Bond Lending and the Law of One Price in China's Treasury Markets

Magnani, Jacopo and Wang, Yabin

Emlyon Business School, Hong Kong Monetary Authority

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Jacopo Magnani *   Yabin Wang[†]

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Abstract

This paper examines how the introduction of bond lending in China's bond market has affected violations of the law of one price, measured by the yield spread between similar treasury bonds. To identify the effect of bond lending, we exploit the fact that in China identical bonds are traded on two segmented markets and bond lending has been introduced in only one of the two markets. We find that the introduction of bond lending has led to a decline in deviations from the law of one price. Consistent with an interpretation based on limits to arbitrage, a significant fraction of the deviations from the law of one price in our sample represent actual profit opportunities and the introduction of bond lending has reduced arbitrage profits.

*Department of Finance, Emlyon business school.

[†]Research Department, Hong Kong Monetary Authority. The views expressed are those of the author and do not necessarily reflect the official positions of the Hong Kong Monetary Authority.

1 Introduction

The law of one price (LOP) is a cornerstone of financial economics. It maintains that assets with the same cash flows should be traded at the same price. The LOP principle not only provides the foundations of many theoretical models (such as Black and Scholes (1973)), but also the justification of investment strategies used in markets.[1] Violations of LOP are often observed, but there are different interpretations in the literature: one approach suggests that non-fundamental factors such as noise and sentiment (Lamont and Thaler (2003a)) are the causes for LOP violations, while another approach views price discrepancies as the result of structural differences in dimensions like liquidity or pledgeability (see for instance Garleanu and Pedersen (2011), Cipriani et al. (2018), and also the literature on the "on-the-run" premium that we discuss below). To better understand the nature of LOP violations, it is useful to analyze how they are affected by changes in market regulations and policies.

In this paper we provide evidence on the effect of bond lending on LOP violations in bond markets. This is an important empirical question because of the existing opposite theoretical possibilities offered by the literature. A disequilibrium interpretation of LOP violations suggests that allowing arbitrageurs to borrow bonds for short-selling will reduce mispricing and LOP deviations. On the other hand, the search-based theory of Vayanos and Weill (2008) predicts that the introduction of short-sales can create equilibria where assets with identical cash flows have different liquidity and thus are traded at different prices.

Empirically, it is challenging to identify the causal effect of security lending or short-selling on LOP violations. Although plausibly exogenous changes in regulations about short sales are not rare, it is often difficult to construct an appropriate comparison. To address this issue, we exploit two unique features of China's bond market. First, identical bonds are traded in two parallel but segmented markets, the interbank market and the exchange market. Second, at the end of 2006 bond lending was introduced only in the interbank market. Thus, we can estimate the effect of bond lending by comparing the dynamics of LOP violations for the same set of bonds across the two markets before and after the introduction of bond lending. Our empirical identification strategy is similar to that of Chen et al. (2019), who estimate the value of asset pledgeability by exploiting a policy shock that reduced the pledgeability of some bonds on the exchange market only.

[1] For example, one of the strategies of the Long Term Capital Management hedge fund was meant to arbitrage the price difference between US Treasury bonds with similar cash flows.

To measure LOP violations, we first construct pairs of treasury bonds with similar residual cash flows and maturity dates.[2] We use daily transaction data from 2000 to 2019 to measure LOP deviations as the yield spread between matched treasury bonds that are traded within a reasonably short time window. We then analyze how the introduction of bond lending in China's national interbank market has affected LOP deviations. Our approach allows us to control for market-fixed effects that capture differences in investor bases between markets and other unobservable characteristics,[3] as well as for observable market-specific time-varying variables such as market volume. Moreover, our empirical approach controls for observable and unobservable pair-specific time-varying factors, thus ruling out biases arising from changes in the composition of our sample around the time of the policy change. Our estimates show that the introduction of bond lending has led to a decline of on average 29 to 34 basis points in LOP deviations, consistent with the limits-to-arbitrage view (e.g. Lamont and Thaler (2003a)). Moreover, we find that this effect is stronger for pairs of bonds with a larger difference in their issuance dates, as suggested by the theory.

We then test other theory-based hypotheses concerning arbitrage profits and liquidity. The limits-to-arbitrage view hypothesizes that arbitrage profits net of lending fees are positive at least before the introduction of bond lending and they decline as a result of arbitrage activity. The liquidity-premium view formalized in Vayanos and Weill (2008) instead predicts that while notional gross arbitrage profits increase after the introduction of bond lending, net arbitrage profits are negative. Consistent with the limits-to-arbitrage view, we find that at least some of the LOP deviations in our sample represent true profit opportunities and that the introduction of bond lending has reduced gross arbitrage profits by more than 50 basis points as a percentage of the value of borrowed bonds. Finally, we show that the introduction of bond lending did not lead to asymmetric changes in the liquidity of matched bonds, contrary to the prediction of the asymmetric equilibrium of Vayanos and Weill (2008)'s model.

This paper contributes to several strands of literature. First, we contribute to the literature on China's bond markets. China's bond market has experienced rapid growth and a series of reforms in recent years and has attracted a growing amount of academic works.

[2] While corporate bonds are also listed on both the interbank market and the exchange market, the number of different corporate bonds with similar maturity dates issued by the same entity is limited. Combining bonds issued by different entities is problematic because yields reflect also issuer-specific characteristics such as credit risk.

[3] Liu et al. (2019) find that the same enterprise bond trades at a higher yield in the exchange market because of higher demand from yield-chasing retail investors.

Amstad and He (2020) provides a comprehensive overview of China's bond markets. In particular, some of the papers in the literature have analyzed differences in bond prices between the exchange market and the interbank market. Chen et al. (2019) evaluates the effects of a policy change that reduced the pledgeability of some bonds in the exchange market, while leaving the pledgeability of the same set of bonds in the interbank market unaffected. Fan and Zhang (2007) analyze the discrepancy in interest rates of bond repurchase agreements between the exchange market and the interbank market. Liu et al. (2019) show that enterprise bonds tend to have higher prices in the exchange market than in the interbank market due to the demand effect of yield-chasing retail investors. An important distinction between our paper and the previous literature is that while other works have focused on differences in bond prices between the two markets, we analyze LOP violations within each market.

Second, we contribute to the literature on short-selling restrictions as limits to arbitrage. A large number of paper have shown that short-sale constraints explain mispricing in asset markets, including stocks overpricing (Jones and Lamont (2002)), cross-sectional stock returns anomalies (Nagel (2005), Chu et al. (2020)), put-call parity violations in the options market (Ofek et al. (2004)) and LOP violations in equity carve-outs (Lamont and Thaler (2003b)). The literature has not yet studied the effect of short-selling restrictions on LOP violations in bond markets.

Finally, we contribute to the literature on the "on-the-run" premium. The empirical stylized fact that motivates this literature is that the most recently issued US Treasury bonds sell at a premium relative to similar but more seasoned treasury bonds.[4] This finding arises from the excess liquidity embedded in the on-the-run bonds (Amihud and Mendelson (1991), Warga (1992), Krishnamurthy (2002), Goldreich et al. (2005), Christensen et al. (2020)). In related work, Graveline and McBrady (2011) argue that the "on-the-run" premium reflects the asset's specialness, that is the fact that on-the-run bonds can be loaned at higher fees than off-the-run bonds. Although there are technical differences, for example, in how we construct pairs of similar bonds, between our empirical approach and this line of literature, our paper also deals with yield differentials between comparable treasury bonds. Relative to the existing literature, we adopt a novel methodological approach by studying how yield differentials respond to the introduction of bond lending.

[4] Contrary to the findings from the US, Chen et al. (2015) find a negative on-the-run premium on China's interbank market.

2 Institutional Background

In this section, we provide background information on China's two co-existing bond markets, the introduction of bond lending in the interbank market and the aggregate bond lending activity.

2.1 China's Parallel Bond Markets and Treasury Trading

Segmentation is a special feature of China's bond market. Two markets co-exist for primary bond issuance and secondary trading and are oversighted by different regulatory bodies: the interbank market (i.e. China Foreign Exchange Trade system) and the exchange market (i.e. Shanghai Stock Exchange and Shenzhen Stock Exchange).[5] The exchange market was established first in 1990. However, due to concerns about banks' speculation in the stock market through debt financing and repo transactions, a separate market was established exclusively for banks in 1997. Other participants were later allowed to operate in the interbank market, including securities companies, insurance firms and mutual funds. Non-bank financial institutions also participate in the exchange market together with individual and corporate investors.[6] The two markets differ not only in the investor base, but also in market structure and trading protocols. The interbank market is an over-the-counter (OTC) market, based essentially on bilateral bargaining, whereas trading on the exchange is centralized and order-driven.

Treasury bonds are dual-listed and traded in both markets.[7] Treasury bonds trading in the interbank market accounts for almost 99% of the total trading volume in the two markets between 2000 and 2019. During the same period, the average trade size of treasury bond was 837 million RMB in the interbank market and 26.5 million RMB in the exchange market. While trades tend to be larger in the interbank market, participants trade treasuries more actively on the exchange market. For bonds that record any trading during their listing period, the average number of trading days is 96 days on an annual basis in the exchange market and 50 days in the interbank market. Similar trading patterns are

[5]See Amstad and He (2020) for an overview of China's bond market development, and different types of debt instruments traded in two markets. More recently in July 2020, China has approved to connect the interbank and the exchange bond markets, which would in theory unify domestic bond markets and eliminate price disparities across the trading venues (see Announcement No.7 [2020] of PBoC and CSRC `http://www.pbc.gov.cn/en/3688253/3689009/3788480/4061345/index.html`).

