The More Illiquid, The More Expensive: A Search-Based Explanation of the Illiquidity Premium

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Abstract

Using a search-based trading model, we show that either an illiquidity price premium or discount can arise between two assets with identical fundamentals. Liquidity between the two assets diverges endogenously in a self-reinforcing manner as trading is concentrated in the more liquid asset. When buyers are marginal investors, prices are determined by buyers' tradeoff between immediacy and trading gains, generating the illiquidity price discount wherein the liquid asset is more expensive than the illiquid asset. When there is strong selling pressure, however, sellers become marginal investors and the illiquidity price premium arises, because they demand a higher selling price for the illiquid asset by trading off immediacy for trading gains. Using an identification strategy that exploits same-issuer bonds but with differing liquidity, we confirm these theoretical predictions by showing that illiquid bonds have higher prices than liquid bonds during fire-sale episodes, while liquid bonds carry higher prices in normal periods.

JEL Classification: G10, G12, G20, D83

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1 Introduction

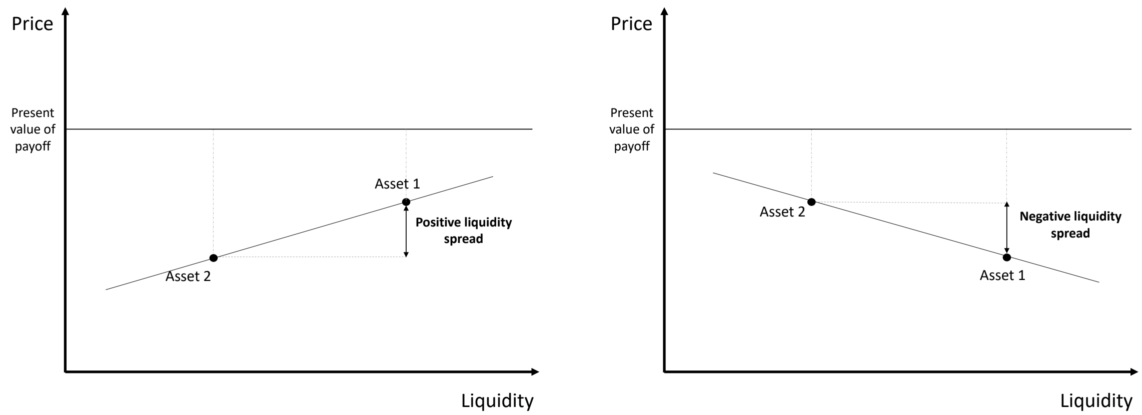
How does illiquidity affect asset prices in over-the-counter (OTC) markets? According to classical theories, holding illiquid assets require higher compensation and, therefore, they should be cheaper than their counterparts with higher liquidity.[1] That is, price differentials between liquid and illiquid assets (henceforth, "liquidity spreads") are generally positive. Although many empirical studies agree with such theoretical predictions, some recent studies also document that liquid assets experience bigger price declines in times of market distress than illiquid assets so that the liquidity spreads can be narrower.[2] These findings can run counter to the usual intuition of flight to liquidity: investors will prefer liquid assets more in distress times and their price declines should be smaller. In this paper, we provide a search-based theoretical model to explain this seemingly-counter-intuitive empirical phenomenon and further show that not only price declines are higher for liquid assets but also their price levels can be lower than those of illiquid assets. We also confirm our theoretical predictions by showing that in the U.S. corporate bond market illiquid bonds can have higher prices than liquid bonds with identical cash flows, using an identification strategy that compares same-issuer bonds with differing illiquidity.

We provide a simple yet powerful mechanism based on search frictions that intuitively explains negative liquidity spreads. We argue that liquidity spreads can flip signs depending on market-wide sell pressure. When buyers are marginal investors, their valuation determines asset prices. They need to be compensated through illiquidity discount (i.e. higher profit) for sacrificing immediacy in trading. Consequently, illiquid assets should generally be less expensive than liquid assets when buyers are marginal investors. When selling pressure is stronger, however, sellers become marginal investors whose risk premium will mainly determine asset prices. Sellers also consider tradeoff between immediacy and trading profits, but the effect of their valuation on asset prices is the opposite of that of buyers. Sellers have higher disutility of holding assets as a result of holding costs and choose which assets to liquidate based on the tradeoff. They want to be compensated by high profits (i.e. high sale prices) for sacrificing immediacy from trading illiquid securities. Therefore, illiquid assets become more expensive than liquid assets when sellers dominate the market. Figure 1 illustrates this.

To formalize the aforementioned idea, we study a search-based trading model with two types of assets in an infinite horizon, traded in two markets with identical search frictions. In each market, only one type of assets is traded. Both types of assets have identical cash flows and have random maturities. There is a continuum of risk-neutral investors who enter the markets from an outsider investor pool, either as a buyer or a seller. A buyer, who does not own any asset but has higher valuation, will search for a counterparty to buy from. A seller, who already owns an asset

[1] See Duffie, Gârleanu, and Pedersen (2005), Duffie, Gârleanu, and Pedersen (2007), Vayanos and Wang (2007), Vayanos and Weill (2008), Weill (2008), Lagos and Rocheteau (2009), Lagos, Rocheteau, and Weill (2011), among many others

[2] In the sovereign bond market, Boudoukh, Brooks, Richardson, and Xu (2019) show the relative discount of illiquid bonds becomes smaller in periods of widening credit spreads.



(a) buyers are marginal investors (b) sellers are marginal investors

Figure 1. Liquidity Spreads under Different Price Pressure

but has lower valuation, will also search for a counterparty to sell to. When a buyer and a seller meets from a successful search, they trade by bargaining. When a buyer obtains an asset from the bargaining, she becomes an inactive owner because holding an asset is optimal. An inactive owner may become a seller in case she receives a low preference shock (which is interpreted as a liquidity shock.) A seller who sells his holding exits the market and goes back to the outside investor pool. An important assumption is that there are local buyers and sellers who enters exclusively into only one market, while there are also discretionary buyers and discretionary sellers who can choose to enter one of the two markets. The intensity of arrival of discretionary buyers and discretionary sellers are interpreted as market-wide buying pressure and selling pressure, respectively.

We show that there exists a symmetric steady-state equilibrium where prices are identical between two markets. In that case, liquidity between the two markets are also identical. There also exists an asymmetric steady-state equilibrium where liquid assets are more expensive than illiquid assets when market-wide buying pressure is stronger than market-wide selling pressure. More importantly, we also show the existence of an asymmetric steady-state equilibrium where illiquid assets are more expensive than liquid assets when market-wide selling pressure is stronger than market-wide buying pressure. Those two types of asymmetric equilibria are exclusive of each other, meaning that they do not co-exist. Therefore, market-wide buying or selling pressure can tilt the market in one way or the other, thereby changing the sign of liquidity spreads.

Why does such an asymmetric equilibrium arise? This is the result of the feedback mechanism between market liquidity and concentration of investors. Investors seek to join more liquid market *ceteris paribus*, but, as more investors join one market, liquidity increases further in that market whereas liquidity deteriorates in the other market. An archetype example of our result is the reversal of liquidity spreads during the time of distress. A severe liquidity shock to investors in bad times can make them want to liquidate their holdings aggressively, causing market-wide selling pressure which dominates buying-pressure. Sellers initially start selling liquid assets because the liquid market is more preferable in terms of both immediacy and trading profits. When this happens, discretionary buyers all gather into the more liquid market to benefit from higher liquidity when they need to liquidate in the future. Because this makes the illiquid market even less attractive to sellers, the difference in liquidity between the two markets intensifies further and sellers require higher compensation through higher selling prices. Consequently, illiquid assets become more expensive than liquid assets unless the market restores in the future the original level balance between buying and selling pressure. This mechanism demonstrates how endogenous liquidity can greatly amplify the price impact of a liquidity shock and can reverse the spread of liquidity premia between liquid and illiquid assets.

We then examine the empirical implications of the model using corporate bond data from the Trade Reporting and Compliance Engine (TRACE) for the period from 2005 through 2017. We find that yields of more liquid bonds increase more than less liquid bonds with almost identical cash flows following fire sale events, and more interestingly, the liquidity spread becomes negative. We focus on the following events in our empirical results: the recent financial crisis period following 2008, the period when funding liquidity measured by the TED Spreads is low, the events of large investor redemption requests in corporate bond mutual funds (CBMFs), and the credit rating downgrade events of corporate bond issuers. Our key idea of the empirical strategy is to find a pair of bonds that have (almost) identical cash flows but differing liquidity. To this end, we match a bond to another bond that is issued by the same issuer and have same maturities and credit rating but different bond age, following the identification method in Choi et al. (2019). We examine the yield spreads of these matched pairs between old and young bonds (liquidity spreads henceforth). To the extent that young bonds are more liquid (i.e. on-the-run) than old bonds (i.e. off-the-run), this empirical strategy allows us to compare the pricing effect of liquidity on two bonds with the same cash flows.

Using these matched bond pairs, we provide four key results that support our theoretical model. First, we show that liquidity spreads become significantly negative following the liquidity events that we consider. For example, the average liquidity spread falls to -0.4% following the announcement of Lehman Brothers' bankruptcy, suggesting that liquid bonds were in fact cheaper than illiquid bonds during the time of distress. Our evidence also suggests that the negative liquidity spreads are more likely where the relative search friction of illiquid bond to liquid bond is higher and the arbitrage is more difficult to be implemented. Second, we find that the relationship between market liquidity and bond prices are positive on average but becomes negative when funding liquidity (measured by the TED spreads) is low or market-wide outflows from CBMFs are large. Third, we find that the prices of liquid bonds become significantly lower than those of the matched illiquid bond after credit rating downgrades. These results are all consistent with the model's implication that the price of more liquid bonds can be lower when the sellers are the marginal investors.

Note that we do not argue that our mechanism is the only economic force at work. There are other potential explanations. Boudoukh, Brooks, Richardson, and Xu (2019), for example, argue the liquidity spread narrows (but is still positive) because of price pressure arising from flight from low-quality sovereign bonds. Chaderina, Mürmann, and Scheuch (2018) document that liquid price declines are greater following rating downgrades because of coordination failure in insurance companies' bond liquidation. Lou and Sadka (2011) show that liquid stock returns are lower during financial crisis because they are more sensitive to market wide returns. Our view is that these explanations including ours are not necessarily mutually exclusive. Certainly, a more realistic view is that all these forces can even have amplifying effects on the pricing impact of illiquidity.

