average across maturities on each trading day to obtain daily liquidity measures. Summary statistics for these liquidity measures are listed in Table 3. The bid-ask spread has much fewer observations than other measures, which leads to the composite bond liquidity index obtained by the PCA method shorter than that obtained by the simple average method.

Table 3: Summary statistics for daily liquidity measures

Variable	Obs	Mean	Max	Min	Sd
Bid-ask spread	3104	1.04	8.41	0	0.79
Amihud ratio	3902	0.02	10.11	0	0.18
Price dispersion	3928	0.04	2.64	0	0.14
Price amplitude	3620	0.01	0.41	0	0.02
Turnover ratio	3948	2.43	50.07	0	2.32
Trade number	3948	0.35	5.272	0	0.509
Quote number	3948	1.06	26.112	0	1.952

Source: Authors' estimates.

Table 4 presents the correlation matrix for daily bond liquidity measures. The quote number and trade number are highly correlated while other pair-wise correlations are relatively low. All price- and quantity-measures are positively correlated among themselves, but negatively correlated between them most times. The correlation matrix provides useful information that correlations among some liquidity measures should be controlled for when constructing the liquidity composite index, and our PCA approach fits to address the issue.

Table 4: Correlations between liquidity measures

	Bid-ask spread	Amihud ratio	Price dispersion	Price amplitude	Turnover ratio	Trades	Quotes
Bid ask spread	1						
Amihud ratio	0.20	1					
Price dispersion	0.43	0.32	1				
Price amplitude	0.31	0.20	0.39	1			
Turnover ratio	-0.07	-0.10	-0.09	0.02	1		
Trades number	0.17	-0.09	-0.19	-0.10	0.34	1	
Quotes number	0.10	-0.06	-0.17	-0.12	0.23	0.86	1

Source: Authors' estimates.

3.3 Composite liquidity index

We apply the principal component analysis (PCA) to build the composite liquidity index, accounting for correlations of measures by effectively assigning each measure its weight. Specifically, the PCA is aimed at conducting the Eigenvalue decomposition of the observed covariance matrix of the initial liquidity measures such that, the resultant Eigenvectors (i.e., the loading vectors for the principal components) are mutually orthogonal. Each principal components (PC) is a linear combination of the initial liquidity measures.[21] For instance, the ith principal component is

$$PC_i = a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \qquad (1)$$

where x_j (j=1,2,…n) denotes the jth initial liquidity measure with its loading a_{ij} (j=1,2,…n) . The composite liquidity index represented by the first i principal components is simply read as

$$Compindex = (k_1PC_1 + k_2PC_2 + \ldots + k_iPC_i) \qquad (2)$$

where k_i is the weight for the i^{th} principal component, which is simply the share of the i^{th} ordered Eigenvalue in the total of the first i Eigenvalues. The explanatory power of principal components is recorded in Table 5. We take the first 5 principal components to construct the composite index according to Equation (2), as they are able to account for 92% of the total variance (Eigenvalues) of all principal components.[22]

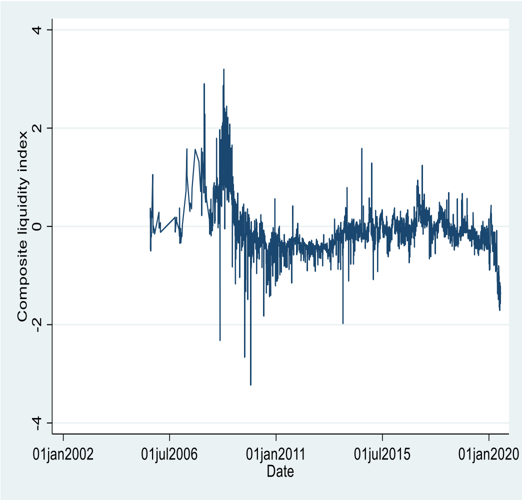
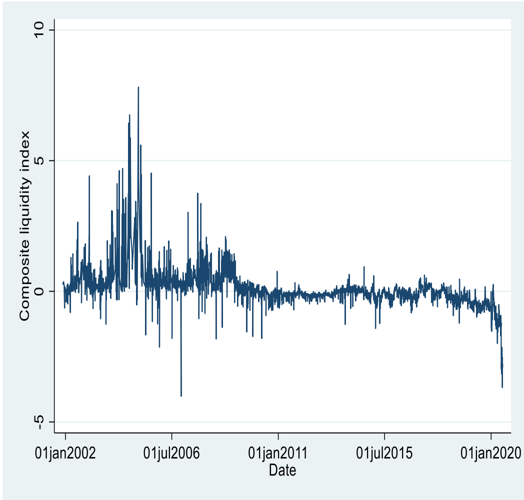
Table 5: Variance explained by principal components

Component	Eigenvalue	Proportion
Comp1	2.223	0.318
Comp2	1.844	0.263
Comp3	0.924	0.132
Comp4	0.809	0.116
Comp5	0.6	0.086
Comp6	0.476	0.068
Comp7	0.123	0.018

Source: Authors' estimates

[21] Before conducting the exercise, we first multiply -1 to all 3 quantity measures, so that larger (and positive) values of 7 measures all point to more illiquid market condition, and smaller (and negative) values of these measures point to more liquid market condition. Then we normalize all seven measures into zero-mean and unity-variance ones (Z-score) before aggregation.