[6]Commercial banks are not allowed to participate in repo transactions in the exchanges market and have limited access to the exchange market, although some restrictions were removed in 2010.

[7]Other securities that are listed on both markets include financial bonds, enterprise bonds, local government bonds, municipal corporate bonds, government-backed agency bonds and asset backed securities.

also found across all debt instruments in the two markets according to Chen et al. (2019).[8] The reason for this pattern is that the interbank market is dominated by large institutional investors such as large state banks and national joint-stock commercial banks that favor a "buy-and-hold" investment strategy.

2.2 The Introduction of Bond Lending in the Interbank Market in 2006

Although securities lending has long been used in international bond markets, it was introduced in China only in the end of 2006. In November 2006, securities lending was introduced in the national interbank bond market by the People's Bank of China (PBoC) with the goal of facilitating market liquidity and enhancing market effectiveness.[9] In the publications of PBoC and China Central Depository and Clearing Co., LTD (CCDC), bond lending is defined as a type of bond financing business in which the bond borrower provides a certain amounts of collateral and borrows the object bond from the bond provider, under the agreement that the loaned securities (the object bond) are returned and the collateral passed back to the borrower on a future date. During the lending period, the bond borrower should refund any incurred interest payment of the object bond to the bond provider in time. The bond borrower pays the bond lending cost to the bond provider and the cost standard is determined by both parties through negotiations.

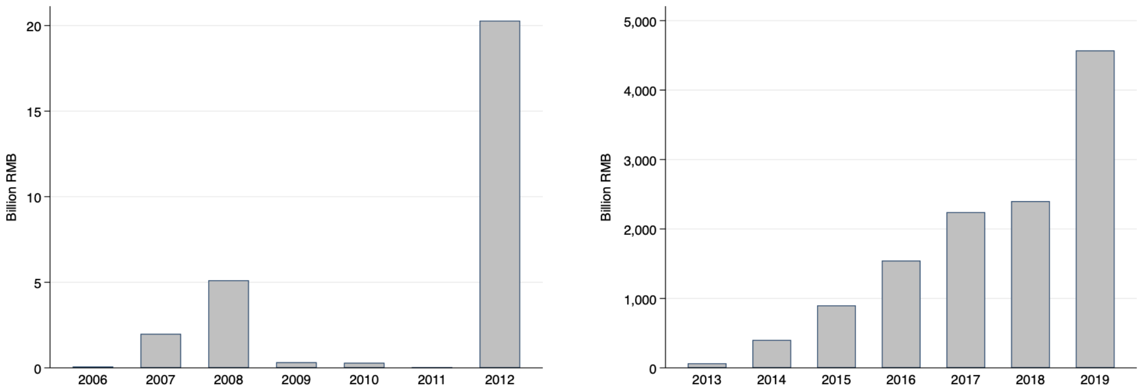
The introduction of bond lending was meant to facilitate market liquidity, accelerate bond turnover and provide investors with a new instrument for risk management and the implementation of complex investment strategies.[10] It established a mechanism for shorting bonds, allowing investors to sell bonds they do not own.[11] Importantly for our empirical analysis, a similar mechanism for shorting bonds was absent in the exchange market and is still missing (despite a bond lending trial on the Shanghai Stock Exchange in March

[8]According to Chen et al. (2019), while more than 90% of the monetary volume of spot transactions for all bonds takes place on the interbank market, the exchange market accounts for 75% to 95% of all spot transactions in terms of the number of trades. The average trade size for spot transactions is 100 to 200 million RMB on the interbank market, compared to 0.3 to 1 million on the exchange average over all debt instruments.

[9]Announcement [2006] No.15 of the People's Bank of China on Interim Provisions on the Administration of Bond Lending and Borrowing Business in the National Interbank Bond Market on 2 November 2006. http://www.gov.cn/govweb/zwgk/2006-11/06/content_433729.htm

[10]See PBoC's announcement http://www.pbc.gov.cn/english/130721/2831941/index.html

[11]Although outright repos, introduced in 2004 in both bond markets, could also be used for short-selling, repos are designed as a mechanism for lending and borrowing cash, rather than a security financing mechanism. In section 6.4 we further discuss this point.



(a) 2006-2012

(b) 2013-2019

Figure 1: The growth of bond lending settlement volume in the interbank market.

2015). As remarked in the "China's Bond Market Overview" published by CCDC in 2016, "at present, bilateral bond lending is only established in the interbank market."

Since its inception, bond lending experienced steady growth in 2007 and 2008 in the interbank market, with settlement volume reaching around 2 billion RMB and 5 billion RMB respectively, see Figure 1a. Between 2009 and 2011, bond lending activities subsided, partially because of the global financial crisis and partially due to limited participation by larger bank institutions. As shown in Figure 1, bond lending transactions started to grow at a rapid pace in 2012 and total transactions reached 4570 billion RMB by the end of 2019. The average growth rate during 2012 and 2019 is around 158%. In 2019, monthly trading volume of securities lending accounts for 3% of the total trading in the cash bond interbank market. This is comparable to the volume of important debt instruments such as medium-term notes, short-term commercial papers and local government bonds.[12] The main participants in bond lending transactions are large national commercial banks, joint stock commercial banks, securities funds, insurance funds and money market funds. As illustrated in Table 1 for December 2019 data, in recent years national banks have dominated the market in terms of trading amount, but securities companies have been the most active participants in terms of number of trades. National commercial banks and joint stock commercial banks are often lenders in this market, while city and rural commercial banks and securities companies are usually borrowers (see Table 2 in the Appendix for

[12]In December 2019, the trading volume of different debt instruments in cash bond market is distributed as the following: interbank CD (24%), policy financial bond (35%), treasury bond (22%), medium-term note (3.7%), short-term commercial paper (2.7%), local government bond (2.6%), securities lending (2.5%), and others (5.5%). Source: http://www.chinamoney.com.cn/english/mdtmtov

details on 2019 data).

Lending fees vary by the type of institutions involved in the transaction, the transaction amount, the object bond and the contract length. Table 1 reports average lending fees by institution type in December 2019 (for more details see Table 3 in the Appendix). In terms of debt instrument, lending of treasuries takes almost half of the total transactions. For example, between 2017 and 2019, 43% of all bond lending transactions are for treasury bonds on average, with policy bank bonds take another 43% and the remaining goes to lending of local government bonds.

Table 1: Participants structure in the bond lending transaction in December 2019

Institution type	Trading amount (RMB bn)	Share	# of transaction	Share	Lending fee (%) weighted avg
National commercial bank	360	31%	943	23%	0.5213
Joint stock commercial bank	165	14%	648	16%	0.6995
City commercial bank	132	11%	659	16%	0.7033
Rural commercial bank	69	6%	417	10%	0.7764
Securities company	188	16%	1176	29%	0.6992
Others	253	22%	257	6%	0.4264
Total	1167		4100		0.5903

Source: Bond lending Monthly Bulletin, December 2019, China Foreign Exchange Trade System
Notes: Transactions (classified as per institution types) are the sum of buy and sell direction transactions. "Others" include credit union, insurance companies, money market fund, including wealth management products issued by banks, foreign institutions, non-financial institutions, etc. Lending fee is the weighted average among institutions within the institution type by trading amount.

3 Data

We rely on treasury bond characteristics and daily transaction data in the exchange and interbank markets from WIND and China Foreign Exchange Trading System (CFETS). The data covers bond level fixed characteristics including a bond identifier, a cross-market identifier for dual-listed bonds, the issuance date, the issuance amount, the maturity date, the coupon rate, the term and the coupon frequency. It also includes bond level daily transaction data on the yield to maturity, the close price, the daily high and low prices, the transaction amount, the turnover ratio, and bid and ask prices in the interbank market. We extract all treasury bonds issued between January 1, 2000 and December 9, 2019 in the interbank market and the exchange market.[13] We do not use data on lending activity for individual bonds, since such data is not available for the entire study period and the whole sample of bonds.

3.1 Sample Selection

Within each market, we construct treasury bond pairs by matching bonds that have similar residual cash flows. To form a pair we require that the maturity dates of the two bonds are no more than five days apart. We choose a 5-day window because this ensures that the two bonds are similar while allowing a sufficient number of observations. Our results are robust to different choices of this parameter. In each pair, the matched bonds have almost identical maturity dates and differ in their issuance dates. For each pair, we refer to the bond issued more recently as the "new" bond and to the bond with an earlier issuance date as the "old" bond.

Since our goal is to measure LOP deviations at the pair level, we match transactions data for the new bond and the old bond in each pair. To obtain a sufficient number of observations, we match daily transaction data for the new bond and old bond in a pair within a window of $+/$-3 days.[14] Thus, given an observation for the new bond at date t, if we can find an observation for the old bond occurring between $t-3$ and $t+3$, we record both observations as occurring at time t. If there is no exact day match and there are multiple observations on the old bond within the window, we average them using trading-volumes as weights (discussed in more detail below).