We also want to emphasize, however, that our study differs from these studies in the following important ways. We provide a full-scale dynamic equilibrium model to show how search frictions can explain our empirical findings. More importantly, we show how the liquidity spread can become *negative*: not only price declines are greater, but the price levels of liquid assets are lower than those of illiquid assets. As our model shows, incorporating search friction is crucial in generating this effect. In a trading venue like exchanges where search frictions are minimal, we do not expect to see such an inversion of liquid versus illiquid prices. Our empirical findings also differ from those previous papers that focus on time-series price declines of liquid and illiquid bonds. Our novel results are that illiquid bond prices can in fact be higher than liquid bond prices, which we show using the identification strategy exploiting the same issuer bonds with different liquidity.

The paper is organized as follows. In Section 2, we discuss related literature. In Section 3, we illustrate the main intuition using a simple model. In Section 4, we describe the main model. In Section 5, we solve for the equilibrium of the model and discuss the theoretical predictions. In Section 6, we describe the empirical setup. In Section 7, we discuss our empirical findings. In Section 8, we conclude.

2 Literature Review

Our paper is related to the literature on search-based asset pricing models. In their seminal work, Duffie, Gârleanu, and Pedersen (2005) show that liquidity premium arises due to search frictions using an OTC market setup with a single asset. Duffie, Gârleanu, and Pedersen (2005) further extend this framework with risk averse investors to study asset pricing implications in OTC markets. More closely-related works to our paper include search-based models with multiple assets such as Vayanos and Wang (2007) and Weill (2008), and Vayanos and Weill (2008). Vayanos and Wang (2007) and Weill (2008) show that buyers' market choice can create cross-sectional variations in prices due to endogenous liquidity difference. In these models, however, sellers do not have market choices. On the other hand, Vayanos and Weill (2008) feature short sellers who can choose markets. They show that cross-sectional variations in prices can arise due to endogenous liquidity difference short sellers face when covering their short positions. One common feature among the existing OTC market models with multiple markets is that sellers are never marginal investors who drive cross-sectional variations. As a result, liquid assets are generally more expensive whenever there are cross-sectional variations.[3] Our paper differs from this line of literature because we allow sellers become marginal investors instead of buyers, which is the key mechanism which generate negative liquidity spread between liquid and illiquid assets.

Our paper is also related to the limits-to-arbitrage literature. This line of literature often focuses on the feedback between capital constraint and mispricing. In time series, the violation of the law of one price arises due to the intertemporal linkage of mispricing wedge when investors are capital-constrained (Shleifer and Vishny (1997), Gromb and Vayanos (2002), Brunnermeier and Pedersen (2009), Kondor (2009), Dow, Han, and Sangiorgi (2019)). In cross-section, mispricing wedge can be larger for more illiquid assets than liquid assets because investors have be compensated with higher profits for illiquid investment (Shleifer and Vishny (1990)). Our model differs from those papers in that we explicitly model liquidity using search frictions. We contribute to this line of literature by providing a mechanism of the violation of the law of one price where the sign of relative mispricing flips cross-sectionally due to changes in marginal investors.

There is a growing theoretical literature that studies investors' endogenous market choice among multiple trading venues— for identical or correlated assets with same or different trading mechanisms. A strand of literature studies incentives to choose a counterparty and endogenize over-the-counter networks (Zhu (2012), Hugonnier, Lester, and Weill (2016), Babus and Parlatore (2019)). Observing that some assets are often available in both over-the-counter markets and centralized exchanges, several authors have explored choices between these two trading venues: such as default, search friction, price impacts, and information asymmetry between sellers and buyers (Kirilenko (2000), Viswanathana and Wang (2002), Praz (2015), Bolton, Santos, and Scheinkman (2016), Yoon (2016), Lee and Wang (2019), and Dugast, Üslü, and Weill (2019)). Our paper contributes to this line of literature by explaining how cross-market liquidity difference and asset prices are formed by market choices under search frictions.

Our paper contributes to the literature on price pressures in bond markets (Greenwood and Vayanos (2014), Ellul, Jotikasthira, and Lundblad (2011a), Feldhütter (2012), Manconi, Massa, and Yasuda (2012), D'Amico and King (2013), Goldstein, Jiang, and Ng (2017), Boudoukh, Brooks, Richardson, and Xu (2019), Choi, Hoseinzade, Shin, and Tehranian (2019), Helwege and Wang (2019)). Especially, our paper provides the mechanism and rationale behind recent findings of Boudoukh, Brooks, Richardson, and Xu (2019) that liquid government bonds become cheaper during times of distress.

Our paper also contributes to the literature on the pricing of liquidity (Amihud and Mendelson (1988), Acharya and Pedersen (2005)), the liquidity premium of corporate bonds (Chen, Lesmond, and Wei (2007), Lin, Wang, and Wu (2011), De Jong and Driessen (2012), Acharya, Amihud, and Bharath (2013)), and that of sovereign bonds (Cornell and Shapiro (1989), Amihud and Mendelson (1991), Longstaff, Neis, and Mithal (2005), Pasquariello and Vega (2009), Favero, Pagano, and Von Thadden (2010), Goyenko, Subrahmanyam, and Ukhov (2011), among many others) by docu-

[3] Most of the existing papers with multiple assets also have generic symmetric equilibria where there is no cross-sectional variation.

menting the seemingly counter-intuitive situation in relative prices of liquid securities during times of flight from liquidity.

3 An Illustration with a Simple Model

We first demonstrate the main mechanism using a simple stylized model. Consider two identical assets (asset 1 and asset 2) which pay one unit of consumption good in the next period. The discount rate is fixed to zero. Asset 1 is traded in market 1, and asset 2 is traded in market 2. Due to search frictions, an investor is able to trade if the investor is matched with a counterparty. An investor choosing market $k = 1, 2$ is matched successfully with probability f_i. We assume $f_1 > f_2$ so that that market 1 is more liquid than market 2.

Consider a risk-neutral buyer who can choose to trade in either of the two markets. With a successful match in market k, the buyer acquire asset k by paying price p_i. Otherwise, the buyer keeps the reservation utility of zero. The buyer's value of trading in market k is given by

$$V_i = Pr(\text{Success}) \times \text{Trading gains} + Pr(\text{Fail}) \times \text{Reservation value} = f_i(1 - p_i)$$

If the buyer is indifferent between the two markets, the expected value of choosing each market should be the same:

$$f_1(1 - p_1) = f_2(1 - p_2)$$

Because the probability of a successful buying trade is higher for asset 1 (i.e., $f_1 > f_2$), the trading gain of the buyer should be smaller for the asset (i.e., $1 - p_1 < 1 - p_2$.) That is, the price of asset 1 should be higher than that of asset 2. The liquidity spread between asset 1 and 2 is positive because

$$p_1 - p_2 = \frac{f_1 - f_2}{f_1} (1 - p_2) > 0$$

Therefore, when buyers are marginal investors, it has to be the case that liquid assets should be more expensive.

Now, we consider the case of a seller who can choose between the two markets. We assume that the seller has a lower valuation of the asset than the buyer; he has to pay a holding cost of δ if he does not sell it immediately. The seller's value of trading in market k is given by

$$V_i = f_i p_i + (1 - f_i)(1 - \delta) = f_i(p_i - 1 + \delta) + 1 - \delta$$

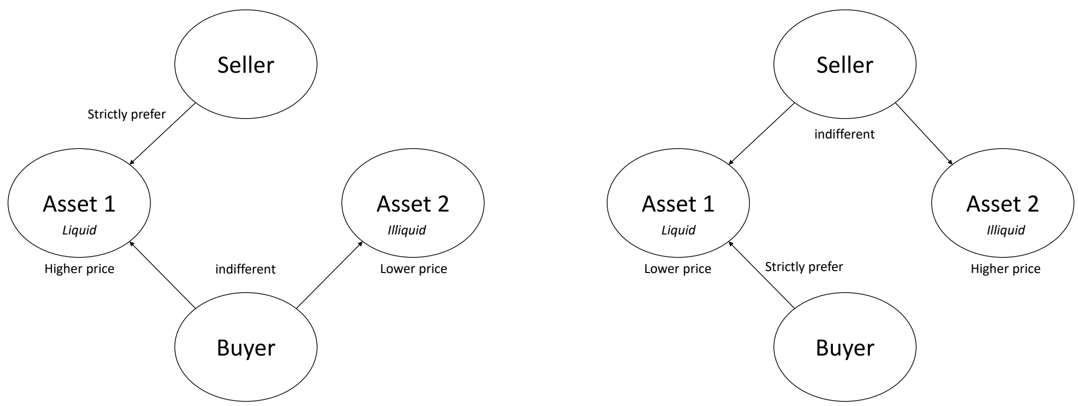
If the seller is indifferent between the two markets, the expected value of choosing each market should be the same:

$$f_1(p_1 - 1 + \delta) = f_2(p_2 - 1 + \delta)$$

Because the probability of a successful selling trade is higher for asset 1 (i.e., $f_1 > f_2$), the trading gain of the seller should be smaller for the asset (i.e., $p_1 - 1 + \delta < p_2 - 1 + \delta$.) That is, the price of asset 1 should be lower than that of asset 2. The liquidity spread between asset 1 and 2 is negative because

$$p_1 - p_2 = \frac{f_2 - f_1}{f_1} (p_1 - 1 + \delta) < 0$$

Therefore, when sellers are marginal investors, it has to be the case that liquid assets should be cheaper.



(a) buyers are marginal investors

(b) sellers are marginal investors

Figure 2. Liquidity Premia under Different Marginal Investors

Fixing liquidity as an exogenous input, this simple model illustrates the relation between liquidity and asset prices in two different cases by setting marginal investors differently. When there are sufficiently large number of buyers relative to that of sellers, buyers become marginal investors, in which case asset prices are set by the trade-off between liquidity and trading gains in terms of buyers' valuations. In this case, sellers strictly prefer trading in liquid market. On the other hand, when there are sufficiently large number of sellers relative to that of buyers, an opposite situation arises. This is illustrated in Figure 2. To fully investigate this question, however, one should solve a dynamic equilibrium model which endogenizes liquidity by incorporating all investors' choices into the equilibrium solution. We study this in the next section.

4 Model

4.1 Description

We consider a multi-market dynamic trading model with search frictions. The risk-free rate is exogenously given by r. There are two assets labeled as asset 1 and 2. In each market 1 and 2, investors trade asset 1 and 2, respectively. Both assets pay a unit of consumption good per a unit of time, and there is no final payoff. Each unit of asset matures with a Poisson intensity of χ. The assumption of staggered maturities is for technical convenience; as it will become clear in the laws of motion, this assumption keeps the mass of supplied assets in the market stable.[4] We further assume that assets are traded by one unit which is indivisible, and no short sales are allowed.