[22] In line with Altman (2011) to rank the relative importance of explanatory variables, it can be verified based on Eigenvalues and Eigenvectors that, the bid-ask spread, the price amplitude, and the turnover ratio are (almost equally) the most important contributors to the composite liquidity volatility, to which each contributing around 21%-23%. Contribution of the price dispersion is around 18%, followed by the Amihud ratio of 11%. Contributions of trades and quotes are small, around 2%-4%. An alternative way is to construct price and quantity indices separately using PCA, and then aggregate the two sub-indices using PCA again to obtain a composite liquidity index. The composite index constructed this way is smoother due to double "averaging" of liquidity measures. It also gives more weight to the Amihud ratio and the price amplitude.

Figure 6: Composite liquidity index by PCA method	Figure 7: Composite liquidity index by simple average method
	
Source: Authors' estimates	Source: Authors' estimates

The composite liquidity index obtained by PCA is presented in Figure 6. Note that higher (and positive) value of liquidity index points to more illiquid market condition, and lower (and negative) value of the index points to more liquid market condition. Figure 6 shows that (1) the liquidity index was far more volatile before 2010; (2) market liquidity improved significantly since 2010, which could be due to authorities' liquidity injection after the global financial crisis; (3) liquidity condition further improved so far in 2020, on global monetary easing after the outbreak of the COVID-19 pandemic. As discussed earlier, it lacks observations before 2006.[23] Alternatively, we take the simple average of 7 liquidity measures to construct the composite index and show it in Figure 7.

In the following two sections, we use the liquidity index obtained by the PCA method for our analysis, as this index is less distorted by missing values and can better address the interconnectedness among liquidity measures.

[23] By this method, the observations of the composite index would be fewer than what would be obtained by taking simple average across 7 liquidity measures due to missing values of these measures.

4. Macro events and liquidity conditions: a brief overview

To study the bond market liquidity swings, we conduct a simple event study, examining several episodes associated with large liquidity stress or easing. Since the augmented Dickey-Fuller test does not detect the unit root of the liquidity index, we propose an AR(4) process with calendar effects to fit the index and calculate its predicted value, according to sample (partial) autocorrelations:[24]

$$Compindex_t = \sum_{i=1}^{4} \beta_i Compindex_{t-i} + \sum_{i=1}^{12} \gamma_i M_i + \sum_{i=1}^{5} \rho_i W_i + \varepsilon_t \quad (3)$$

where *Mi* and *Wi* are dummies for month-of-the-year and day-of-the-week effects respectively. As defined, a large positive gap between the index value and its predicted value suggests an episode with liquidity stress, while a large negative gap indicates an episode with liquidity easing. Figures 8-12 below illustrate five episodes in a 7-day window, where each episode occurs at $t = 0$. Several other macrofinancial indicators are also plotted in order to examine their potential co-movements with the liquidity index. Their definitions are listed in Table A1 in the appendix. All the values of variables are normalized to 1 if they are positive (and -1 if they are negative) at $t = 0$.

We find that some of the significant liquidity changes could be attributed to extreme global shocks, while others are often associated with domestic (monetary and fiscal) policy shocks. Figure 8 covers the episode of the Lehman Brothers bankruptcy during the global financial crisis. Liquidity stress loomed before the announcement of bankruptcy and continued into the second day of the announcement before the situation improved and stabilized. For this particular event, the US financial market liquidity stress (represented by MOVE, VIX and USTED) appears to have a quick contagious effect on Chinese financial market, causing a large swing in the domestic bond and the RMB foreign exchange markets (i.e. CGBYLDV and CNYIMPV). The relatively quick rebound of market liquidity was partially due to the swift monetary policy responses,

[24] Liquidity developments are subject to calendar effects such as the Chinese New Year effect, varying both according to the day of the week and the month of the year. Alternatively, a process of volatility may be added to form ARCH or GARCH model to address time varying volatility, but that does not change the coefficient estimates in general. Also, one may use a one-week window to filter out some noises of the liquidity index first and then estimate the AR process. But that does not change the basic episodes with liquidity distress or easing.

including lowering the required reserve ratio (RRR) in September 2008 for the first time in two years.[25]

Figure 9 covers the European debt crisis in December 2009, marked by a downgrade of Greek sovereign debt by both Fitch and Moody's. The initial impact on domestic liquidity was high, but the situation alleviated after two days. Meanwhile, both the RMB foreign exchange and money markets were staying put, so were the US and global markets, suggesting the bond liquidity stress in the two days was mainly due to a panic.