Importantly, we only use observations on trades that occurred at a time when both bonds in a pair have a single residual cash flow consisting of the face value payment and possibly a final coupon payment. For example if we are matching a bond with semiannual coupon payments and a zero-coupon bond, we only consider trades within six months of the maturity date. This allows us to compare the yields to maturity of the two bonds in a pair without further assumptions or adjustments, similar to Amihud and Mendelson (1991).

Finally we can match dual-listed bond pairs across markets. Dual-listed bonds have the same bond-level characteristics such as issuance dates, maturity dates, and coupon

[13] Our sample includes newly issued book-entry treasury bonds and does not include their subsequent offerings. We drop bonds that are never traded in any of the two markets since issuance.

[14] This procedure is important to guarantee a sufficient number of observations, since Chinese treasury markets are not as active as the US market. Our results are robust to different choices of the number of days in the window.

frequency across markets, but they have different transaction data in each market.

Our original data includes 209 unique bonds (not including subsequent offering) issued in the interbank market and 99 bonds issued in the exchange market (Table 1 in the Appendix present the summary statistics of the original sample prior to the matching-pair analysis). Based on the above sample selection criteria, we are finally left with 78 pairs - 17 pairs from the exchange market and 61 pairs from the interbank market. All the bonds forming the 17 pairs in the exchange market are dual-listed. Our final matched sample includes trading period from June 2005 to December 2019. Table 2 shows the number of observations for each year and in each market. Table 3 summarizes number of observations for each new-old maturity combination. Table 4 in the Appendix provides information on the number of exact daily matches.

Table 2: Number of observations by year and market

	Interbank		Exchange	
	# of pairs	# of trades	# of pairs	# of trades
2005	8	95	3	399
2006	12	137	3	289
2007	3	4	0	0
2008	5	76	1	82
2009	4	27	1	30
2010	1	59	0	0
2011	6	143	1	1
2012	4	142	2	12
2013	1	4	0	0
2014	10	112	1	2
2015	14	386	6	178
2016	12	309	4	421
2017	5	102	3	68
2018	6	467	3	82
2019	8	157	1	6

3.2 Descriptive Statistics on Yield Spreads

Using our matched sample, we construct pair-wise yield differences. We define the yield to maturity spread of a bond pair $i \in \{1, ..., N\}$ in market $m \in \{E, I\}$ (where E stands for

Table 3: Number of observations (pairs) for each combination of maturities

Maturity at issuance (years)	old bond								
new bond	1	2	3	5	7	8	10	15	Total obs.
0.25	24	25			4		14		67
	(1)	(1)			(1)		(2)		(5)
1		461	853	698	266		278		2556
		(4)	(9)	(8)	(9)		(5)		(35)
2			134	20	16		436		606
			(2)	(3)	(2)		(6)		(13)
3				376	18		66		460
				(9)	(3)		(4)		(16)
5					71		1	17	89
					(4)		(1)	(1)	(6)
7						1	11		12
						(1)	(2)		(3)
Total obs.	24	486	987	1094	375	1	806	17	3790
	(1)	(5)	(11)	(20)	(19)	(1)	(20)	(1)	(78)

exchange market and I stands for interbank market) on date t as:

$$y_{imt} \equiv y_{old,imt} - y_{new,imt} \tag{1}$$

where $y_{new,imt}$ and $y_{old,mt}$ are the respective yields to maturity. For each observation on $y_{new,imt}$, if there is no matching old bond transaction data at date t, we impute $y_{old,imt}$ by computing the trading volume-weighted yield to maturity of the old bond between $t-3$ and $t+3$ (if there is no old bond trading data in this window, we drop the date-t observation altogether).

As the focus of our study is on the level of mispricing for a pair of similar bonds, rather than on whether the new bond is under- or over-priced relative to the old bond, we take the absolute value of the yield spread defined in equation (15) to obtain a measure of deviations from the LOP:

$$Y_{imt} \equiv |y_{imt}| = |y_{old,imt} - y_{new,imt}| \tag{2}$$

We now provide some descriptive statistics about pairwise yield differentials in our

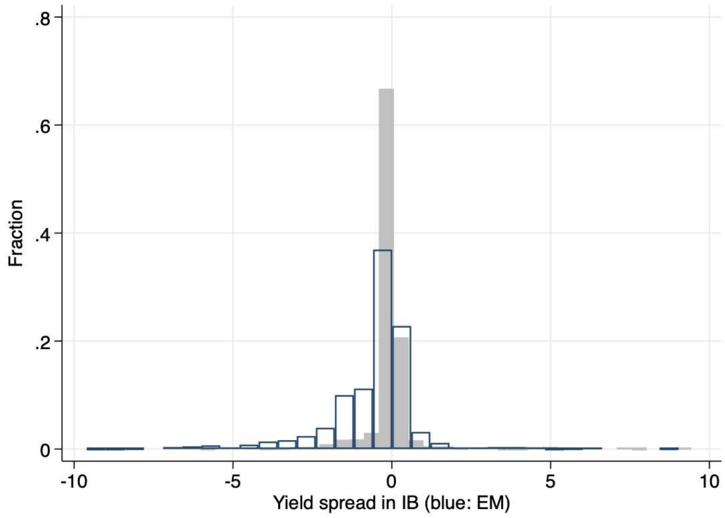


Figure 2: Distribution of the old bond-new bond yield spread y_{imt}

Figure 2 shows the distribution of yield spread between old and new bonds of matched pairs. In specific, the figure plots the distribution of $y_{imt} = y_{old,imt} - y_{new,imt}$, where m refers to exchange or interbank market.

sample. Figure 2 presents the distribution of the yield difference between the new bond and the old bond y_{imt} (Figure 2 in the appendix plots yield to maturity for new and old bonds separately). In both markets, we observe both positive and negative yield spreads. The fact that the old bond often has a lower yield to maturity than the new bond seems at odds with the "on-the-run premium" documented in the literature, such as Warga (1992), Krishnamurthy (2002), Goldreich et al. (2005), and Christensen et al. (2020) who find that the most recently issued US Treasury bonds sell at a premium relative to similar but more seasoned bonds. The pattern we document however is consistent with the negative on-the-run premium found in the Chinese bond market by Chen et al. (2015).[15] At any rate, one should be cautious in comparing our analysis with findings about the on-the-run premium. The on-the-run bond is usually defined as the most recently issued bond with a given maturity, while off-the-run bonds are previously issued bonds with the same maturity. However, in our paper, the new bond and old bond in a given pair do not have the same maturity at issuance and the new bond is not necessarily the most recently issued treasury with a given maturity.

[15] Potential explanations include effects from liquidity premium in Chinese Treasury markets and the irrational disposition effect, i.e. the fact that investors are more reluctant to sell the old off-the-run bonds when they incur a loss from the investment, which leads to a higher price and a lower yield for old bonds Chen et al. (2015).

Another prominent feature of Figure 2 is that the fraction of observations close to zero is larger in the interbank market than in the exchange market, suggesting lower deviations from LOP in the former. To better analyze LOP deviations and their dynamics, we look at the absolute yield spread Y_{imt}. Figure 3 plots the average absolute yield spread for each year between 2005 and 2019, pooling observations between the two markets. Figure 3 shows that the absolute yield difference has declined over time, suggesting China's bond markets have become more efficient between 2005 and 2019.

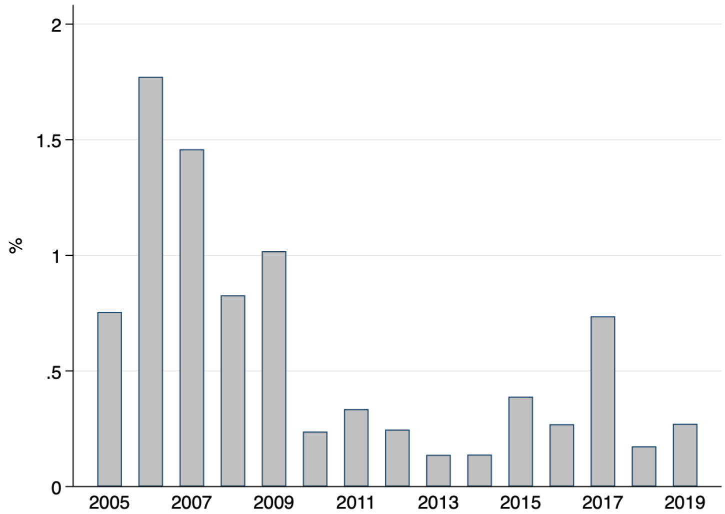


Figure 3: Absolute yield spread over time

Figure 3 shows the average level of the absolute yield spread across market from 2005 to 2019. The absolute yield spread is defined as is defined as $Y_{imt} = |y_{old,imt} - y_{new,imt}|$, where m refers to exchange or interbank market. Each bar represent the yearly average of daily observations Y_{imt} across market.

Further probing into each market separately, evidence suggests the efficiency in the interbank market improved more pronouncedly over time than in the exchange market. Figure 4 plots the monthly average absolute yield spread over time for the exchange market and the interbank market respectively. While spikes in the absolute yield spread persist throughout the sample period in the exchange market, the absolute yield spread is consistently closer to zero in the interbank market during the later years of our study.