All investors are risk-neutral and infinitely-lived, with preference defined by a discount rate of r. Investors enter the market as buyers or sellers from an outside investor pool depending on their trading needs.

Buyers initially do not hold any position, and can hold at most one unit of assets. There are "local buyers" who can buy only in one market, and "discretionary buyers" who can buy in any of the two markets. Local buyers who can trade in only one market enter at the rate of ϕ^b in each market, and discretionary buyers enter at the rate of ϕ^b_d. Upon the entrance, discretionary buyers choose to buy in either of the two markets. Buyers become "inactive owner" once they own a position because buyers do not have any holding cost. Inactive owners are subject to an idiosyncratic preference shock (or liquidity shock) with a Poisson intensity κ which gives them a holding cost of δ per unit of time. Those shocked inactive owners become sellers. Upon selling their positions, they exit the market and go back to the outside investor pool.

Unlike buyers, some investors enter the market as sellers because they already hold a position when they enter the market. There are "local sellers" who hold one unit of either asset 1 or 2, and "discretionary sellers" who hold one unit of both assets. Local sellers who can trade in only one market enter at the rate of ϕ^s in each market, and discretionary sellers enter at the rate of ϕ^s_d. Upon the entrance, discretionary sellers choose to sell in either of the two markets. Both local sellers and discretionary sellers have a holding cost of δ until they sell one unit of their position. One can interpret that discretionary sellers are larger traders who can holder a larger portfolio than local sellers. For mathematical simplicity, we further assume that a discretionary seller's positions in asset 1 and 2 have an identical maturity (i.e., the arrival of maturity is synchronized.) As shown later in the paper, this assumption gives the same trading surplus for both local and discretionary sellers.[5] Upon selling one unit of their positions, sellers exit the market and go back to the outside investor pool. Figure 3 illustrates the flow of investors between the two markets.

Investors can trade assets by finding a counterparty according to a random search which follows

[4]See, for example, He and Xiong (2012) for further discussions on the assumption.

[5]The assumption of synchronized maturities for each individual discretionary seller is a purely technical assumption which simplifies our analysis. Without this assumption, trading surplus of a discretionary seller becomes different from that of a local seller, which creates multiple trading prices. However, it does not affect the results qualitatively in any other way than making calculations more complex.

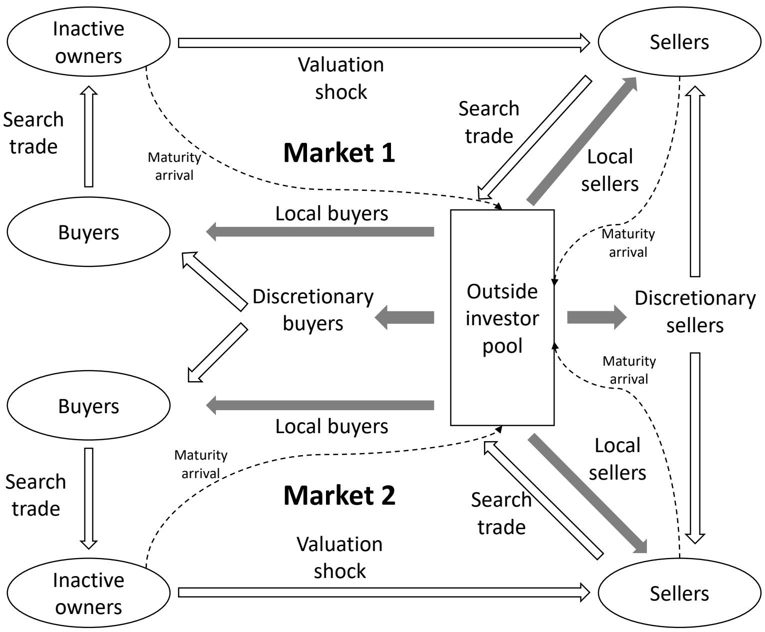


Figure 3. The Flow of Investors between the Two Markets

a Poisson process. In both markets, the Poisson intensity of finding a counterparty is λ which describes the search technology in the market. We denote the mass of buyers and sellers in market i at time t by $\mu_i^b(t)$ and $\mu_i^s(t)$. The total mass of matched pairs in market i at time t is given by $\lambda\mu_i^b(t)\mu_i^s(t)$. Therefore, the probability of buying and selling in market i at time t is given by

$$\lambda_i^b(t) \equiv \lambda\mu_i^s(t), \quad \lambda_i^s(t) \equiv \lambda\mu_i^b(t), \tag{1}$$

respectively. When an investor finds a counterparty for trading an asset, the transaction price is determined by bargaining for the asset between two investors where the bargaining powers of seller and buyer are exogenously given by q and $1-q$, respectively.

To focus on economically meaningful outcomes, we introduce a parametric restriction on the intensity of investors' arrivals.

Assumption 1 $\chi(\phi^b + \phi_d^b) \leq (\chi + \kappa)\phi^s$.

This assumption ensures that the mass of sellers (thus, the successful buying probability) is positive regardless of discretionary investors' choice of markets.[6]

[6]As we show later, μ_i^s in equation (13) is positive even in the worse case, in which no discretionary sellers enter market i (i.e., $\eta_i = 0$) and all discretionary buyers enter market i (i.e., $\gamma_i = 1$).

4.2 Laws of Motion

We denote the portion of discretionary buyers who choose to enter market i by ν_i, and the portion of discretionary sellers who choose to enter market i by η_i. In one market, any investor can be described by three types: buyer (b), inactive owner (o), seller (s).

The laws of motion for mass μ_i^σ of type $\sigma \in \{b, o, s\}$ in market i are given by

$$\dot{\mu}_i^b(t) = -\lambda\mu_i^s(t)\mu_i^b(t) + \phi^b(t) + \phi_d^b(t)\nu_i(t); \tag{2}$$

$$\dot{\mu}_i^o(t) = -(\chi + \kappa)\mu_i^o(t) + \lambda\mu_i^b(t)\mu_i^s(t); \tag{3}$$

$$\dot{\mu}_i^s(t) = -(\chi + \lambda\mu_i^b(t))\mu_i^s(t) + \phi^s(t) + \phi_d^s(t)\eta_i(t) + \kappa\mu_i^o(t). \tag{4}$$

The first equation of the laws of the motion is the one for the mass of buyers in market i. The first term describes the departure from the buyer pool due to a successful trade. The second term describes the entry of local buyers, and the third term describes the entry of discretionary buyers who choose to enter market i. The other two equations are laws of motion for inactive owners and sellers which can be similarly interpreted.

As shown in the Appendix, the value functions V_i^σ of type σ in market i satisfy the Hamilton-Jacobi-Bellman (HJB) equations as follows:

$$\dot{V}_i^b(t) = rV_i^b(t) - \lambda_i^b(t)(V_i^o(t) - V_i^b(t) - P_i(t)); \tag{5}$$

$$\dot{V}_i^o(t) = rV_i^o(t) - \kappa(V_i^s(t) - V_i^o(t)) - \chi(V^n - V_i^o(t)) - 1; \tag{6}$$

$$\dot{V}_i^s(t) = rV_i^s(t) - \lambda_i^s(t)(P_i(t) + V^n - V_i^s(t)) - \chi(V^n - V_i^s(t)) - (1 - \delta), \tag{7}$$

where $V^n = 0$ which is the value of exiting the market and going back to the outside investor pool, and $P_i(t)$ is the price of asset i at time t. The first equation of HJBs is the one for the value of a buyer. It shows that the value increases whenever the price P_i is less than the surplus $V_i^o(t) - V_i^b(t)$. The second and third equations are the HJBs for the value of an inactive owner and a seller which can be similarly interpreted.

The price of asset in market i is determined by Nash (1950) bargaining with a seller bargaining power q:

$$P_i(t) = (1 - q)\Delta V_i^s(t) + q\Delta V_i^b(t), \tag{8}$$

where $\Delta V_i^s(t) \equiv V_i^s(t) - V_n$ and $\Delta V_i^b(t) \equiv V_i^o(t) - V_i^b(t)$ which describe the seller's surplus and the buyer's surplus at time t, respectively.

4.3 Market Choice

A discretionary buyer, who enters the market without any position, maximizes value by choosing between market 1 and 2 to buy a new position. Therefore, at time t, the portion of discretionary buyers who choose market 1 is given by

$$\nu_1(t) \in \begin{cases} 0 & \text{if } V_1^b(t) < V_2^b(t) \\ [0,1] & \text{if } V_1^b(t) = V_2^b(t) \\ 1 & \text{if } V_1^b(t) > V_2^b(t) \end{cases} \tag{9}$$

and $\nu_2(t)$ is equal to $1 - \nu_1(t)$.

Likewise, a discretionary seller, who enters the market with a position on each asset, maximizes value by choosing between market 1 and 2 to sell one unit of holdings. Therefore, at time t, the portion of discretionary sellers who choose market 1 is given by

$$\eta_1(t) \in \begin{cases} 0 & \text{if } V_1^s(t) < V_2^s(t) \\ [0,1] & \text{if } V_1^s(t) = V_2^s(t) \\ 1 & \text{if } V_1^s(t) > V_2^s(t) \end{cases} \tag{10}$$

and $\eta_2(t)$ is equal to $1 - \eta_1(t)$.

5 Equilibrium

The stationary equilibrium of the model is defined in a standard manner:

Definition 1 *A market equilibrium is a collection of masses $\{(\mu_i^b, \mu_i^o, \mu_i^s)\}_{i=1,2}$, market choices $\{\nu_i, \eta_i\}_{i=1,2}$, value functions $\{(V_i^b, V_i^o, V_i^s)\}_{i=1,2}$, and prices $\{P_i\}_{i=1,2}$ which satisfy*
(i) $\{(\mu_i^b, \mu_i^o, \mu_i^s)\}_{i=1,2}$ are given by (2)-(4),
(ii) $\{\nu_i, \eta_i\}_{i=1,2}$ are given by (9) and (10),
(iii) $\{(V_i^b, V_i^o, V_i^s)\}_{i=1,2}$ are given by (5)-(7),
(iv) $\{P_i\}_{i=1,2}$ are given by (8).