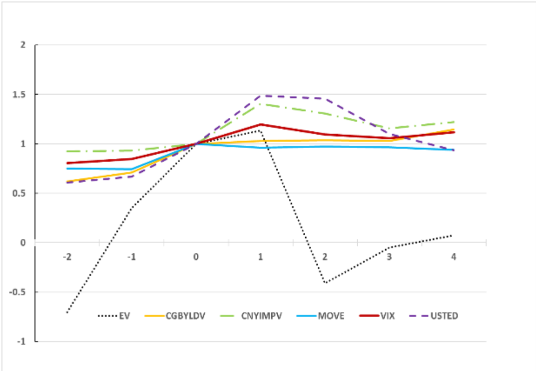
Figure 10 depicts the Chinese banking liquidity crunch in June 2013, evidenced by a rapid rise in the interbank overnight lending rates to a high of 30% from its usual rate of less than 3%. The sharp rise in the interbank funding cost drove liquidity index up significantly on impact and over the following three days. The shortfall in interbank credit occurred shortly after the US tapering in May 2013, though the US liquidity indicators did not show much distress in the episode.

Figure 11, on the other hand, illustrates a considerable improvement in liquidity following the launch of Bond Connect in July 2017, which enables offshore investors to buy and sell bonds in China's interbank market and hold these securities in their Hong Kong custodian's accounts. The event led to an increase in bond liquidity in the seven-day window, though much of the effect may appear in the medium to longer term. The episode did not appear to have an impact on other segments of the domestic market.

Figure 12 presents a temporary shortfall in bond liquidity on 29 May 2020, when it was close to the deadline for corporate tax payment. The corporate tax payment along with new government bond issuance in May drained market liquidity, driving up money market rates. However, the PBoC conducted a RMB300 billion reverse Repo on the same day, effectively lowering money market rates and easing bond market liquidity in the following days.

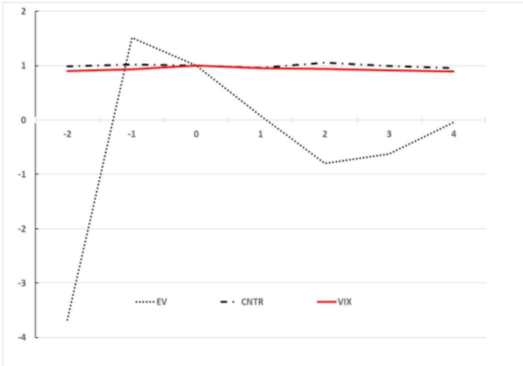
[25] During mid - 2006 to September 2008, China went through a tightening cycle with the PBoC increasing the RRR 18 times. In Sept 2008, the PBoC started to lower RRR for the first time in two years, and by the end of 2008 RRR had been lowered four times. This happened right after a series of negative financial events in the US financial market, including the announcement of Lehman Brothers bankruptcy and the takeover of AIG by the US Federal Reserve on 15-16 September in 2008. Only then the US financial crisis started showing serious signs of what would evolve into a global financial crisis.