4 Hypotheses

Our paper aims at testing how the introduction of bond lending in China's interbank market has affected LOP deviations, as measured by the absolute yield spread between bonds with

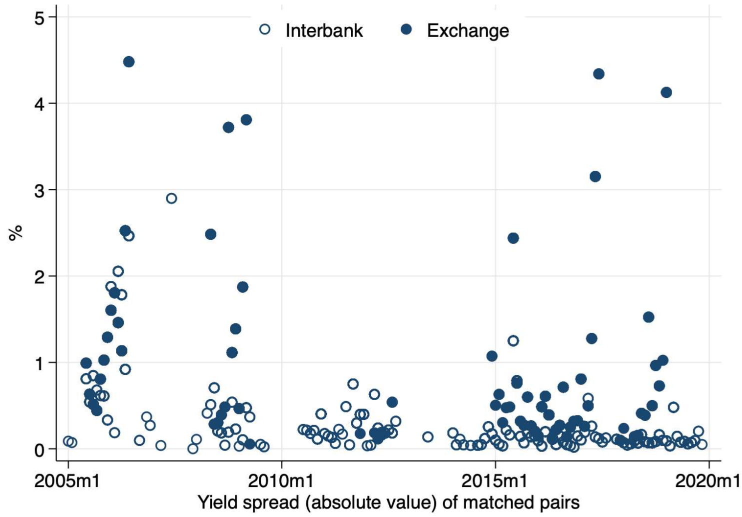


Figure 4: Absolute yield spread over time, by market

Figure 4 is a scatterplot of the average absolute yield spread across market from January 2005 to December 2019. The absolute yield spread is defined as $Y_{imt} = |y_{old,imt} - y_{new,imt}|$, where m refers to exchange or interbank market. Each dot represent the monthly average of the daily observations Y_{imt} in each market.

similar residual cash flows. Interestingly, theoretical arguments provide opposite predictions on how bond lending should affect LOP deviations. In this section we distinguish between two theoretical frameworks, that we call the limits-to-arbitrage view and the liquidity-premium view, and formulate testable hypotheses.

The theory of limits to arbitrage suggests that bond lending will reduce deviations from LOP. This assumes that LOP deviations are due to non-fundamental factors such as noise and sentiment (Lamont and Thaler (2003a)). LOP deviations then are true profit opportunities and bond lending can be used by arbitrageurs to realize these profit opportunities. Arbitrageurs can buy the cheaper bond and short sell the more expensive one. In turn, by increasing the demand for the cheaper bond and the supply of the more expensive one, arbitrage trades will induce the market to correct the initial mispricing (assuming market prices respond to supply and demand pressures).

Contrary to the above prediction, there are also theoretical arguments suggesting that the introduction of bond lending in over-the-counter markets will increase LOP deviations. Vayanos and Weill (2008) show that the introduction of short-sales in a search market model can create an equilibrium where assets with identical cash flows are traded at different prices.[16] In such equilibrium, market participants prefer trading one of the assets

[16] The paper of Vayanos and Weill (2008) aims at explaining the on-the-run premium but the same formal model can be applied in our case, since the mechanism does not rely on treasury auction cycles or

because it is more liquid and this in turn increases that asset's liquidity. The more liquid asset trades at a premium over the less liquid one because its price reflects the savings in search costs. Critically, Vayanos and Weill (2008) show that these asymmetric equilibria can arise only if short-sellers are present because they are constrained to buy back the asset they have previously borrowed. In the absence of this constraint, the asymmetric equilibrium unravels as buyers prefer the cheaper asset. Inspired by these theoretical considerations, we formulate the following hypotheses:

Hypothesis 1a *Limits-to-arbitrage view: the introduction of bond lending will decrease LOP deviations.*

Hypothesis 1b *Liquidity-premium view: the introduction of bond lending will increase LOP deviations.*

Note that both Hypothesis 1a and Hypothesis 1b are derived from theoretical frameworks that involve short-selling rather than security lending. In our empirical analysis, we do not observe short-selling directly. However, under the plausible assumption that bond lending is used at least in part to facilitate the short-selling of bonds, the underlying mechanisms also leads to a prediction on the effect of bond lending. This holds even if there are other mechanisms that can be used for shorting bonds, such are repos, as long as they are not perfect substitutes of bond lending (see Section 6.4 for further discussion of this issue).

Theory also suggests how the effect of bond lending on LOP deviations will interact with bond-specific characteristics, such as the time since issuance. When two bonds with the same cash flows have a larger gap in their issuance dates, it is more likely that unsophisticated investors will perceive them as structurally different and will be willing to pay different prices for them. This in turn creates bigger arbitrage opportunities and should result in a larger decline in LOP violations once bond lending is allowed. Moreover, a larger maturity gap may also act as an effective equilibrium selection mechanism in a model like Vayanos and Weill (2008) where multiple equilibria are possible. Vayanos and Weill (2008) show that for small search frictions the only remaining equilibrium is that short-sellers concentrate in the asset with the larger effective supply (see their Proposition 11). Since a bond's effective supply decreases over time as the bond becomes locked away in the portfolios of buy-and-hold investors, LOP violations are more likely to arise within pairs where one bond was issued much earlier than the other.

other details of the definition of on- and off-the-run bonds.

Hypothesis 2 *The effect of bond lending on LOP deviations is stronger for pairs of bonds with a larger difference in their issuance dates.*

Note that this hypothesis holds under both the limits-to-arbitrage view and the liquidity-premium view and therefore it does not allow us to distinguish between them.

The limits-to-arbitrage view and the liquidity-premium view make different predictions about arbitrage profits. The limits-to-arbitrage view is based on the assumption that there are opportunities for arbitrageurs to earn positive profits net of the costs of arbitrage, which mainly consist of the lending fee the borrower of the asset need to pay to the lender. Thus, notional net profits should be positive at least before the introduction of bond lending. Since bond lending is assumed to allow arbitrageurs to correct market mispricing, there will be fewer additional opportunities to exploit LOP violations after bond lending is introduced. Therefore, net and gross profits should decline with bond lending. According to the liquidity-premium view, instead, the introduction of bond lending will increase notional gross profits from arbitrage. The reason is that bond lending allows a systematic yield spread between identical bonds to emerge. However, as shown by Vayanos and Weill (2008) (see their Proposition 10), arbitrage profits net of lending fees will be negative. Net profits are negative because the asset with the higher price is also very costly to borrow, due to its specialness.

Hypothesis 3a *Limits-to-arbitrage view: gross arbitrage profits decline after the introduction of bond lending and arbitrage profits net of lending fees are positive at least before the introduction of bond lending.*
Hypothesis 3b *Liquidity-premium view: gross arbitrage profits increase after the introduction of bond lending, but net arbitrage profits are negative.*

Finally, the liquidity-premium view makes a distinctive prediction about liquidity. If the introduction of bond lending leads to the asymmetric equilibrium analyzed in Vayanos and Weill (2008), then it should result in systematic differences in liquidity between bonds with similar cash flows.

Hypothesis 4 *Under the liquidity-premium view, the introduction of bond lending will increase the difference in liquidity between matched bonds.*

5 Empirical Strategy and Results

In this section we present the approach and the results of the empirical analysis. Sections 5.1, 5.2 and 5.3 provide tests of our main hypotheses, that is whether the introduction of bond lending increased or decreased LOP deviations. Section 5.4 analyzes how the introduction of bond lending has affected arbitrage profits. Section 5.5 tests for effects on liquidity.

5.1 Non-Parametric Test

We begin the empirical analysis by testing Hypothesis 1 in a non-parametric approach. To do this, we restrict attention to dual-listed bonds that are traded on both the interbank market and the exchange market on the same set of dates. Define Δ_{it} as the cross-market difference in the absolute yield spread of bond pair i at time t:

$$\Delta_{it} = Y_{iIt} - Y_{iEt} \tag{3}$$

Here the index i is the cross-market identifier of a pair of bonds that is listed on both markets. We refer to Δ_{it} as the interbank market excess mispricing. We compare the distribution of Δ_{it} before and after the introduction of bond lending in the interbank market, which occurred in November 2006. Thus we divide our sample in two subsamples: the pre-policy subsample, made of observations before 2007, and the post-policy subsample, made of observations starting in 2007. Comparing the two subsamples provides an estimate of the causal effect of bond lending on LOP deviations. Clearly, our test assumes that if bond lending had not been introduced in the interbank market, the distribution of Δ_{it} would have remained constant over time for bond pair i. Using cross-market matches allows us to remove confounding compositional effects due to pair-specific factors that may affect mispricing. These factors are allowed to be time-varying, but we have to assume they are common between markets for a given bond pair i.

Figure 5 plots the CDFs of Δ_{it} in the pre- and post-policy samples. It is possible to observe that the median value of Δ_{it} is smaller in the post-policy sample than in the pre-policy sample. Indeed, the pre-policy distribution of Δ_{it} first-order stochastically dominates the post-policy distribution of Δ_{it}. Thus, evidence suggests the introduction of bond lending has reduced LOP deviations, consistent with the limits-to-arbitrage view (Hypothesis 1a). To test whether the difference in the distribution of Δ_{it} before and after the introduction of bond lending is statistically significant we use a one-sided non-parametric Wilcoxon rank-sum test. The test rejects the null-hypothesis of no difference with a p-value of 2.508×10^{-11}.