5.1 Steady State Analysis

In this section, we focus on the steady state equilibrium of the model. In the steady state, the inflow and the outflow should be equalized for mass of each type. Therefore, (2) implies that the steady state mass of matched pairs in market i should be equal to the mass of entering buyers:

$$\lambda \mu_i^s \mu_i^b = \phi^b + \phi_d^b \nu_i. \tag{11}$$

Then, (3) and (11) imply the following steady state mass of active owners:

$$\mu_i^o = \frac{\lambda \mu_i^b \mu_i^s}{\chi + \kappa} = \frac{\phi^b + \phi_d^b \nu_i}{\chi + \kappa}. \tag{12}$$

which is due to the fact that the flow-out of inactive owners should be equal to their flow-in in the steady state. Finally, (4) together with (11) and (12) yields the steady-state mass of sellers and buyers as follows:

$$\mu_i^s = \frac{\phi^s + \phi_d^s \eta_i}{\chi} - \frac{\phi^b + \phi_d^b \nu_i}{\chi + \kappa}, \tag{13}$$

$$\mu_i^b = \frac{\phi^b + \phi_d^b \nu_i}{\lambda \left[\frac{\phi^s + \phi_d^s \eta_i}{\chi} - \frac{\phi^b + \phi_d^b \nu_i}{\chi + \kappa} \right]}. \tag{14}$$

In the first equation, the mass of sellers in the steady-state depends on the difference between entering sellers and entering buyers with some adjustments due to asset maturities and type changes (liquidity shocks.) In the second equation, the mass of buyers in the steady-state depends on the mass of entering buyers with an adjustment due to the probability of successful buying trades.

In the steady state, the change in the value should be zero for the value of each type. Therefore, (5)-(7) imply

$$(r + \lambda_i^b) V_i^b = \lambda_i^b (V_i^o - P_i); \tag{15}$$

$$(r + \kappa + \chi) V_i^o = \kappa V_i^s + \chi V^n + 1; \tag{16}$$

$$(r + \chi + \lambda_i^s) V_i^s = \lambda_i^s (P_i - V^n) + \chi V^n + 1 - \delta. \tag{17}$$

Using (15)-(17) together with (8) yields

$$\begin{pmatrix} r + \chi + q\lambda_i^s & -q\lambda_i^s \\ -\frac{r\kappa}{r+\kappa+\chi} - (1-q)\lambda_i^b & r + (1-q)\lambda_i^b \end{pmatrix} \begin{pmatrix} \Delta V_i^s \\ \Delta V_i^b \end{pmatrix} = \begin{pmatrix} 1 - \delta \\ \frac{r}{r+\kappa+\chi} \end{pmatrix}. \tag{18}$$

As shown in the Appendix, using (8) and (18), we can obtain the steady state price for asset i:

$$P_i = \frac{1}{r + \chi} - \frac{\delta}{r + \chi} \left[\frac{\left(1 - \frac{r+\chi}{r+\kappa+\chi} q\right) r + (1-q)\lambda_i^b}{r + (1-q)\lambda_i^b + \frac{r}{r+\kappa+\chi} q \lambda_i^s} \right], \tag{19}$$

where the first term is the present value of payoff until the random maturity τ_χ which arrives with a Poisson maturity intensity χ:

$$\mathrm{E}_t \left[\int_t^{\tau_\chi} e^{-r(u-t)} du \right] = \frac{1}{r + \chi}, \tag{20}$$

and the second term is the illiquidity discount which arises due to search frictions.

We define marginal investors as those investors who are indifferent between the two markets. That is, marginal investors are those who affect pricing in both markets, thus, they determine cross-sectional variations of prices and liquidity premia of the two assets. The fundamental of the two assets are equal due to (20), but their prices may still differ because marginal investors require different compensations given different liquidity.

If buyers are marginal investors (i.e., $V_1^b = V_2^b$), (15) implies that prices should satisfy the following relation:

$$\frac{\lambda_1^b}{r+\lambda_1^b}(V_1^o - P_1) = \frac{\lambda_2^b}{r+\lambda_2^b}(V_2^o - P_2), \tag{21}$$

which in turn implies that the profit of trading more liquid asset (in terms of successful buying probability) should be lower, i.e.,

$$V_1^o - P_1 < V_2^o - P_2 \quad \text{if and only if} \quad \lambda_1^b > \lambda_2^b. \tag{22}$$

where $V_i^o - P_i$ captures the trading profit in market i because V_i^o is the benefit of being an inactive owner and P_i is the cost. On the other hand, if sellers are marginal investors (i.e., $V_i^s = V_2^s$), (17) implies that prices should satisfy the following relation:

$$\frac{\lambda_1^s}{r+\chi+\lambda_1^s}P_1 = \frac{\lambda_2^s}{r+\chi+\lambda_2^s}P_2, \tag{23}$$

which in turn implies that the price of more liquid asset (in terms of successful selling probability) should be lower, i.e.,

$$P_1 < P_2 \quad \text{if and only if} \quad \lambda_1^s > \lambda_2^s. \tag{24}$$

This result is in line with the intuition presented by a simple model in Section 3. We summarize this by the following lemma.

Lemma 1 *If buyers are marginal investors, $\lambda_1^b - \lambda_2^b$ and $(V_1^o - P_1) - (V_2^o - P_2)$ have an opposite sign. If sellers are marginal investors, $\lambda_1^s - \lambda_2^s$ and $P_1 - P_2$ have an opposite sign.*

Lemma 1 shows the possibility that the spread of liquidity premia can be reversed depending on who are marginal investors in the economy. In case market 1 is generally more liquid for both buyers and sellers (i.e., $\lambda_1^b > \lambda_2^b$ and $\lambda_1^s > \lambda_2^s$), (16) and (17) imply that $V_1^o > V_2^o$. Then, (22) implies that $P_1 - P_2 > V_1^o - V_2^o > 0$. Therefore, in case one market is generally more liquid for both buyers and sellers, liquid asset is more expensive if buyers are marginal investors, but illiquid asset becomes more expensive if sellers are marginal investors. Now, the remaining important question to answer is under what situations buyers or sellers become marginal investors, which we study this in the next subsection.

5.2 Steady State Equilibrium

In this section, we provide a sufficient and necessary condition, in primitive terms, under which steady state equilibrium exists. There are four types of steady state equilibria depending on the identity of marginal investors. First, both discretionary buyers and discretionary sellers are indifferent between the two markets (i.e., both are marginal investors). Following our discussion in

Section 3, prices are equalized between the two markets. Second, discretionary buyers are marginal and price in the market where all discretionary sellers enter is higher than price in the other market where no discretionary sellers enter. Third, discretionary sellers are marginal and price in the market where all discretionary buyers enter is lower than price of the other market. Lastly, no trader is marginal in both markets.

Now, we discuss when symmetric or asymmetric equilibria exist. First, *symmetric equilibrium always exists and is unique.* A unique symmetric equilibrium arises naturally due to symmetry of parameters; the two markets have same search technology $\lambda_1 = \lambda_2$ and identical local investors' arrival rates ϕ^b and ϕ^s. In the symmetric equilibrium, an equal portion of discretionary buyers and sellers enter each market: i.e., $\eta_1 = \eta_2 = 0.5$ and $\nu_1 = \nu_2 = 0.5$ (see Proposition 2 (1).)

When would asymmetric equilibria exist? As an example, we discuss the class of asymmetric equilibria in which discretionary buyers are marginal. A similar argument can describe asymmetric equilibria in which the discretionary sellers are marginal. From Nash bargaining price (8), the indifference condition of a marginal buyer ($V_1^b = V_2^b$) is simplified to[7]

$$\lambda_1\mu_1^s(1-q)(\Delta V_1^b - \Delta V_1^s) = \lambda_2\mu_2^s(1-q)(\Delta V_2^b - \Delta V_2^s), \tag{26}$$

where $\Delta V_i^b \equiv V_i^o - V_i^b$ and $\Delta V_i^s \equiv V_i^s - V^n$ for each i. By plugging the steady state value function (15)-(17) into (26), we get the indifference condition of discretionary buyers in terms of investors' mass in the steady state:

$$\frac{\lambda_1\mu_1^s}{(r+\chi+\kappa)(r+\lambda_1\mu_1^s(1-q)) + rq\lambda_1\mu_1^b} = \frac{\lambda_2\mu_2^s}{(r+\chi+\kappa)(r+\lambda_2\mu_2^s(1-q)) + rq\lambda_2\mu_2^b}. \tag{27}$$

All discretionary buyers choose market 1 (i.e., $\nu_1 = 1$) if the value of choosing in market 1 is strictly greater than that of choosing market 2 (or equivalently, the left-hand-side of (27) is strictly greater than the right-hand-side). Likewise, all choose market 2 (i.e., $\nu_1 = 0$) if the left-hand-side is strictly smaller than the right-hand-side.

A key observation is that the expected payoff in market 1 is decreasing in ν_1 taking $\eta_1 = 1 - \eta_2$ as fixed, and by $\nu_2 = 1 - \nu_1$ the expected payoff in market 2 is increasing in ν_1. The monotonicity of expected payoffs in the marginal trader's market choice ν_1 immediately implies that a solution $\nu_1 \in [0, 1]$ that solves the indifference condition (27) is *unique* when it exists.

The value of choosing one market monotone decreases in the number of other discretionary buyers' choosing the market. When more buyers enter the market, sellers are matched with a

[7] To see this, from (15), $V_1^b = V_2^b$ is equivalent to

$$\lambda_1^b(V_1^o - V_1^b - P_1) = \lambda_1^b(V_2^o - V_2^b - P_2). \tag{25}$$

Substituting (8) into prices P_1 and P_2 in the above equation yields (26).

higher intensity and leave the market faster:

$$\mu_1^s = \frac{\phi^s + \phi_d^s \eta_1}{\chi} - \frac{\phi^b + \phi_d^b \nu_1}{\chi + \kappa}. \tag{28}$$

The fewer sellers remains in the market, the lower trading probability buyers get in the market 1. On the other hand, as ν_1 increases, taking η_1 as given, the trading surplus $\Delta V_1^b - \Delta V_1^s$ in market 1 decreases if q is sufficiently large, and increases otherwise.

$$\Delta V_1^b - \Delta V_1^s = \frac{r\delta}{(r + \chi + \kappa)(r + \lambda_1 \mu_1^s (1 - q)) + r\lambda_1 \mu_1^b q}. \tag{29}$$

Even when buyers take all trading surplus (i.e., $q = 0$), the increase of trading surplus is dominated by the decrease of sellers' mass μ_1^s as long as $r > 0$. When the trading surplus is split between buyers and sellers through $q > 0$, the increase of buyers' mass μ_1^b dampens the total surplus further, and thus, the dominance of the decrease in the trading probability $\lambda_1 \mu_1^s$ is even stronger with $q > 0$. Hence, as ν_1 increases, the left-hand-side of (27) decreases and the right-hand-side increases, and guarantees the uniqueness of $\eta_i \in [0, 1]$ when it exists.