Figure 8: Lehman bankruptcy on 16 September 2008



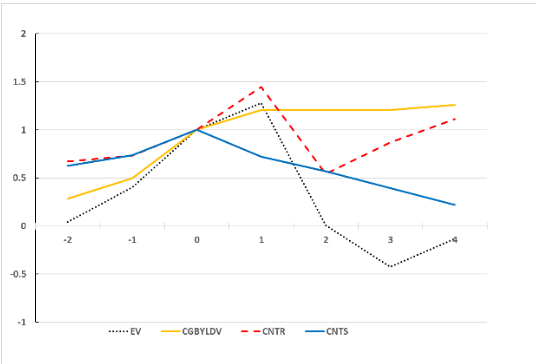
Source: Authors' estimates

Figure 9: Greece sovereign debt downgraded on 8 December 2009



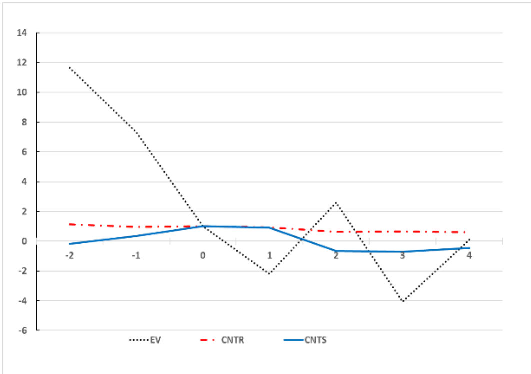
Source: Authors' estimates

Figure 10: Chinese banking liquidity crisis on 20 June 2013



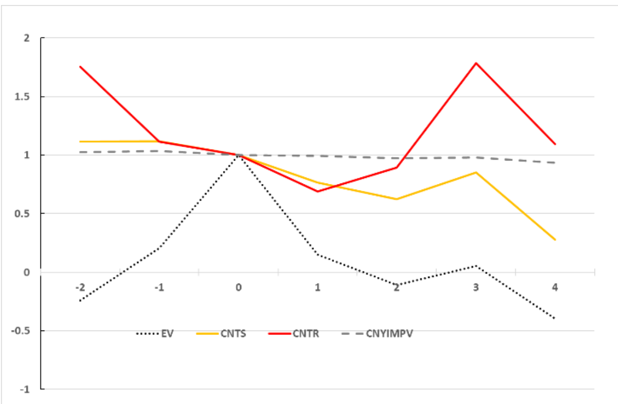
Source: Authors' estimates

Figure 11: Launch of Bond Connect Scheme on 3 July 2017



Source: Authors' estimates

Figure 12: A temporary shortfall in bond liquidity due to multiple factors on 29 May 2020



Source: Authors' estimates

5. Explaining liquidity index variation

Based on findings of how various macrofinancial indicators co-move with bond market liquidity in the above event study, in this section we investigate the driving force of market liquidity in a more systematic way using econometric analysis. We first perform OLS regressions linking our constructed liquidity index to domestic and global macrofinancial indicators, most of which are already used in the event study in the previous section. We then apply the regime switching model to estimate the likelihood that market liquidity suddenly evaporates and use it to focus on the role of these determinants during liquidity freeze.

Following Hoyos et al. (2020), we categorize financial and macro indicators into domestic funding liquidity indicators, domestic financial market volatility indicators, the US and global macrofinancial indicators. (see Table A1 and A2 in the appendix for detailed definitions and correlations of these variables).[26] We use each group of indicators as independent variables before putting them together in regressions.

5.1 Regression evidence: OLS

Market liquidity variations are often associated with stress in funding liquidity, as argued by Brunnermeier and Pedersen (2009). Tighter funding liquidity will push up the borrowing costs, and lenders are less likely to lend. Government bonds are often used in the repo market as high-quality collateral. A less active funding market and rising borrowing cost will drive up demand for holding government bonds as safe assets, and thereby reduce bond trading and market liquidity. Column (1) in Table 6 shows that tighter domestic funding liquidity (or tighter money market condition) indeed is associated with lower bond market liquidity, with the coefficient of both 1-month Chinese treasury-repo spread (CNTR) and Chinese treasury-IRS spread (CNTS) being (significantly) positive. These two funding liquidity indicators explain 48% of the liquidity index variation.[27]

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[26] Table A2 shows that three U.S. indicators are highly correlated with each other, and they are also highly correlated with domestic stock volatility. Other pairwise correlations are relatively low, but they can still affect coefficient estimates as shown in the following regressions.

[27] Broker and dealer's leverage, as suggested by Adrian et al. (2017), can also be a domestic funding liquidity indicator. When funding market is squeezed, brokers and dealers find it more difficult to borrow to finance their business, and this in turn reduces market liquidity. Consistent with this argument, we find that higher broker's leverage is associated with higher market liquidities when leverage is the single

Table 6: Factors to explain domestic bond market liquidity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Domestic funding liquidity	*Domestic financial market volatility*	*U.S. and global macrofinancial indicators*		*All indicators*		
CNTR	0.033***				0.018	0.019*	0.022*
	(3.003)				(1.633)	(1.661)	(1.907)
CNTS	0.030				0.144***	0.151***	0.153***
	(1.317)				(5.909)	(6.055)	(6.125)
CGBYLDV		0.707***			0.530***	0.603***	0.616***
		(21.055)			(13.580)	(14.428)	(15.806)
CNSSEV		0.002**			0.002***	0.002**	0.001*
		(2.465)			(2.641)	(2.403)	(1.716)
CNYIMPV		0.044***			0.017**	0.028***	0.024***
		(7.218)			(2.504)	(4.068)	(3.390)
USTED(-1)			0.460***		0.345***		
			(13.545)		(12.049)		
MOVE(-1)			0.002***			0.001***	
			(4.324)			(2.757)	
VIX(-1)			0.002				0.004***
			(1.421)				(4.052)
BrentR(-1)				-0.007***	-0.004*	-0.005**	-0.004
				(-2.711)	(-1.707)	(-2.005)	(-1.566)
CESIGL(-1)				-0.003***	-0.001*	-0.001***	-0.001**
				(-8.425)	(-1.778)	(-3.862)	(-2.361)
N	2731	2971	2205	2251	2020	2064	2064
Adj R2	0.48	0.60	0.60	0.52	0.63	0.60	0.61

Note: T-statistics in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source: Authors' estimates

Domestic funding liquidity is shown to be highly relevant with market liquidity, which prompts us to check the second order effect of domestic financial market movement on bond market liquidity. Presumably in times of stress, tighter funding liquidity could be caused by various financial market volatility shocks. Column (2) in Table 6 shows that high domestic bond market volatility (CGBYLDV), equity market volatility (CNSSEV) and option-implied CNY volatility (CNYIMPV) are all related to low bond market liquidity, as Adrian et al. (2017) find in the US Treasury market.[28]

explanatory variable in the full sample. However, the regression using post-2009 sub-sample shows the role of brokers and dealers in the bond market becomes weaker, as the coefficient sign turns positive and insignificant.