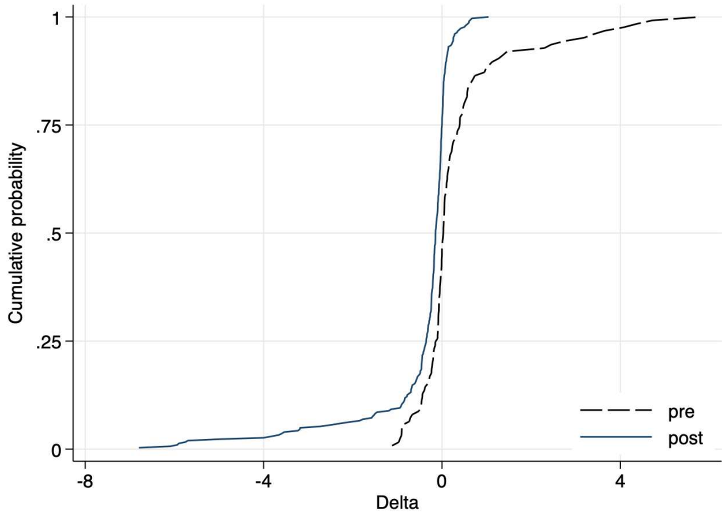


Figure 5: Distribution of the interbank market excess mispricing

Figure 5 plots the CDF of the excess mispricing in the interbank market (Δ_{it}) before and after 2007 - the introduction of bond lending in the interbank market. The excess mispricing is defined as $\Delta_{it} \equiv Y_{iIt} - Y_{iEt}$.

5.2 Main Regression Analysis

We now test the main hypothesis using a difference-in-differences regression design. The dependent variable is the absolute yield difference Y_{imt} of bond pair $i \in \{1, ..., N\}$ in market $m \in \{E, I\}$ on a trading day t. The pair index i represents a cross-market identifier, so that all observations on that pair are indexed by i no matter whether they are collected from the exchange market or the interbank market. Note however that our sample for the regression analysis contains also pairs of bonds that are traded on only one market and pairs that are traded on both markets but on different dates.

The treatment group is made of observations from the interbank market $m = I$. The treatment time is denoted by t^*. Bond lending was officially introduced in the interbank market in November 2006. For clarity, and since in our sample there are not trading observations in November of December 2006, we choose t^* to be January 1, 2007. We define the following dummy variable for observations in the interbank market after the introduction of bond lending:

$$D_{mt} = \begin{cases} 1 \text{ if } m = I \text{ and } t \geq t^*; \\ 0 \text{ otherwise} \end{cases} \tag{4}$$

Our baseline regression model is as follows:

$$Y_{imt} = \alpha_i + f_m + \delta D_{mt} + ttm_{it} + \tau_t + \varepsilon_{imt} \tag{5}$$

where α_i is a pair-fixed effect, which captures pair-specific factors that may drive mispricing. f_m is a market fixed effects, equal to 1 if $m = I$ and 0 otherwise, that controls for market-specific factors that affect mispricing. To control for the effect of the business cycle and other macroeconomic factors, we include year-fixed effects, τ_t (note that τ_t is the same for all observations in the same year). We control for the time-to-maturity of bonds in pair i at time t, ttm_{it}.

To test Hypothesis 1 we focus on the estimated coefficient δ, which measures the causal effect of bond lending on LOP deviations. The main identification assumption of our estimation is that if bond lending had not been introduced in the interbank market, the dynamics of LOP deviations would have been identical between the interbank market and exchange market. We will provide evidence and arguments in support for this assumption in Section 6. At this point, we can partially address concerns by controlling for time-varying factors that may differentially affect mispricing across the two markets. In particular bond yields are likely to be affected by market-wide trading activity and liquidity. If the interbank market volume evolves in systematically different ways from volume in the exchange market and market-wide volume also affects mispricing, this could introduce a confounding factor. To address this issue, we adopt a different version of the baseline regression where we control for the monthly percentage change of treasury trading in each market g_{mt} (note g_{mt} is constant for all observations within the same month in market m):

$$Y_{imt} = \alpha_i + f_m + \delta D_{mt} + ttm_{it} + \tau_t + g_{mt} + \varepsilon_{imt} \tag{6}$$

Another assumption underlying our baseline model is that the dynamics of mispricing are the same across pairs with identical time to maturity. If this assumption is violated, changes in the composition of the sample around the treatment time t^* could lead to biased estimates of δ. To control for this issue, we further consider an alternative and more general specification for our model, where we allow for time-varying pair-fixed effects:

$$Y_{imt} = \alpha_{it} + f_m + \delta D_{mt} + ttm_{it} + \tau_t + \varepsilon_{imt} \tag{7}$$

Again, we also add our control for market-wide time-varying factors g_{mt} in a subsequent version:

$$Y_{imt} = \alpha_{it} + f_m + \delta D_{mt} + ttm_{it} + \tau_t + g_{mt} + \varepsilon_{imt} \tag{8}$$

Table 4: The Effect of Bond Lending on LOP Deviations

Absolute yield spread	(1) Y_{imt}	(2) Y_{imt}	(3) Y_{imt}	(4) Y_{imt}
f_m	0.330***	0.335**	0.289**	0.294*
	(0.117)	(0.127)	(0.136)	(0.147)
D_{mt}	-0.776***	-0.792***	-0.731***	-0.748***
	(0.179)	(0.189)	(0.191)	(0.201)
ttm_{it}	-0.002***	-0.002***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)
g_{mt}		0.159*		0.184**
		(0.087)		(0.089)
Observations	3,790	3,790	3,790	3,790
R-squared	0.442	0.444	0.480	0.482
Pair FE	Y	Y		
Time-varying pair FE			Y	Y
Year FE	Y	Y	Y	Y

Notes: Column (1)-(2) are estimated from specification (5) and column (3)-(4) are estimated from specification (7). f_m takes the value one for interbank market. D_{mt} captures the treatment effect and takes the value one for observations starting from 2007 in the interbank market. All regressions control for the bond pair's time to maturity on date t (ttm_{it}). Column (2) and (4) control for the monthly growth of treasury trading amount in each market (g_{mt}). Robust standard errors clustered at the bond-pair level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4 reports the regression results. Across all specifications we find a significant negative δ estimate. Thus, our regression analysis confirms that the introduction of bond lending has decreased LOP deviations, consistent with the limits-to-arbitrage view (Hypothesis 1a). On average, our findings point to a reduction in LOP deviations in the range of 29 to 34 basis points. The regression results also show that the absolute yield spread is on average higher in the interbank market and is positively correlated with the market-wide percentage change in the volume of treasury trading. Finally, the absolute yield spread is declining in the time to maturity, a result consistent with the finding of Amihud and Mendelson (1991) on the spread between US treasury notes and bills.

5.3 Heterogeneity

In this section we test Hypothesis 2, that is whether the effect of bond lending on LOP deviations (established in the previous section) is be stronger for pairs of bonds with a larger gap in their issuance dates. We define the "maturity gap" of pair i, gap_i, as the time (in days) between the issue dates of the two bonds in the pair. Note that gap_i is positive by construction and it varies only across bond pairs but not over time. We then modify the baseline regression by interacting relevant variables with gap_i. Our specification therefore is:

$$Y_{imt} = \alpha_i + f_m + \delta D_{mt} + ttm_{it} + gap_i + f_m \times gap_i + \gamma D_{mt} \times gap_i + \tau_t + g_{mt} + \varepsilon_{imt} \quad (9)$$

The coefficient γ on the interaction $D_{mt} \times gap_i$ measures how the effect of bond lending interacts with the maturity gap. As before, we estimate four versions of this regression, which sequentially control for market-wide treasury volume and allow for time-varying pair-fixed effects.

Results are presented in Table 5. Across all specifications the coefficient on $D_{mt} \times gap_i$ is negative, although we estimate the coefficient with lower precision than in the previous section. A negative interaction coefficient implies that bond lending causes a larger reduction in LOP deviations for pairs with a larger maturity gap.

5.4 Effects on Arbitrage Opportunities

In previous sections we have shown that the introduction of bond lending has reduced the yield differential between treasury bonds with similar residual cash flows. This suggests that bond lending allows arbitrageurs to engage in trades that correct market mispricing. In this section, we study the implications for arbitrage profits, similar to Krishnamurthy (2002) and Amihud and Mendelson (1991).