Proposition 2 provides a sufficient and necessary condition of existence of each type of equilibrium. Parts (i), (ii), and (iii) show that there exists a unique (pair of) asymmetric equilibria, and provide exclusive conditions on which type of equilibrium arises: marginal buyers, marginal sellers, or no marginal trader, respectively. For simplicity, we focus on asymmetric equilibrium in which market 1 is more liquid that market 2. There always exist a pair of asymmetric equilibria — (η_i, ν_i) and $(1 - \eta_i, 1 - \mu_i)$ — if there is any.

Proposition 2 (Steady State Equilibria) *There exists a unique symmetric equilibrium with* $\eta_i = \nu_i = \frac{1}{2}$. *There also exists an asymmetric equilibrium such that*

(i) (Marginal Buyers) discretionary buyers are marginal and all sellers enter market 1 *(i.e.,* $\eta_1 = 1$*) when*

$$\frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi + \kappa} < \Phi_1(\phi_d^s; \phi^b, \phi^s) \equiv \frac{1}{2A}\Big(- B + \sqrt{B^2 + 4AC\frac{\phi_d^s}{\chi}}\Big), \tag{30}$$

(ii) (Marginal Sellers) discretionary sellers are marginal and all buyers enter market 1 *(i.e.,* $\nu_1 = 1$*) when*

$$\Phi_2(\phi_d^b; \phi^b, \phi^s) \equiv \frac{1}{2D}\Big(- E + \sqrt{E^2 + 4DF\frac{\phi_d^b}{\chi + \kappa}}\Big) < \frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi + \kappa}, \tag{31}$$

(iii) (Corner Equilibrium) both discretionary buyers and sellers enter market 1 *(i.e.,* $\eta_1 = 1$ *and* $\nu_1 = 1$*) when*

$$\Phi_1(\phi_d^s; \phi^b, \phi^s) \le \frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi + \kappa} \le \Phi_2(\phi_d^b; \phi^b, \phi^s), \tag{32}$$

where $\Phi_2(\phi_d^b;\phi^b,\phi^s) \geq \Phi_1(\phi_d^s;\phi^b,\phi^s)$ *holds;* $A = r + (1-q)(\chi+\kappa) + q(\chi+\kappa)\frac{\phi^s}{\chi}(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa})^{-1} > 0$, $B = A(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}) + q(\chi+\kappa)\frac{\phi^s}{\chi} > 0$, $C = q(\chi+\kappa)(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}) > 0$, $D = \lambda(1-q)$, $E = (r + 2\lambda(1-q)(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa})) > 0$, *and* $F = (\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa})(r + \lambda(1-q)(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}))\frac{\chi+\kappa}{\phi^b} > 0$.

When an asymmetric equilibrium exists, it is *unique within its equilibrium-type* by the monotonicity of indifference condition in a marginal trader's market choice. Proposition 2 shows that asymmetric equilibrium is unique *even across types of asymmetric equilibria*: For instance, if there exists an asymmetric equilibrium where discretionary buyers are marginal, then there is *no other asymmetric equilibrium* in which discretionary sellers are marginal or in which all discretionary investors enter the same market. Figure 4 shows the condition on (ϕ_d^b, ϕ_d^s), of which each area corresponds to each asymmetric equilibrium.

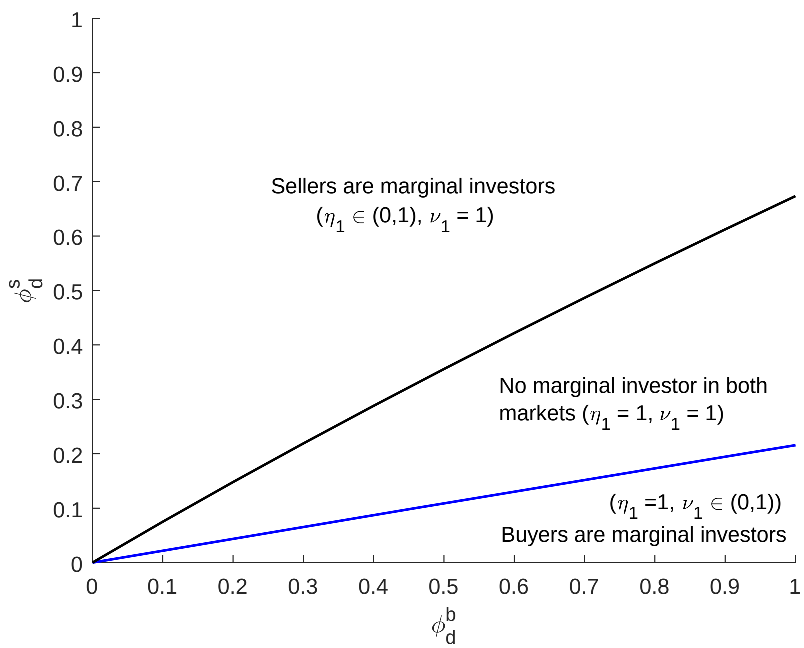


Figure 4. Existence of Asymmetric Equilibrium

In an asymmetric equilibrium, which market would be more liquid in the sense of successful matching probability? Consider an asymmetric equilibrium in which the discretionary buyer is marginal and all discretionary sellers enter market 1 (i.e., $\nu_1 \in (0,1), \eta_1 = 1$). By rewriting his indifference condition (27), the successful buying probability in market 1 relative to that in market 2 is represented by

$$\frac{\lambda_1\mu_1^s}{\lambda_2\mu_2^s} = \frac{r+\chi+\kappa+q\lambda_1\mu_1^b}{r+\chi+\kappa+q\lambda_2\mu_2^b} < \frac{\lambda_1\mu_1^b}{\lambda_2\mu_2^b}. \tag{33}$$

The inequality holds due to the strict preference of discretionary sellers to market 1, which implies that $\lambda_1\mu_1^b > \lambda_2\mu_2^b$. This implies that the successful trading probability of sellers is higher in market 1 where they enter. From the buyers' indifference in (33), $\lambda_1\mu_1^s > \lambda_2\mu_2^s$ holds, and thus, the trading probability of buyers is higher in market 1. This concludes that the market 1 is more liquid for both sellers and buyers.

Lemma 3 extends the result to all asymmetric equilibrium:

Lemma 3 (Liquidity in Asymmetric Equilibrium) *In an asymmetric equilibrium with either $\nu_1 = 1$ or $\eta_1 = 1$, the market 1 is more liquid than market 2 for both buyers and sellers:*

$$\lambda_2 \mu_2^s < \lambda_1 \mu_1^s; \qquad \lambda_2 \mu_2^b < \lambda_1 \mu_1^b. \tag{34}$$

From Lemma 1 and Lemma 3, the relative liquidity of the markets determines the ranking of prices in an asymmetric equilibrium. If buyers are marginal investors, the market where all discretionary sellers enter is more liquid for both buyers and sellers, and equilibrium price is *higher* compared to the other market. If sellers are marginal investors, the market where all discretionary buyers enter is more liquid and equilibrium price is *lower* than the other market. Proposition 2 allows us to state the results in primitive terms: When discretionary buyers arrive more frequently than sellers (i.e., ϕ_d^b is sufficiently larger than ϕ_d^s), equilibrium is symmetric ($P^1 = P^2$) or marginal buyers pay a positive liquidity premium ($P^1 > P^2$). When sellers' arrival intensity ϕ_d^s is relatively larger than buyers ϕ_d^b, equilibrium is either symmetric ($P^1 = P^2$) or marginal sellers pay the liquidity premium ($P^1 < P^2$).

6 Empirical Setup

The key prediction of our model is that illiquid securities can have higher prices than liquid securities of the same cash flows when the mass of seller is greater than the buyer mass. To test this prediction, we focus on fire sale episodes in the corporate bond market by examining pairs of bonds with almost identical cash flows but different liquidity. We first explain our empirical strategy to identify the effect of liquidity on bond prices during such episodes, controlling for the cash flows of bonds.

6.1 Identification Methodology

To identify the impact of liquidity on security prices, it is crucial to control for any unobservable time-varying information that is related to the fundamental cash flows of bonds. Our key idea to control for the fundamentals of bonds is to examine the yields of corporate bond pairs that are issued by a same firm and have very similar maturities but with different liquidity, following the identification strategy of Choi, Hoseinzade, Shin, and Tehranian (2019).

To obtain the cross-sectional difference in liquidity within a same issuer, we exploit the on-the-run versus off-the-run effect associated with the age of bonds. As times passes after issuance, bonds tend to become more illiquid because larger amounts of the issued bonds are absorbed into the portfolios of buy-and-hold investors (e.g. insurance companies and pension funds) who are the major investors in the bond market.[8]

We thus construct pairs of relatively liquid and illiquid bonds based on the age of bonds. Within an issuer we define liquid bonds as bonds with age younger than 3 years. We then match the bond with another bond (the illiquid bond) issued by a same firm with a difference in time-to-maturity less than one year and a minimum age of 5 years. We also require that the matched bonds should have a same credit rating and seniority. If there are multiple available matches, we choose the oldest one. If multiple matches are still available, we choose one with the closest time-to-maturity. In this way, we ensure that the matched bonds have almost identical fundamental values.

6.2 Data and Variable Construction

Our data source for corporate bond pricing is the enhanced Trade Reporting and Compliance Engine (TRACE) database from the Financial Industry Regulatory Authority (FINRA). We use bond pricing data from February 2005 through June 2017.[9] We exclude retail-sized trades (i.e., trades with volumes below $100,000) following Bessembinder, Kahle, Maxwell, and Xu (2008). In addition, we use the Mergent Fixed Income Securities Database (FISD) to obtain bond-specific information including ages, credit ratings, maturity, amounts outstanding, and other characteristics. We use fixed coupon bonds after excluding convertible and foreign currency bonds.

In addition, we obtain data on mutual fund flows and characteristics from the Center for Research in Security Prices (CRSP) survivorship-bias-free mutual fund database. We define corporate bond funds as mutual funds that have the Lipper objective code A, BBB, HY, SII, SID, or IID, or the CRSP objective code starting with IC. We also obtain mutual fund quarterly holdings from the Morningstar Direct database.