[28] A few notes on the variable selection: (1) A good substitute for the government bond yield volatility is the bond yield volatility for China Development Bank (CDBYLDV), which exerts similar significant effects on market liquidity. Note that we do not include them together in the same regression due to their high correlation of 0.82. (2) The implied volatility of CNY is found to be more significant in explaining the bond market liquidity than CNY historical volatility. (3) We prefer CNSSEV to CNETFV as the stock volatility measure because the former covers longer horizon. (4) We use the first order Brent oil price

We test the spillover effects of the US and global market movement (with one-day lag for causality consideration) on domestic bond market liquidity condition. As shown in column (3) and (4) in Table 6, high US TED spread (USTED), bond market volatility (MOVE) and stock futures volatility (VIX) contribute to low domestic bond market liquidity, while higher oil returns (BRENTR, presumably pushed up by demand) and positive Citi global index (CESIGL) suggest a good global economic environment, leading to a better domestic bond liquidity condition.

Finally, we combine all groups of indicators and show that all factors together explain more than 60% of domestic bond market liquidity variation (columns (5)-(7)). The coefficient sign and significance of these factors remain except for the oil price movement, whose effect seems to be absorbed by other variables.

Considering the potential structural break around 2009 when bond liquidity started to improve and volatility began to decline (Figures 6-7), we re-do our regression analysis using post-2009 sub-sample (see results in Table A3 in the appendix). While domestic factors are still shown to be the main drivers of market liquidity, the global economic condition CESGIL, and US bond and futures market volatility seem to play a less important role.[29]

To sum up, the regression results suggest that bond market liquidity is mainly and consistently driven by domestic funding conditions, its correlation with US and global factors is to a lesser extent and mostly before the global financial crisis.

5.2 Regime switching model

Market liquidity tends to switch abruptly between different levels (Figures 6-7) and may exhibit different correlations during different "regimes", which could be characterized in a regime switching framework. In this section we focus on the role

movement instead of Brent oil price volatility because of the estimated coefficient for the former is more stable in regressions. (5) We do not include Citi US economic surprises or Citi emerging market economic surprises mainly due to their high correlations with the Citi global economic surprises (CESIGL). Each of them has coefficient sign similar to CESIGL in regressions.

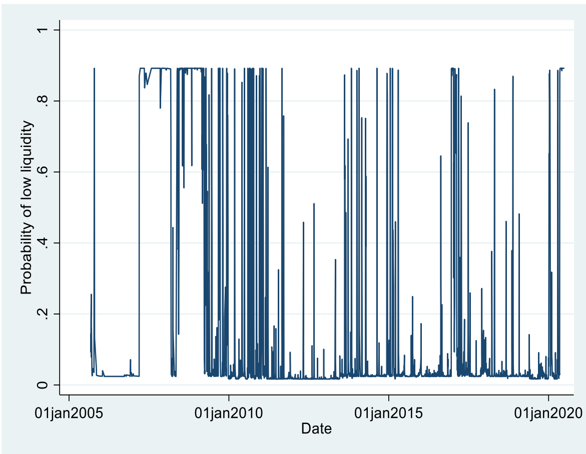
[29] In particular, VIX is no longer significant post 2009, and the global positive shock (CESIGL) reverses its sign. In fact, a positive sign remains even when CESIGL is the single explanatory variable, which may be related to domestic counter-cyclical monetary and fiscal policies. We leave it for future investigation.

played by various determinants particularly during liquidity shortages. Following Hoyos et al. (2020) and IMF (2015), we first use a dynamic Markov Switching model to estimate the regime of liquidity condition as follows:

$$Compindex = a_0^k + \varepsilon_t^k \quad (4)$$

with $\varepsilon \sim N(0, \delta^k)$ and k =1, 2, 3 refers to high, mild, and low liquidity condition respectively.[30] The estimated probability of low liquidity is shown in Figure 13.

Figure 13: Probability of low liquidity



Note: The estimated probability of low liquidity shown in Figure 13 ranges between 0.014 and 0.891. Source: Authors' estimates

As expected, the highest liquidity stress identified occurred in periods that coincide with several major macro events: in March 2007-March 2008 the global economy was headed towards imminent financial crisis; in June 2008-February 2009 banking giants Bear Sterns and Lehman Brothers failed one after another; and finally during March 2009-April 2011 market liquidity became extremely volatile when debt crisis spread across European economies.[31] Despite an overall high liquidity situation

[30] The joint hypotheses of equality of α and δ between any two states are rejected at 1% significant level by the Chi-square tests, suggesting the 3-state assumption is more reasonable than a 2-state assumption. The parameters for the three states are listed in Table A4 in the appendix.