To describe arbitrage profits, consider two bonds, indexed by 1 and 2, with the same maturity date and no remaining dividends and assume $r_1 > r_2$, where r is the daily yield to maturity. The arbitrage trade involves buying bond 1, borrowing bond 2 and selling bond

Table 5: Heterogeneous Effects of Bond Lending on LOP Deviations

Absolute yield spread	(1) Y_{imt}	(2) Y_{imt}	(3) Y_{imt}	(4) Y_{imt}
f_m	0.005	-0.017	-0.064	-0.088
	(0.018)	(0.018)	(0.113)	(0.105)
D_{mt}	-0.068	-0.052	-0.040	-0.022
	(0.220)	(0.224)	(0.243)	(0.242)
ttm_{it}	-0.002***	-0.002***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)
$f_m \times gap_i$	0.161***	0.174***	0.175*	0.190*
	(0.0293)	(0.0240)	(0.101)	(0.104)
$D_{mt} \times gap_i$	-0.509**	-0.528**	-0.482*	-0.502*
	(0.215)	(0.217)	(0.251)	(0.255)
g_{mt}		0.173*		0.196*
		(0.088)		(0.099)
Observations	3,790	3,790	3,790	3,790
R-squared	0.447	0.449	0.484	0.486
Pair FE	Y	Y		
Time-varying pair FE			Y	Y
Year FE	Y	Y	Y	Y

Notes: Column (1)-(2) are estimated from specification (9) with pair fixed effect and column (3)-(4) are estimated with time-varying pair fixed effect. gap_i is defined as the difference in the days since issuance between the older bond and the newer one in the bond pair. f_m takes the value one for interbank market. D_{mt} captures the treatment effect and takes the value one for observations starting from 2007 in the interbank market. All regressions control for the bond pair's time to maturity on date t (ttm_{it}). Column (2) and (4) control for the monthly growth of treasury trading in each market (g_{mt}). Robust standard errors clustered at the bond-pair level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

2. The investor holds this position until maturity, for a total of n days. We assume the investor uses the face value payment from bond 1 to cover the payment due to the lender of bond 2 at maturity. This implies that $Q_1 \times FV_1 = Q_2 \times FV_2$, where Q_j is the quantity of bond j and FV_j is its face value. Denote the annualized lending fee by F (which may also depend on n). Then arbitrage profits are given by:

$$\Pi \equiv P_2Q_2 - P_1Q_1 - F\frac{n}{360}P_2Q_2 \tag{10}$$

Dividing both sides of the equation by P_2Q_2, we can express the profit as a fraction of the value of borrowed bonds in the following way:

$$\frac{\Pi}{P_2Q_2} = 1 - \frac{P_1Q_1}{P_2Q_2} - F\frac{n}{360} \tag{11}$$

Using the definition of yield to maturity, this gives:

$$\frac{\Pi}{P_2Q_2} = 1 - \frac{FV_1Q_1}{(1+r_1)^n}\frac{(1+r_2)^n}{FV_2Q_2} - F\frac{n}{360} = 1 - \frac{(1+r_2)^n}{(1+r_1)^n} - F\frac{n}{360} \tag{12}$$

To measure arbitrage opportunities we use the annualized gross profits on the value of borrowed bonds defined as:

$$\pi \equiv \frac{360}{n}\frac{\Pi}{P_2Q_2} + F \tag{13}$$

Using equations (12) and (13), the annualized gross profit rate π can be computed as:

$$\pi = \frac{360}{n}\left[1 - \frac{(1+r_2)^n}{(1+r_1)^n}\right] \tag{14}$$

We focus on gross profits (π) instead of net profits (Π) for two reasons. First, to our knowledge data on lending fees is available only for recent years and its quality is limited (for instance it is not possible to observe the lending fee for specific treasury bonds, but only for a given maturity). Second, we wish to compute notional arbitrage profits also for periods before bond lending was allowed in the interbank market and for bonds trading in the exchange market. No data on lending fees is available for these observations. Thus, we first compute gross profits π for each observation and then we perform several analyses, including comparing gross profits to an average lending fee based on available data.

To make our estimates of arbitrage profits as realistic as possible, whenever bid and ask quotes are available we use them. Thus, whenever possible we set r_1 equal to the ask yield of bond 1 and r_2 equal to the bid yield of bond 2.[17] Finally, in the rest of this section we set $\pi = 0$ when the notional arbitrage profits would be negative, i.e. when the ask yield of bond 1 is lower than the bid yield of bond 2. In this case no arbitrage is possible and we assume the trade would not be initiated.

Figure 6 shows the distribution of gross profits in our sample. While many of the data points in our sample involves profits close to zero, there is a significant number of profitable trade opportunities. Moreover, a considerable share of observations represent arbitrage opportunities not only in terms of gross profits but also net profits. For example, if we assume lending fees are around 0.6% per annum (average lending fees are between 0.4% and 0.8% in 2019, see Table 1), then 25% of observations are consistent with positive net profits. Average gross profits are especially large before 2007 in both markets (equal to 1.02% and 1.48% for the interbank market and exchange market, respectively), but have declined more sharply in the interbank market than in the exchange market from 2007 (to 0.27% and 1.31%, respectively).

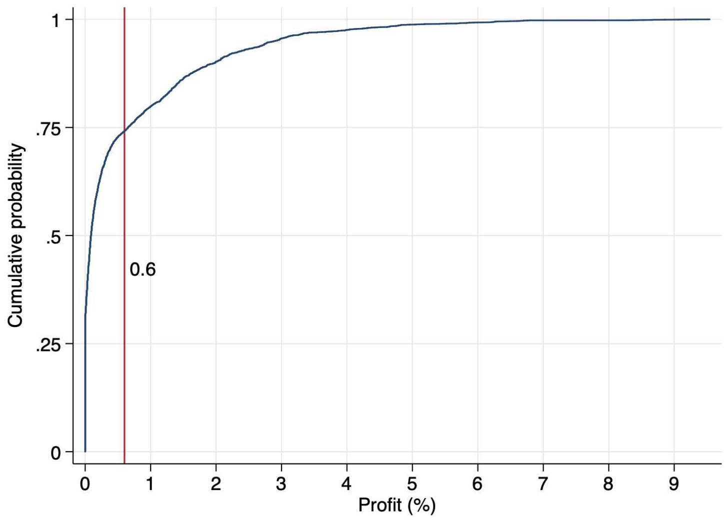


Figure 6: The distribution of gross arbitrage profits

Figure 6 plots the cumulative distribution of annualized gross arbitrage profits as a percentage of the value of borrowed bonds. The histogram is based on data from both markets, from January 2005 to December 2019. Profits are computed as in equation (14), using bid and ask yields when available. Profits are zero when no arbitrage is possible. The red vertical line represents a benchmark lending fee of 0.6%.

After establishing that at least some of the LOP deviations documented in previous sections represent true profit opportunities, we want to quantify the effect of bond lending

[17] Note that bid and ask quotes are not available for trades in the exchange market.

in terms of arbitrage profits. To this end, we repeat our difference-in-differences analysis using gross profits as dependent variable. The results are reproduced in Table 6. Our regression analysis shows that the introduction of bond lending has reduced gross arbitrage profits by more than 0.5%. This suggests that as bond lending has allowed arbitrageurs to correct market mispricing more effectively, there are fewer additional opportunities to exploit LOP violations. Overall, our findings on arbitrage profits are consistent with the qualitative predictions of the limits-to-arbitrage view, described in Hypothesis 3a.

Table 6: Effects on Arbitrage Profits

Arbitrage profit π	(1)	(2)	(3)	(4)
f_m	0.264	0.269	0.228	0.234
	(0.314)	(0.300)	(0.221)	(0.211)
D_{mt}	-0.576*	-0.594*	-0.546**	-0.565**
	(0.352)	(0.340)	(0.271)	(0.265)
ttm_{it}	-0.001**	-0.001**	-0.001***	-0.001**
	(0.001)	(0.001)	(0.001)	(0.000)
g_{mt}		0.184***		0.197**
		(0.066)		(0.084)
Observations	3,790	3,790	3,790	3,790
R-squared	0.390	0.392	0.420	0.423
Pair FE	Y	Y		
Time-varying pair FE			Y	Y
Year FE	Y	Y	Y	Y

Notes: Column (1)-(2) are estimated from specification (5) and column (3)-(4) are estimated from specification (7). f_m takes the value one for interbank market. D_{mt} captures the treatment effect and takes the value one for observations starting from 2007 in the interbank market. All regressions control for the bond pair's time to maturity on date t (ttm_{it}). Column (2) and (4) control for the monthly growth of treasury transaction amount in each market (g_{mt}). Robust standard errors clustered at the bond-pair level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5.5 Effects on Liquidity

In this section we test whether the introduction of bond lending has led to asymmetric changes in the liquidity of matched bonds, as predicted by the liquidity-premium view

(Hypothesis 4). To do this we define the liquidity difference for pair i at time t in market m as:

$$L_{imt} = \left| log\left(\frac{L_{\textit{old},imt}}{L_{\textit{new},imt}}\right) \right| = \left| log(L_{\textit{old},imt}) - log(L_{\textit{new},imt}) \right| \tag{15}$$

where $L_{\textit{old},imt}$ and $L_{\textit{new},imt}$ are measures of the liquidity of the old bond and new bond respectively. We use four different liquidity measures that are typically employed in the literature: the daily trading amount, the daily turnover ratio (defined as daily transaction volume over outstanding volume), the Amihud ratio (calculated as the bond's daily return over its trading volume) and the daily high-low price spread (calculated with the daily high and low clean prices). The first two are quantity-based measures of liquidity, while the last two are price-based measures of liquidity. For each of the four liquidity measures, we repeat our difference-in-differences estimation using the liquidity difference as dependent variable. In each of the four liquidity difference regressions, we adopt pair fixed effects while controlling for the market-specific change in treasury trading as follows:

$$L_{imt} = \alpha_i + f_m + \delta D_{mt} + ttm_{it} + g_{mt} + \tau_t + \varepsilon_{imt} \tag{16}$$

Table 7 shows the results. Across all four specifications, the introduction of bond lending has a statistically insignificant effect on the difference in the liquidity of matched bonds. This holds for both quantity-based and price-based measures of liquidity. This finding contradicts the liquidity-premium view's prediction that allowing short-selling will lead to asymmetric changes in the liquidity (Hypothesis 4). The absence of liquidity effects is consistent with our results on LOP deviations and arbitrage profits.