Our main variable of interest is the yield-to-maturity obtained from the enhanced TRACE. We exclude observations with negative yields. We define the daily yield as a trading-volume-weighted yield for each day, following Bessembinder, Kahle, Maxwell, and Xu (2008). We construct a measure for the liquidity premia, *Liquidity Spread*, as yield differences between liquid bond i and illiquid bond j of a matched pair for day t as following:

$$Liquidity\ Spread_{i,j,t} \equiv Yield^{(illiq)}_{j,t} - Yield^{(liq)}_{i,t} \tag{35}$$

Then we define monthly *Liquidity Spread* as median of daily *Liquidity Spread* during the month for each matched pair. By construction, the negative *Liquidity Spread* means that price of liquid

[8]Many papers document the bond age as a strong proxy for the liquidity. See, e.g., Sarig and Warga (1989), Alexander, Edwards, and Ferri (2000), Schultz (2001), Houweling, Mentink, and Vorst (2005), and Ericsson and Renault (2006), among many others. Also, once a bond becomes illiquid, it tends to stay illiquid to its maturity (e.g., Sarig and Warga (1989)).

[9]The TRACE becomes fully comprehensive after February 7, 2005 as it begins the full dissemination of bond transactions for the entire universe of corporate bonds. To filter the reporting errors in TRACE, We follow the filtering procedures described in Dick-Nielsen (2009). We refer the SAS codes from Dick-Nielsen (2014) and also employ price-sequence-based filters (reversal and median filters) as suggested in Dick-Nielsen (2014) and Edwards, Harris, and Piwowar (2007).

bond is lower (i.e. yield is higher) than its matched counterpart of illiquid bond. In all our empirical analyses, we only use daily yields where both bonds of a matched pair have available daily yields for the same day to mitigate the price staleness problems. As a result, our sample of the matched bonds includes 425,196 daily yields. All variables are detailed in Appendix B.

6.3 Summary Statistics of Matched Bond Pairs

The matching described in Section 6.1 yields 2,142 unique matched pairs of bonds from 515 unique issuers during our sample period from February 2005 through June 2017. Table 1 provides summary statistics. By construction, they have very similar time-to-maturities but very different age. On average, young bonds in our sample have the average age of 0.95 years, while old bonds have the average age of 7.52 years. Meanwhile, average time-to-maturities for the young and matched old bonds are 4.57 and 4.42, respectively. Approximately 80% of the bonds in our sample are investment-grade (IG) bonds, showing the sample is skewed towards relatively safer bonds. This is because safe IG firms tend to have more instances of multiple bond issues than HY firms.

In Table 2, we check the quality of the matching process by examining sample differences between old and young bonds. Although we matched young and old bonds based on maturity, young bonds have on average longer maturity than old bonds by about 0.19 years. Note that the magnitude is rather small and is not economically significant, although it is significant in a statistical sense. More importantly, the old bond has approximately 35%, 42%, 53%, 40%, and 25% higher values of illiquidity measures such as *Amihud*, *IRC*, *Bid-ask 1*, *Bid-ask 2*, and *Roll*, respectively. All five illiquidity measures indicate that the young bond is more liquid than the matched old bond.

7 Empirical Results

7.1 Time Series Evidence for Negative Liquidity Spread

Our model implies that the price of liquid bonds can be lower than the price of illiquid bonds during market-wide distressed periods. In this section, we test this model implication by examining time series of *Liquidity Spread* during market distress periods.

In Figure 5, we plot the time series of average monthly *Liquidity Spread* from February 2005 through June 2017. Panel A uses all 2,142 unique matched pairs whereas Panels B, C, and D use a sub-sample of bonds with above AA credit ratings, investment grade bonds, or high yield bonds, respectively. Panel A shows that average *Liquidity Spread* is generally positive except around the GM and Ford downgrades in 2005 and the financial crisis period after September 2008. In particular, average *Liquidity Spread* drops rapidly to -0.4% level after the Lehman Brothers collapse in September 2008. The *Liquidity Spread* reverts towards the near-zero level around 2010. *Liquidity Spread* decreases again following the Taper Tantrum in 2013. Panel B shows similar patterns within investment grade bonds and high yield bonds. The changes in

Liquidity Spread are larger in high yield bonds, potentially due to higher liquidation costs and more limits to arbitrage. In sum, the results are consistent with our model implication that the liquid bond can be priced lower than illiquid bond with identical cash flows.

One potential concern in interpreting the time-variation of *Liquidity Spread* in Figure 5 is that the composition of bonds are changing over time. In Figure 6, we visually inspect this possibility by plotting time series of average differences in time-to-maturity and age between the matched bond pair and confirm that there was no rapid changes in difference in maturity or age. In fact, Figure 7 illustrates that large outflows from the bond mutual fund sector coincide with market distress events (e.g. the Lehman Brothers collapse and the Taper Tantrum) and also with negative *liquidity Spread*.

7.2 Investor Trading Decisions in a Seller-Driven Market

Our model implies that investors in the seller-driven market can endogenously choose to sell a liquid bond at a cheaper price than selling an illiquid bond at a higher price. In this section, we provide direct evidence on the investor choice of selling between liquid and illiquid bonds by examining mutual fund trading decisions. The key idea is to examine CBMFs under severe outflows that actually hold the pair of liquid and illiquid bonds of the same issuers.

In Figure 8, we provide a nonparametric plot of trade and quarterly flows by using kernel-weighted local polynomial smoothing. The trade is measured as par-value changes in CBMFs holdings in a bond during a quarter. We use quarterly flows to match frequency of the holding data. We only use CBMFs which hold at least one pair of the matched bonds (i.e., both the liquid and the matched illiquid bond) at least one quarter during the sample periods. The sample period is the post-Lehman crisis periods (2008 Q3 through 2009 Q2) and the post Taper Tantrum in 2013 (2013 Q2 through 2013 Q4).

Figure 8 shows that the fitted slope of liquid bond (solid line) is much steeper than those of illiquid bond (dashed line), especially in the outflow region. For example, when fund flows change from 0% to -20%, holding else constant, average sales for the liquid bonds increase (i.e., $Trade$ decreases) about 50% of its sample standard deviation whereas average sales for the illiquid bonds increase only marginally. This is consistent with our presumption that investors choose to sell the liquid bonds when the sellers are more likely to be the marginal investors, even when the liquid bond is cheaper.[10]

7.3 Price of Liquid and Illiquid Bonds around the Market-wide Shocks

The results discussed in Section 7.1 visually show that the price of liquid security can fall below to the price of illiquid security during the market-wide distressed periods. In this section, we formally investigate yield changes during such periods, using regression analyses.

[10] Table 3 shows that during the Taper Tantrum event the price of liquid bonds does not become cheaper than the price of illqiuid bonds on average, although the liquid bond price falls. Our results in Figure 8 are qualitatively similar by using the post-Lehman crisis period only (unreported).

In Table 3, we run difference-in-difference regressions around two market-wide events (the Lehman Brothers Bankruptcy in September 14, 2008 and Taper Tantrum episode in May 22, 2013), which witnessed substantial amounts of investor money to flow out of corporate bond markets.The treatment group in our difference-in-difference regressions consists of young bonds with age less than three years. The control group consists of old bonds based on the the matching procedure in Section 6.1. Specifically, we estimate the following regression model:

$$Yield_{i,t} = \alpha + \beta_1 Treat_i \cdot Post_t + \beta_2 Treat_i + ctrls_{i,t} + \varepsilon_t \tag{36}$$

where $Yield_{i,t}$ is the monthly (or daily) yield of bond i, $Treat_i$ is a dummy variable indicating the treatment group, and $Post_t$ is a dummy variable indicating the month (or day) of event and afterwards. We control for time-to-maturity and amount outstanding and also include issuer-times-time fixed effects to control for issuer-level time-varying information that can drive bond yield changes. The $Post_t$ term is subsumed by the fixed effects. We use sub-sample period around the events: January 2008 through June 2009 for the Lehman collapse event and January 2013 through December 2013 for the Taper Tantrum event.

Table 3 Panel A shows the estimation results. The results indicate that yields of the treated bonds increased after the events compare to changes in yields of the matched control bonds. In Column (1), for example, the coefficient estimate on $Treat \cdot Post$ was positive (0.342) and statistically significant at the 1% level. This means that changes in yields of treated bonds are 0.342% larger on average than changes in matched control bonds around the Lehman collapse event. The estimated coefficient on $Treat$ indicates that on average yields of the treated bond are lower before the event by -0.139%. Thus, the magnitude of yield changes after the event is large enough to make the yield of treated bonds higher than the yield of matched control bonds ($-0.139\% + 0.342\% > 0$). The results for Taper Tantrum event are similar but the magnitude of yield changes after the treatment was smaller than those for the Lehman collapse.

In Panel B of Table 3, we examine how do the search friction and limits to arbitrage affect the price declines of liquid bonds relative to the matched illiquid bonds during the event of Lehman Brothers Bankruptcy. Specifically, we separately run the difference-in-difference regression (i.e., equation 36) for two subgroups of the matched sample bonds where one group is more likely to have higher search friction (i.e., lower matching probability) and more difficult to arbitrage than the other group. We employ various variables related to the search friction and limits to arbitrage.[11] In Columns (1) and (2), for example, we measures the relative strength of dealer connection for the treated bond and matched control bonds. When the relative dealer connectedness of treated bond is higher (e.g., Column 1), investors more likely choose to sell the liquid bonds than the matched illiquid bonds because sellers would expect that the better connected dealers can more easily find the potential buyers. Thus, the price of liquid bonds might fall more relative to the matched control bonds. Indeed, our results in Columns (1) and (2) are consistent with this story.

[11] The variable definitions are detailed in the Appendix B.

Similarly, the results in Panel B implies that the negative liquidity spreads are more likely when the search friction of illiquid bonds is higher than liquid bonds and the arbitrage strategy is more difficult to implements.

Overall, the results are consistent with our model prediction that liquid bond prices can become lower than illiquid bond prices with the same cash flows.

7.4 The Effect of Market Liquidity on Bond Prices When the Market Condition is Bad

In this section, we further examine the impact of liquidity on bond prices based on the market conditions. In particular, we employ the TED spread as a proxy of funding liquidity. When funding liquidity is low (and thus the TED spread is high), there are supposedly much more sellers in the market and they are likely to be marginal investors. To test this story, we run the following panel regression with our sample of matched bonds from February 2005 through June 2017, using interactions of illiquidity measures with the TED spread:

$$Yield_{i,t} = \alpha + \beta_1 Illiq_{i,t-1} \cdot TED_t + \beta_2 Illiq_{i,t-1} + ctrls_{i,t} + \varepsilon_t \tag{37}$$

where $Yield_{i,t}$ is the monthly yield of bond i, TED_t is the average TED spreads during the month t, and $Illiq_{i,t-1}$ is the lagged illiquidity of bond measured by the five measures in Table 2. The control variables, $ctrls_{i,t}$, include logged time-to-maturity and logged amount outstanding. We also inlcude issuer-times-month fixed effects.