[31] Figure 13 also revealed some heightened liquidity volatility but not associated with those "renowned" events: August 2013 –April 2014, December 2014 – April 2015, and Dec 2016 – April 2017, when the situation in general is not as intense as during the period of those major events.

in the first half of 2020 (see also Figures 6-7), the probability of liquidity stress is occasionally high.

We then examine the role of various macrofinancial indicators in liquidity stress using the same specification as in Table 6 with the estimated probability of low liquidity as dependent variable. Results are reported in Table 7. Several points are worth highlighting. First, the combined explanatory power of all the factors is still high, explaining 42% of the variation in the probability of liquidity stress. Although in normal times heightened domestic treasury-IRS swap spread (CNTS) is associated with low liquidity, this relationship breaks down. Similar findings also appear with domestic stock market volatility (CNSSEV), whose relationship with market liquidity is reversed during liquidity stress. In terms of US indicators, only the coefficient of the US Ted spread is positive and significant when they are the exclusive explanatory variables in Regression (3). Furthermore, the sign of all their coefficients becomes negative in Regressions (5)- (7), suggesting that less spillovers from the US market are displayed in the event of domestic liquidity shortages, in the sense that domestic market liquidity tends not to co-move with the US financial market condition. The global variables perform pretty much the same as in the baseline regressions.[32]

Table 7: Factors to explain low liquidity probability obtained from regime switching model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Domestic funding liquidity	*Domestic financial market volatility*	*U.S. and global macrofinancial indicators*		*All indicators*		
CNTR	0.025***				0.023***	0.026***	0.023***
	(3.326)				(2.801)	(3.224)	(2.836)
CNTS	-0.038**				0.021	0.023	0.021
	(-2.454)				(1.161)	(1.321)	(1.205)
CGBYLDV		0.289***			0.229***	0.270***	0.243***
		(12.665)			(8.008)	(9.120)	(8.780)
CNSSEV		-0.002***			-0.002***	-0.002***	-0.002***
		(-3.665)			(-4.089)	(-4.062)	(-3.256)
CNYIMPV		0.027***			0.029***	0.033***	0.035***
		(6.467)			(5.900)	(6.616)	(7.009)
USTED(-1)			0.071***		-0.048**		
			(2.959)		(-2.275)		

[32] We also use the 5-day moving average of the liquidity index to estimate the state probabilities to account for potential bias estimates due to noises from the "raw" liquidity index. The low liquidity probability for smoothed index is shown in Figure A1 and the corresponding regression results are reported in Table A5 in the appendix. The change in low liquidity probability turns out to be less intense than in Figure 13. The regression results are largely in line with that using the raw liquidity index.

MOVE(-1)			-0.000			-0.002***	
			(-0.496)			(-4.751)	
VIX(-1)			0.001				-0.004***
			(1.567)				(-5.175)
BrentR(-1)				-0.000	0.000	-0.000	-0.001
				(-0.004)	(0.075)	(-0.161)	(-0.624)
CESIGL(-1)				-0.002***	-0.001***	-0.001***	-0.002***
				(-10.670)	(-6.604)	(-6.204)	(-7.819)
N	2731	2971	2158	2204	1999	2043	2043
Adj R2	0.39	0.49	0.43	0.45	0.46	0.46	0.46

Note: T-statistics in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source: Authors' estimates

6. Comments on bond market liquidity and investors' trading strategies

The composite liquidity index suggests market liquidity of China's government and agency bonds largely remained stable in the last decade, highlighting a lack of government bonds trading proportional to their market capitalization. As for comparison, the market capitalization of policy bank bonds is slightly lower than that of government bonds in 2019, their trading volume is more than twice the size of government bonds (Figures 1-2). One major reason is the prevalent role of domestic banks in the investor structure (Figure 5), with their trading style being traditionally conservative. Meanwhile, various funds are keen to trade agency bonds rather than government bonds, because they can enjoy advantageous tax treatment toward agency bond trading .[33] Although the central government bonds and policy bank bonds are almost perfectly substitutable, the latter provides relatively high yields with almost no default risks and this makes them more attractive.