6 Robustness

In this section we discuss potential limitations of our empirical analysis and provide a number of robustness tests of our findings concerning the effect of bond lending on LOP deviations.

6.1 Placebo Test

We examine the dynamics of the relation between the introduction of bond lending and LOP deviations. We do this by including a series of dummy variables in the baseline regression to trace out the year-by-year effects on the absolute yield spread:

Table 7: Effects on Liquidity

L_{imt}	(1) Trading amount	(2) Turnover ratio	(3) Amihud ratio	(4) High-low price spread
f_m	-2.059***	-1.570***	-1.831***	0.207**
	(0.647)	(0.574)	(0.653)	(0.077)
D_{mt}	0.0686	-0.282	0.0436	-0.192
	(0.685)	(0.622)	(0.771)	(0.211)
ttm_{it}	-0.001	0.000	-0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.000)
g_{mt}	0.225	0.299*	0.054	0.106
	(0.143)	(0.171)	(0.273)	(0.142)
Observations	3,411	3,415	1,833	1,228
R-squared	0.426	0.355	0.333	0.184
Pair FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y

Notes: All columns are estimated with pair fixed effect and year fixed effect. Column (1)-(4) report separate regression results using the absolute value of log difference between the older and the new bond in a bond pair at date t in trading amount, turnover over, Amihud ratio (i.e. price dispersion) and daily high-low price spread respectively. Robust standard errors clustered at the bond-pair level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

$$Y_{imt} = \alpha_i + f_m + \delta_1 D_{mt}^{-2} + \delta_2 D_{mt}^{-1} + ... + \delta_{15} D_{mt}^{12} + g_{mt} + \tau_t + \varepsilon_{imt} \tag{17}$$

where the bond lending dummy variables are defined as:

$$D_{mt}^k = \begin{cases} 1 \text{ if } m = I \text{ and } t - t^* = k; \\ 0 \text{ otherwise} \end{cases} \tag{18}$$

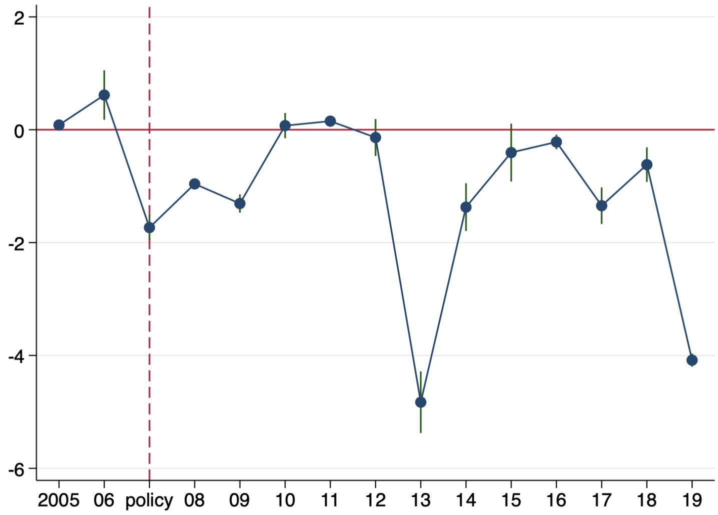


Figure 7: Effects on deviations from LoP over time

Figure 7 plots the estimated δ coefficients and the 95 % confidence intervals, which are adjusted for clustering at the pair level. Under the null hypothesis of no pre-treament trends, we expect the δ coefficients for $t < t^*$ to be zero (where the treatment year is $t^* = 2007$). Inspection of Figure 7 shows that the δ coefficients in year 2005 and 2006 are close to zero. Although the 2006 coefficient is statistically significant at the 95% confidence level, reassuringly its magnitude is much smaller than the effect we estimate for the years following the introduction of bond lending. The introduction of bond lending is estimated to cause a significant decrease in LOP deviations during the first three years of the policy. Absolute yield spreads in the interbank market fall considerably in 2013 (relatively to their levels in the exchange market) and remain low during the following years. The large estimated effect in 2013 is consistent with the fact that bond lending transactions started experiencing a dramatic growth in that year driven by the increased participation of large commercial banks (see Figure 1a and Figure 1b).

6.2 Correlated Effects from the QFII Program

One potential concern with our approach is that the results may partially reflect the impacts from other reforms of China's bond markets. One of the most important policy changes that have affected the treasury market in the past two decades is the Qualified Foreign Institutional Investor (QFII) program. The QFII program has allowed selected global institutional investors to invest in China's RMB denominated capital market, including China's treasury market. Arguably, the opening up and diversification of the investor base of China's treasury market can improve market efficiency. However, since the QFII program was first launched in the exchange market in November 2002, prior to the introduction of bond lending in the interbank market, the introduction of the QFII program cannot affect our estimates.

In March 2013, the QFII program was extended to the interbank market. Since QFIIs were already permitted to participate in the exchange market, this extension of the program may bias our estimates by differentially affecting the two markets. While the bias may not be large given the low participation rate of foreign investors in China's RMB bond markets, we control for this potential confounding factor by repeating our analysis on a restricted subsample. We constrain the time horizon of our study up to February 2013, right before QFII was launched in the interbank market. Columns (1) and (2) of Table 8 show that the results from this restricted subsample are similar to our baseline results. The estimated effect of bond lending on absolute yield spreads is a reduction of 82-87 basis points.

6.3 Correlated Effects from the Introduction of Treasury Futures

Another policy that may have affected China's bond markets is the (re)introduction of treasury futures in August 2013 (trading of treasury futures was suspended in 1995). Investors can use treasury futures to hedge against interest rate risk. Moreover, to profit from falling bond prices, investors can short the futures and close the position with a counteracting long order. Thus, although shorting mechanisms were severely limited in China's bond markets before the introduction of bond lending, it may be argued that shorting treasuries in the future market could have affected the spot market.

To disentangle possible spillovers from the treasury future market to the treasury spot market, we again constrain the treatment period from 2007 up to August 2013, right before the re-launch of treasury futures. Results from column (3) and (4) of Table 8 show that our estimates from this subsample are similar to our baseline estimates. Bond lending is estimated to reduce absolute yield spreads by 82-87 basis points.[18]

Table 8: Subsample 2005 - 2013

	Prior to QFII 2005-Feb 2013		Prior to Treasury Futures 2005-Sep 2013	
Absolute yield spread Y_{imt}	(1)	(2)	(3)	(4)
f_m	0.360**	0.319*	0.360**	0.319*
	(0.150)	(0.170)	(0.150)	(0.170)
D_{mt}	-0.867***	-0.820***	-0.867***	-0.820***
	(0.230)	(0.242)	(0.230)	(0.242)
ttm_{it}	-0.004***	-0.004***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
g_{mt}	0.180	0.185	0.180	0.185
	(0.150)	(0.153)	(0.150)	(0.153)
Observations	1,496	1,496	1,500	1,500
R-squared	0.511	0.555	0.511	0.555
Pair FE	Y		Y	
Time-varying pair FE		Y		Y
Year FE	Y	Y	Y	Y

Notes: All columns are estimated with year fixed effect. Robust standard errors clustered at the bond-pair level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6.4 Bond Lending and Outright Repos

Our interpretation of the empirical findings relies on the assumption that the introduction of bond lending enabled the short-selling of bonds. However, prior to the launch of bond lending at the end of 2006, there was another mechanism that might have been used to carry out short-selling transactions, namely outright repos. In a repurchase agreement (repo), a cash borrower sells a fixed income security (e.g. a bond) to the cash lender and buys it back at a later date. Under an outright repo transaction, the ownership of the collateral is transferred to the cash lender for the length of the transaction (while this is not the case with a pledged repo agreement). Thus, theoretically the cash lender could use the collateral and engage in a short-sale. The outright repo mechanism was first introduced

[18] Since in 2013 there is only 1 matched bond pair with 4 contemporaneous trading days, results across column (1)-(4) in Table 8 are quite similar.

to China's interbank bond market in May 2004, followed by the outright repo trading on the Shanghai Stock Exchange (SSE) for investors later in the same year.[19]

If bond lending and outright repos were perfect substitutes, then bond short-selling should have been possible even before the introduction of bond lending. In this case, our causal interpretation of the empirical findings would be less plausible. However, there are several reasons why bond lending and outright repos are unlikely to be perfect substitutes. First, while outright repos are designed as a mechanism for borrowing and lending cash, security lending is a mechanism for security financing. For instance, Fan and Zhang (2007) state that "the repo markets in China are mainly markets for participants to borrow or lend money, rather than to borrow or lend securities" (page 940). Second, while during an outright repo period bonds cannot be replaced nor cash settlement is allowed, in the bond lending both parties can replace the pledged bonds or settle the deal in cash when it is due upon mutual agreement (Artitle 7.7 and Article 7.8 of "Rules for Bond Transactions of the National Inter-Bank Market" published by CFETS).[20] Third, the bond lending period ranges from minimum 1 day to the maximum 365 days, and mid-to-long term transactions are often used in short-sales, while the tenor of repos is only up to a maximum of 91 days (Article 6.3 and Article 7.2 of the above Rules). These facts suggest that bond lending and outright repos are not perfect substitutes. Thus, it is likely the introduction of bond lending in Chinese bond markets has enabled more bond shorting activity than previously possible.