The higher (lower) TED spread is related to the more tightened (abundant) funding liquidity, therefore the seller (buyer) is more likely to be the marginal investor. Thus, our model implies that β_1 to be negative. Also, we expect β_2 to be positive because we expect that the illiquid bond is priced lower (i.e., higher yield) than the matched liquid bond during the normal times.

Table 4 shows the estimated results. The results are consistent with the above hypotheses. In Column (1), for example, the estimated coefficient on $Illiq_{i,t-1} \cdot TED_t$ is negative (-0.085) and statistically significant at the conventional level. Also, results show that the estimated coefficient on $Illiq_{i,t-1}$ is positive (0.079) and significant at the conventional level. Thus, holding the TED spreads at 0% and all else constant, a one-standard-deviation increase in *Amihud* illiquidity increases the yield by 0.079%. With the TED spreads of 1%, the coefficient on *Amihud* illiquidity decreases by about 108% ($\approx$ 0.085/0.079) and thus the effects of market liquidity on yield has a flipped sign, which means that more liquid bond price is cheaper than its illiquid counterpart. The results for other liquidity measures in Columns (2) through (5) are both quantitatively and qualitatively similar, consistent with our model implication.

The results above can be driven mainly by the extreme values of the TED spread during the financial crisis. As a robustness check, in Columns (6) through (10) of Table 4 we provide subsample analysis results after excluding the period from 2008Q3 through 2009Q2. The results are qualitatively similar to the results obtained from the main sample.

7.5 The Effect of Market Liquidity on Bond Prices When Mutual Funds are Major Sellers

In this section, we examine the impact of liquidity on bond prices when there are substantial outflows from bond mutual funds. Under severe outflows, mutual funds should liquidate at least part of their bond positions to meet investor redemption requests and thus it is likely that sellers are marginal investors. To the extent that the aggregate outflows from bond mutual funds are a proxy for the increased mass of bond sellers, we expect that sellers are marginal investors given large fund outflows and therefore liquid bond prices are likely to fall below illiquid bond prices.

To further examine this hypothesis, we run the following regressions, using aggregate outflows from corporate bond mutual funds (CBMFs) industry. Specifically, we run the following regression:

$$Yield_{i,t} = \alpha + \beta_1 Illiq_{i,t-1} \cdot Outflows_t + \beta_2 Illiq_{i,t-1} + ctrls_{i,t} + \varepsilon_t \tag{38}$$

where $Outflows_t$ is defined as $-min(flow_t, 0)$. $flow_t$ is the aggregate investor flows of CBMFs during month t. Everything else is same as the regression (37). The advantage of CBMF outflow measure is that this directly measures an actual capital outflows from the CBMFs. The potential limitation of this measure is that CBMFs manage the liquidity relatively well and represent only part of corporate bond investors.[12]

Table 5 provides the results. In Column (1), for example, the coefficient estimates on $Illiq_{i,t-1} \cdot Outflows_t$ is negative (-0.135) and statistically significant at 1% level. With outflows of 0.4%, holding everything else constant, coefficient on $Amihud$ becomes negative ($-0.011 = -0.135 \cdot 0.4 + 0.043$) implying that the price of liquid bond becomes cheaper than price of illiquid bond within a same issuer-month, holding else constant. Results using other illiquidity measures are similar.

7.6 Price of Liquid and Illiquid Bonds around Credit Rating Downgrade Events

In this section, we examine whether our previous results using the market-level conditions can be generalized to local-level shocks. We use credit rating downgrades as events that affects selling probability of bond investors who hold the downgraded bonds. For example, investors might have limited capacity or target-levels in taking credit risks thus they are likely to sell at least part of their downgraded holdings. Especially, insurance companies have regulatory constraints in taking credit risks (e.g., Ellul, Jotikasthira, and Lundblad (2011b)). Also, compositions of bond market indexes changes following downgrades which cause selling pressures from funds following the indexes (e.g., Dick-Nielsen and Rossi (2018)). Thus, we expect that the price of liquid bonds falls more (and below) than price of illiquid bonds around the downgrade events. To investigate this, we run the

[12] The market share of CBMFs in the corporate bodn market is about 10% in the beginning of 2005 which increased to about 24% in 2014. Most of actively managed CBMFs precautionary hold cash-like assets to reduce bond sales driven by investor outflows. See, e.g., Choi, Hoseinzade, Shin, and Tehranian (2019).

following difference-in-difference regression:

$$Yield_{i,t} = \alpha + \beta_1 Treat_i + \beta_2 Treat_i \cdot w_{[-10,-1]} + \beta_3 Treat_i \cdot w_{[0,9]} + ctrls_{i,t} + \varepsilon_t \tag{39}$$

where $Yield_{i,t}$ is yield of bond i at day t, $Treat_i$ is a dummy variable that equals one if the bond is the young bond in a matched pair, $w_{[-10,-1]}$ is a dummy variable that equals one if day t is between -10 and -1 weeks from the downgrade date, and $w_{[0,9]}$ is a dummy variable that equals one if day t is between 0 and 9 weeks from the downgrade date. We control for time-to-maturity and amount outstanding. We also include issuer-times-day fixed effects. Our control group consists of the matched illiquid bonds as in Section 6.1. The sample includes downgrades between February 2005 and June 2017. To be included in the sample, we require that both treated and control bonds are downgraded in a same day. We include the pre-event period dummy (i.e., $w_{[-10,-1]}$) because the downgrade not exogenous at all but can be anticipated.

Table 6 provides the estimated results from regression (39). The results are consistent with our hypothesis that price of liquid bonds fall below to the price of illiquid bonds. In Column (2), for example, estimated coefficients on $Treat_i$ is negative (-0.108) meaning that yield of liquid bond is lower by -0.108% (i.e., price of liquid bond is higher). On the other hands, the estimated coefficients on $Treat_i \cdot w_{[-10,-1]}$ and $Treat_i \cdot w_{[0,9]}$ are positive (0.111 and 0.160, respectively) and statistically significant at the conventional levels. The results indicate that yields of the liquid and matched illiquid bonds become similar ($-0.108\% + 0.111\% \approx 0$) during the 10 weeks before the downgrade week and then the yield of the liquid bonds become higher by on average $0.163\%(= -0.108\% + 0.111\% + 0.160\%)$ during the 10 weeks after downgrades. Results are similar during the distressed periods (Column 2) and all types of downgrades (IG → IG in Column 4, IG → HY in Column 5, and HY → HY in Column 6). If any, magnitudes of yield differences are bigger and the liquid and illiquid bonds tend to be priced similar already before the downgrade events in the distressed periods or for high yield bonds.

Overall, results in Table 6 show that our model implication can be generalized to the local-level shocks such as downgrades of bonds.

8 Conclusion

In this paper, we both theoretically and empirically show that prices of liquid assets in OTC markets can be lower than those of illiquid assets with similar fundamentals. We study a search-based model with two identical assets where investors can choose which asset to trade in a discretionary manner. We show that liquidity spreads (price differentials between the liquid and the illiquid asset) can flip signs depending on market-wide sell pressure. When buyers are marginal investors, liquid assets are generally more expensive than illiquid assets because buyers who hold the illiquid asset should be compensated with higher profits. On the other hand, when sellers are marginal investors, an opposite situation arises. Sellers who sell the illiquid asset should be compensated with higher trading gains through higher prices. This leads to negative liquidity spreads. Such an equilibrium arises due to the feedback between liquidity and investor concentration. We then provide empirical evidence supporting the implications of the model by employing that there are multiple bonds issued by an issuer but with different levels of market liquidity. We find that more liquid bonds become cheaper than older illiquid bonds around liquidity events, such as the 2008 financial crisis, increases in the TED spreads, large outflow shocks to mutual fund investors, and downgrades of bond credit ratings.

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Appendix

A Proofs

The Derivation of Investors' Value Functions:

Let $\tau \equiv \min(\tau_\kappa, \tau_i, \tau_\chi)$ where τ_κ denotes the time at which an inactive seller receives a low preference shock, τ_i denotes the time at which an investor successfully trades in market i, and τ_χ denotes the time at which an investor's . The expected utility of an investor who trades in market i with wealth W_t and type σ at time t is given by

$$U(W_t, \sigma) = W_t + V_i^\sigma(t) \tag{40}$$

where the value function of each type investor is given by

$$V_i^b(t) = \mathrm{E}_t\left[e^{-r(\tau_i - t)}(V_i^o - P_i)1_{\{\tau_i=\tau\}}\right] \tag{41}$$

$$V_i^o(t) = \mathrm{E}_t\left[\int_t^\tau e^{-r(u-t)}du + e^{-r(\tau_\kappa - t)}V_i^s 1_{\{\tau_\kappa=\tau\}} + e^{-r(\tau_\chi - t)}V^n 1_{\{\tau_\chi=\tau\}}\right] \tag{42}$$

$$V_i^s(t) = \mathrm{E}_t\left[\int_t^\tau e^{-r(u-t)}(1-\delta)du + e^{-r(\tau_i - t)}(V^n + P_i)1_{\{\tau_i=\tau\}} + e^{-r(\tau_\chi - t)}V^n 1_{\{\tau_\chi=\tau\}}\right] \tag{43}$$

$$V^n = 0 \tag{44}$$

The Derivation of Investors' Trading Surplus:

From (18), we obtain

$$\begin{pmatrix} \Delta V_i^s \\ \Delta V_i^b \end{pmatrix} = \frac{1}{D_i}\begin{pmatrix} r + (1-q)\lambda_i^b & q\lambda_i^s \\ \frac{r\kappa}{r+\kappa+\chi} + (1-q)\lambda_i^b & r + \chi + q\lambda_i^s \end{pmatrix}\begin{pmatrix} 1-\delta \\ \frac{r}{r+\kappa+\chi} \end{pmatrix}, \tag{45}$$

where

$$D_i \equiv (r+\chi)\left(r + (1-q)\lambda_i^b + \frac{r}{r+\kappa+\chi}q\lambda_i^s\right)$$

Then, (45) is equivalent to

$$\begin{pmatrix} \Delta V_i^s \\ \Delta V_i^b \end{pmatrix} = \frac{1}{r+\chi} - \frac{\delta}{D_i}\begin{pmatrix} r + (1-q)\lambda_i^b \\ \frac{r\kappa}{r+\kappa+\chi} + (1-q)\lambda_i^b \end{pmatrix}. \tag{46}$$

Proof of Proposition 2. First, we simplify discretionary traders' indifference conditions. By plugging the value functions (15)-(17) and by Theorem on Equal Ratios, a marginal buyer's indifference condition is

$$\frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s} = \frac{\Delta V_2^b - \Delta V_2^s}{\Delta V_1^b - \Delta V_1^s} = \frac{(r+\chi+\kappa) + q\lambda_1 \mu_1^b}{(r+\chi+\kappa) + q\lambda_2 \mu_2^b}. \tag{47}$$

The closed form solution of μ_i^b, μ_i^s shows that the relative liquidity $\lambda_i \mu_i^s$ of buyers in market 1 (i.e., the left-hand-side of (47)) decreases as more buyers enter market 1. The the relative illiquidity discount in market 1 (i.e., the inverse of right-hand-side of (47)) decreases, and hence, the right-hand-side of (47) increases as more buyers enter market 1. The monotonicity of $LHS - RHS$ of equation (47) with respect to ν_1, taking η_1 as fixed, shows the *uniqueness* of $\nu_1 = 1 - \nu_2$ that solves the indifference condition (47), when it exists; and moreover, it shows that an asymmetric equilibrium with $\nu_1 = 1 - \nu_2 \in (0,1)$ does not coexist with an asymmetric equilibrium with $\nu_1 = 1$ or $\nu_1 = 0$, given η_1.