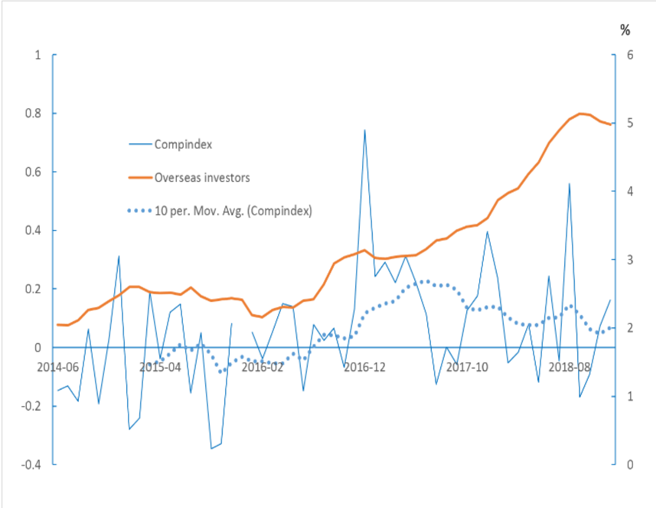
Measures that encourage foreign participation and foreign capital inflows could help to improve government bond liquidity. Although international investors were allowed to enter Chinese capital markets in 2002， it was only after restrictions on foreign investment were further relaxed in 2016 and Bond Connect was launched in 2017 that the effect of international investment on the trend of bond liquidity became significant (Figure 15).[34] Looking forward, a prolonged situation of global low rates and a strong domestic currency are likely to attract more capital inflows, contributing to higher bond market liquidity.[35]

[33] See the online article, "Why the liquidity of government bonds is lower than agency bonds?", *http://bond.jrj.com.cn/2017/07/07111322712664.shtml*, July 2017.

[34] In early 2019, international investors are also allowed to trade domestic futures and option products besides equities and bonds, so that international investors are able to construct their RMB-denominated portfolios from a wide range of asset products.

[35] Some government bonds have reached yield of 3% recently in this low interest rate environment. They offer higher yield than developed markets while exhibiting low volatility vs. major bonds globally (UBS,

Figure 15: Bond holdings by international investors vs. the bond liquidity index



Source: Authors' estimates

On the other hand, there is still room to increase the pool of government bonds to accommodate potential investors in the long run for liquidity improvement, given that China's GDP has reached two thirds of the US', while the capitalization of outstanding Chinese government bonds is around one fifth of the size of US government bonds.

7. Concluding remarks

This paper studies the liquidity of China's government and agency bonds during the past two decades. We construct a bond liquidity index based on price and quantity measures. We find that bond market liquidity condition after 2010 appears to be better than before. Market liquidity is mostly driven by domestic monetary and financial conditions while the US and global factors impact to a smaller degree. Compared with the US bond market, the size of China government bonds market is still small and the foreign participation rate is still low. Recent inclusions of Chinese bond into major global bond indexes underpins the growing demand from foreign investors as China's financial market continues to open up. In July 2020, the central government approved to connect the interbank and the exchange bond markets, in a move to unify domestic

2020).

bond markets and eliminate price disparities across the trading houses. These measures would further improve domestic bond market liquidity down the road.

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Appendix

Table A1: Definition of domestic and global macrofinancial indicators

Variable	Definition	Starting Date
Volatility in domestic financial market		
CN bond mark volatility historical (CGBYLDV)	Annualized 30-day yield volatility of 10-year government bonds	2002 Jan
CN bond mark volatility historical (CDBYLDV)	Annualized 30-day yield volatility of 10-year China development bank bonds	2002 Jan
CN equity market volatility historical (CNSSEV)	Annualized 30-day volatility of SSE composite stock index	2001 Nov
CN equity market volatility implied (CNETFV)	CBOE China ETF Volatility (30-day option implied volatility)	2011 Mar
CN FX market volatility historical (CNYV)	Annualized 30-day standard deviation of CNYUSD exchange rates	2001 Feb
CNY option implied volatility (CNYIMPV)	Implied volatility of 3-month on-the-money CNYUSD option	2002 Dec
Volatility / Stress Variables in the US financial market		
US bond market volatility (MOVE)	MOVE index	2000 Jan
US CBOE volatility index (VIX)	CBOE volatility index	1999 Dec
US TED spread (USTED)	3-month LIBOR minus 3-month T-bill yield	1999 Dec
Domestic funding liquidity / Credit risk variables		
CN treasury-swap spread (CNTS)	1-year interest rate swap rate of FR007 minus 1-year government bond yield	2008 Feb
CN treasury-repo spread (CNTR)	1-month interbank repo rate minus 1-month government bond yield	2002 Jan
Global macro variables		
Brent oil futures movement (BRENTR)	Percentage change in price for Brent oil futures	1999 Dec
Citi global economic surprise index (CESIGL)	Weighted average of 3-month standard deviations of economic surprises	2003 Jan

Sources: Bloomberg, CBOE, Chinabond, Shanghai Stock Exchange, CFETS, Federal Reserve Bank of St. Louis