7 Conclusion

We examine the effect of the introduction of bond lending in China's bond market on yield spreads between similar bonds to understand the nature of deviations from the law of one price (LOP). By comparing the dynamics of yield spreads for the same set of bonds across China's two co-existing bond markets, we rule out biases arising from changes in the composition of our sample around the time of the policy change as well as market-specific factors. We find that the introduction of bond lending has reduced LOP deviations, in accordance with the limits-to-arbitrage view. This effect is stronger for pairs of bonds that have a larger gap in their issuance dates. We document that a considerable number of

[19] In April 2004, the People's Bank of China, China's Ministry of Finance, and China Securities Regulatory Commission jointly issue the "Notice on Developing Outright Repo Trading on Treasury Bonds", http://www.csrc.gov.cn/pub/newsite/flb/flfg/bmgf/scjy/zjjy/201012/t20101231_189821.html

[20] See http://www.chinamoney.com.cn/english/rarrmrrudmrl/20161111/2025.html

observations represent arbitrage opportunities in terms of profits net of bond lending fees. We also show that the introduction of bond lending has led to a decline in gross arbitrage profits, but did not result in asymmetric changes in liquidity between matched bonds, contrary to the predictions of the asymmetric equilibria of Vayanos and Weill (2008)'s model.

The finding that the introduction of bond lending in China's markets has not led to liquidity-based LOP deviations should not be interpreted as a refutation of Vayanos and Weill (2008)'s model, since the model has multiple equilibria, including a symmetric equilibrium where the LOP holds. Moreover, our evidence does not imply the predictions of the asymmetric equilibrium will not be borne out in other settings. Indeed, such asymmetric equilibrium qualitatively and quantitatively matches the empirical evidence about the on-the-run premium in US treasury markets. However, our findings suggest more empirical work is needed to establish settings in which different equilibria of Vayanos and Weill (2008) are likely to arise.

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Additional Figures and Tables

Table 1: Summary statistics of treasury secondary market sample

Interbank market				
Variable	Obs	Mean	Std. Dev.	Median
trading amount (million RMB)	2,828,347	24.71	292.82	0
coupon rate (%)	2,828,347	3.6	.86	3.55
coupon frequency	2,665,070	1.58	.49	2
maturity at issuance (year)	2,828,347	12.86	11.66	10
issuance year	2,828,347	2011.39	4.03	2013
issuance month	2,828,347	6.96	3.14	7
maturity year	2,828,347	2024.22	12.04	2021
maturity month	2,828,347	6.56	3.19	7
# of trading days for active bonds	83,592	754.61	462.31	700
Exchange market				
Variable	Obs	Mean	Std. Dev.	Median
trading amount (million RMB)	1,048,575	.73	20.12	0
coupon rate (%)	1,048,575	3.65	.56	3.57
coupon frequency	1,048,575	1.67	.47	2
maturity at issuance (year)	1,048,575	15.11	12.28	10
issuance year	1,048,575	2013.22	2.6	2014
issuance month	1,048,575	6.7	3.08	7
maturity year	1,048,575	2028.3	11.95	2023
maturity month	1,048,575	6.13	3.11	6
# of trading days for active bonds	28,914	2107.80	1641.53	1071

Notes: The table reports summary statistics for the secondary market treasury transaction data. The sample used for the table includes treasury trading during the sample period (excluding discounted bond and subsequent offerings) prior to the matching pair analysis. The sample period for is January 1, 2000 to December 9, 2019.

Table 2: Bond lending transaction: borrower and lender structure in 2019

Institution type	# of institutions	Bonds lent (RMB bn)
National commercial bank	5	1974
City commercial bank	21	915
Joint stock commercial bank	10	650
Rural commercial bank	10	359
Others	6	216
Securities	6	1
Total	58	4116
Institution type	**# of institutions**	**Bonds borrowed (RMB bn)**
Securities	34	1548
Joint stock commercial bank	11	834
Others	14	829
City commercial bank	20	485
Rural commercial bank	10	215
National commercial bank	2	85
Total	91	3995

Notes: Classification of transactions by institution type in each buy and sell directions are based on top 100 tradings in the year of 2019 published by Chinabond, which covers more than 90% of the total trading took place in 2019. "Others" include credit union, insurance companies, money market fund, and wealth management products issued by banks and securities, and foreign institutions.

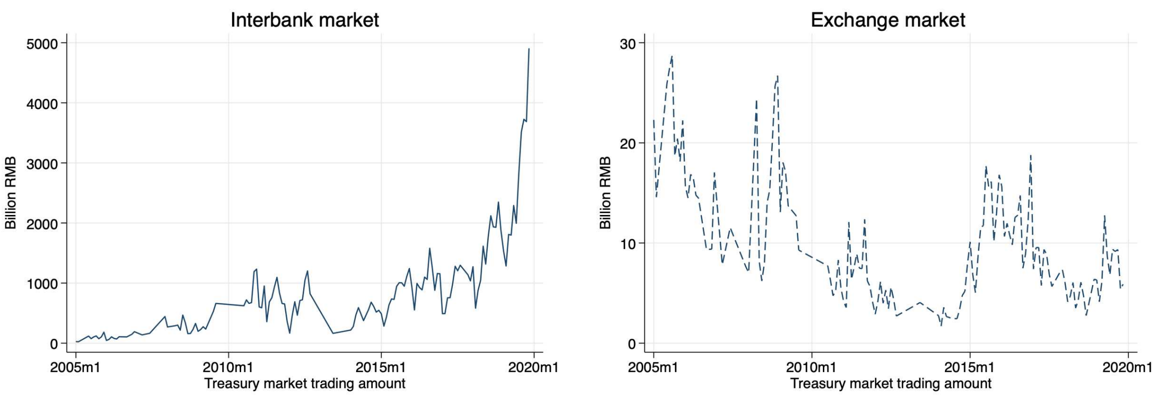
Table 3: Bond lending transactions by bond types: December 2019

Bond type	Trading amount (billion RMB)	Share	# of transaction	Share	Lending fee (%) weighted avg
L001	30	5%	192	9%	0.6150
L007	93	16%	768	37%	0.8845
L014	75	13%	428	21%	0.7362
L021	131	22%	164	8%	0.4489
L1M	149	25%	227	11%	0.4927
L2M	34	6%	100	5%	0.5658
L3M	12	2%	42	2%	0.5430
L4M	12	2%	45	2%	0.5224
L6M	40	7%	56	3%	0.4967
L9M	2	0%	5	0%	0.5150
L1Y	5	1%	23	1%	0.6154
Total	584		2050		0.5903

Source: Bond lending monthly bulletin, December 2019, China Foreign Exchange Trade System

Table 4: Matched pairs trading distribution: same trading day vs trading window

	Day match		Window match	
	# of trades	# of pairs	# of Obs	# of pairs
Interbank market	1036	24	1184	37
Exchange market	1213	9	357	8
Total	2249	33	1541	45



(a) (b)

Figure 1: Treasury trading amount in two markets

Notes: This figure plots the total annual trading amount of treasury in the interbank and exchange from 2005 to 2019.

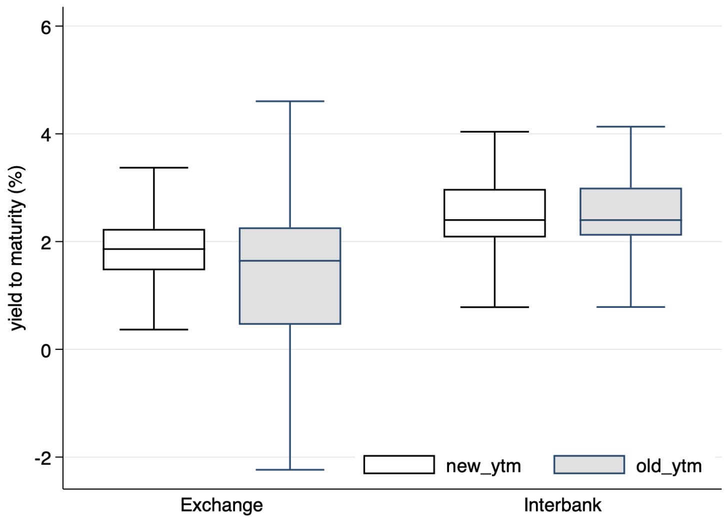


Figure 2: Yields to maturity

Notes: Figure 2 shows boxplots of yield to maturity for matched bonds in the exchange and interbank market. Each boxplot plots value from the top to bottom the corresponding value of upper adjacent value, 75th percentile, median, 25th percentile and lower adjacent value. Note the upper adjacent value is the highest value not greater than 75th percentile + 3/2 (75th percentile - 25th percentile) and the lower adjacent value is the lowest value not less than 25th percentile - 3/2 ((75th percentile - 25th percentile). Outside values of the upper or lower adjacent value are not plotted.