Table A2: Correlations of domestic and global macrofinancial indicators

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) CNTR	1.000									
(2) CNTS	0.196	1.000								
(3)CGBYLDV	0.034	0.135	1.000							
(4) CNSSEV	0.233	0.158	0.266	1.000						
(5) CNYIMPV	0.169	0.382	0.127	0.108	1.000					
(6) USTED	0.182	0.253	0.385	0.390	0.298	1.000				
(7) MOVE	0.174	0.034	0.417	0.533	0.012	0.640	1.000			
(8) VIX	0.170	0.130	0.403	0.443	0.150	0.626	0.727	1.000		
(9) BRENTR	0.007	0.014	0.044	0.041	0.012	0.025	0.028	0.099	1.000	
(10) CESIGL	0.136	0.332	0.202	0.173	0.118	0.288	0.101	0.310	0.009	1.000

Source: Authors' estimates

Table A3: Factors to explain bond market liquidity: post-2009 subsample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CNTR	0.041***				0.021**	0.025***	0.025***
	(4.982)				(2.375)	(2.789)	(2.795)
CNTS	0.143***				0.146***	0.147***	0.148***
	(8.077)				(7.344)	(7.396)	(7.407)
CGBYLDV		0.445***			0.398***	0.416***	0.413***
		(14.844)			(11.625)	(11.707)	(12.196)
CNSSEV		0.003***			0.003***	0.003***	0.003***
		(4.644)			(4.760)	(4.364)	(4.167)
CNYIMPV		0.000			0.002	0.004	0.003
		(0.082)			(0.314)	(0.637)	(0.524)
USTED(-1)			0.325***		0.200***		
			(6.543)		(4.816)		
MOVE(-1)			0.003***			-0.000	
			(6.228)			(-0.154)	
VIX(-1)			-0.004***				0.000
			(-3.245)				(0.476)
BrentR(-1)				-0.005**	-0.004**	-0.004**	-0.004**
				(-2.306)	(-2.084)	(-2.118)	(-2.031)
CESIGL(-1)				0.003***	0.002***	0.002***	0.002***
				(8.766)	(5.540)	(6.102)	(6.175)
N	2460	2523	1872	1913	1818	1859	1859
Adj R^2	0.46	0.49	0.49	0.49	0.56	0.55	0.55

Note: T-statistics in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source: Authors' estimates

Table A4: Parameters for 3 liquidity states

	State 1 High liquidity	State 2 Mild liquidity	State 3 Low liquidity
α	-0.39	-0.041	0.276
	(0.007)	(0.007)	(0.052)
δ	0.140	0.182	1.016
	(0.005)	(0.005)	(0.037)

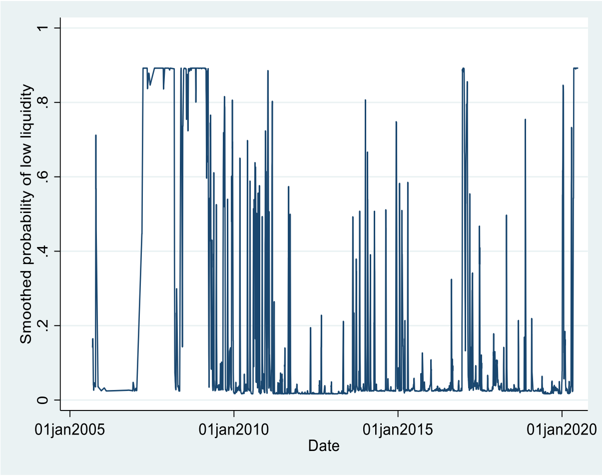
Note: Standard errors in parentheses. Source: Authors' estimates

Table A5: Factors to explain low liquidity probability using moving average liquidity index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CNTRL	0.024***				0.025***	0.028***	0.025***
	(3.609)				(3.573)	(4.123)	(3.627)
CNTS	-0.038***				0.023	0.025*	0.023
	(-2.785)				(1.474)	(1.662)	(1.510)
CGBYLDV		0.287***			0.229***	0.279***	0.246***
		(14.388)			(9.284)	(10.916)	(10.327)
CNSSEV		-0.002***			-0.002***	-0.002***	-0.002***
		(-4.207)			(-4.757)	(-4.606)	(-3.673)
CNYIMPV		0.027***			0.030***	0.033***	0.036***
		(7.514)			(6.922)	(7.821)	(8.205)
USTED(-1)			0.081***		-0.048***		
			(3.810)		(-2.623)		
MOVE(-1)			-0.000			-0.002***	
			(-0.899)			(-6.084)	
VIX(-1)			0.001*				-0.004***
			(1.662)				(-6.184)
BrentR(-1)				0.000	0.001	0.000	-0.001
				(0.204)	(0.350)	(0.025)	(-0.507)
CESIGL(-1)				-0.002***	-0.001***	-0.001***	-0.002***
				(-11.925)	(-7.379)	(-6.799)	(-8.779)
N	2731	2971	2158	2204	1999	2043	2043
Adj R^2	0.44	0.55	0.49	0.51	0.52	0.53	0.53

Note: T-statistics in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source: Authors' estimates

Figure A1: Probability of low liquidity with moving averaged liquidity index



Source: Authors' estimates