Similarly, the indifference condition of a marginal seller is simplified into

$$\frac{\lambda_1 \mu_1^b}{\lambda_2 \mu_2^b} = \frac{\Delta V_2^b - \Delta V_2^s}{\Delta V_1^b - \Delta V_1^s} = \frac{r + \lambda_1 \mu_1^s (1-q)}{r + \lambda_2 \mu_2^s (1-q)}. \tag{48}$$

In equation (48), the left-hand-side is decreasing and the right-hand-side is increasing with respect to $\eta_1 = 1 - \eta_2$, given $\nu_1 = 1 - \nu_2$. If there exists $\eta_1 \in [0,1]$ that solves (48), then it is *unique*. Furthermore, an asymmetric equilibrium with $\eta_1 \in (0,1)$ does not coexist with an asymmetric equilibrium with $\eta_1 = 1$ or $\eta_1 = 0$, given ν_1.

(1) (Symmetric Equilibrium) Suppose that both indifference conditions (47) and (48) holds. Applying Theorem on Equal Ratios, we get

$$\frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s} = \frac{\lambda_1 \mu_1^b}{\lambda_2 \mu_2^b} = \frac{(r+\chi+\kappa) + q\lambda_1 \mu_1^b}{(r+\chi+\kappa) + q\lambda_2 \mu_2^b} = 1. \tag{49}$$

Hence, $\lambda_1 \mu_1^s = \lambda_2 \mu_2^s$ and $\lambda_1 \mu_1^b = \lambda_2 \mu_2^b$ is a necessary condition of symmetric equilibrium. The mass of buyers and sellers in a steady state:

$$\mu_i^s = \frac{\phi_i^s + \phi_d^s \eta_i}{\chi} - \frac{\phi_i^b + \phi_d^b \gamma_i}{\chi + \kappa}; \qquad \mu_i^b = \frac{\phi_i^b + \phi_d^b \gamma_i}{\lambda_i \mu_i^s}. \tag{50}$$

By plugging μ_i^b and μ_i^s into the necessary condition, we solve the discretionary buyers and sellers' market choice: $\eta_i = \nu_i = \frac{1}{2}$. Since equations (50) are linear in η_i and ν_i, the solution $\eta_i = \nu_i = \frac{1}{2}$ is unique.

(2) (Asymmetric Equilibrium) Now we show that an asymmetric equilibrium exists and show under which condition each type of asymmetric equilibrium exists.

(i) (Marginal Buyers) Suppose that discretionary sellers are not indifferent between two markets. Without loss of generality, we assume that all sellers enter market 1, i.e., $\eta_1 = 1, \eta_2 = 0$. A sufficient and necessary condition for $\eta_1 = 1$ being optimal for discretionary sellers is

$$\frac{\lambda_1 \mu_1^b}{\lambda_2 \mu_2^b} \geq \frac{r + \lambda_1 \mu_1^s (1-q)}{r + \lambda_2 \mu_2^s (1-q)}. \tag{51}$$

By plugging μ_i^s, μ_i^b as functions of ν_i (equation (50)), we get a lower bound for $\nu_1 = 1 - \nu_2$:

$$\nu_1 \geq \frac{(\phi^s + \phi_d^s \eta_1)(\phi^b + \phi_d^b) - (\phi^s + \phi_d^s \eta_2)\phi^b}{(\phi^s + \phi_d^s \eta_2)\phi_d^b + (\phi^s + \phi_d^s \eta_1)\phi_d^b} = \frac{(\phi^s + \phi_d^s)(\phi^b + \phi_d^b) - \phi^s \phi^b}{(\phi^s + \phi^s + \phi_d^s)\phi_d^b} \equiv \underline{\nu}_1. \tag{52}$$

If the mass of buyers in market 1 is lower than the bound $\underline{\nu}_1$, a seller in market 1 has a profitable deviation from market 1 to market 2, and thus, it violates $\eta_1 = 1$. The lower bound of ν_1 is value (i.e., $\underline{\nu}_1 \geq 0$). If $\underline{\nu}_1 > 1$ (equivalently, $\phi^s \phi_d^b \geq \phi^b \phi_d^s$), then there is no asymmetric equilibrium with $\eta_1 = 1$.

When $\underline{\nu}_1 \leq 1$, the buyer's indifference condition is a third-order polynomial for $\nu_1 = 1 - \nu_2$. The monotonicity of buyers' indifference condition gives a sufficient and necessary condition for *existence* of asymmetric equilibrium: Given η_i, there exists a *unique* $\nu_1 = 1 - \nu_2 \in [\underline{\nu}_1, 1]$ satisfying (47) if and only if when $\nu_1 = 1 - \nu_2 = \underline{\nu}_1$,

$$\frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s} \geq \frac{(r + \chi + \kappa) + q\lambda_1 \mu_1^b}{(r + \chi + \kappa) + q\lambda_2 \mu_2^b}; \quad \text{equivalently,} \quad \lambda_1(\phi_1^s + \phi_d^s) \geq \lambda_2 \phi_2^s; \tag{53}$$

and when $\nu_1 = 1 - \nu_2 = 1$,

$$\frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s} \leq \frac{(r + \chi + \kappa) + q\lambda_1 \mu_1^b}{(r + \chi + \kappa) + q\lambda_2 \mu_2^b}, \tag{54}$$

equivalently,

$$(\overline{\mu}_1^s - \overline{\mu}_2^s)^2 (r + (1-q)(\chi+\kappa) + q(\chi+\kappa)\frac{\phi^s}{\chi \overline{\mu}_2^s}) + (\overline{\mu}_1^s - \overline{\mu}_2^s)((r + (1-q)(\chi+\kappa))\overline{\mu}_2^s + 2q(\chi+\kappa)\frac{\phi^s}{\chi}) \leq \overline{\mu}_2^s q(\chi+\kappa)\frac{\phi_d^s}{\chi}, \tag{55}$$

where $\overline{\mu}_1^s = \frac{\phi^s + \phi_d^s}{\chi} - \frac{\phi^b + \phi_d^b}{\chi + \kappa}$ and $\overline{\mu}_2^s = \frac{\phi^s}{\chi} - \frac{\phi^b}{\chi + \kappa}$. As we discussed near equation (47), under If inequality (53) is violated, all buyers enter market 2. If inequality (55) is violated, all buyers and all sellers go to market 1. The inequality (55) gives an upper bounds on the difference between ϕ_d^s and ϕ_d^b:

$$\frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi + \kappa} < \Phi_1(\phi_d^s; \phi^b, \phi^s) \equiv \frac{1}{2A}\Big(-B + \sqrt{B^2 + 4AC\frac{\phi_d^s}{\chi}}\Big), \tag{56}$$

where $A = r + (1-q)(\chi+\kappa) + q(\chi+\kappa)\frac{\phi^s}{\chi}(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa})^{-1} > 0$, $B = A(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}) + q(\chi+\kappa)\frac{\phi^s}{\chi} > 0$, and $C = q(\chi+\kappa)(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}) > 0$.

As a last remark, $\phi^s \phi_d^b \geq \phi^b \phi_d^s$ (i.e., $\underline{\nu}_1 > 1$) holds when inequality (56) is satisfied. This is because the slope $\frac{d\phi_d^s}{d\phi_d^b}$ of the boundary of inequality (56) is smaller than $\frac{\phi^s}{\phi^b}$. By taking an implicit differentiation of the boundary (56) with respect to ϕ_d^b, we get

$$\frac{d\phi_d^s}{d\phi_d^b} = \frac{\chi}{\chi+\kappa}\Big(1 - \frac{C}{\sqrt{B^2 + 4AC\frac{\phi_d^s}{\chi}}}\Big)^{-1} \le \frac{\chi}{\chi+\kappa}\frac{B}{B-C}.$$

The inequality holds by the concavity of ϕ_d^s with respect to ϕ_d^b in the boundary of (56). It suffices to show that

$$\frac{\chi}{\chi+\kappa}\frac{B}{B-C} \le \frac{\phi^s}{\phi^b}.$$

By plugging B and C,

$$q(\chi+\kappa)\Big(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}\Big)\frac{\phi^s}{\chi} \le \Big(A\Big(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}\Big) + q(\chi+\kappa)\frac{\phi^s}{\chi}\Big)\Big(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}\Big),$$

which is equivalent to $0 \le A(\frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa})^2$. Because $A > 0$, the inequality holds for any ϕ^s and ϕ^b. Hence, $\phi^s\phi_d^b \ge \phi^b\phi_d^s$ (i.e., $\underline{\nu}_1 > 1$) holds when inequality (56) is satisfied.

(ii) (Marginal Sellers) Suppose that discretionary buyers are not indifferent between two markets, and enter market 1 without loss of generality, i.e., $\nu_1 = 1, \nu_2 = 0$. The same steps as in part (2) derive a sufficient and necessary condition that an asymmetric equilibrium with $\eta_1 \in (0,1)$ and $\nu_1 = 1$ exists.

Buyers optimally choose market 1, i.e., $\nu_1 = 1$, if and only if $\eta_1 = 1 - \eta_2$ satisfies

$$\frac{\lambda_1\mu_1^s}{\lambda_2\mu_2^s} > \frac{(r+\chi+\kappa) + q\lambda_1\mu_1^b}{(r+\chi+\kappa) + q\lambda_2\mu_2^b}. \tag{57}$$

This inequality gives a lower bound for $\eta_1 = 1 - \eta_2$:

$$\eta_1 \ge \frac{\chi}{(\lambda_1+\lambda_2)\phi_d^s}\Big(\lambda_2\Big(\frac{\phi^s+\phi_d^s}{\chi} - \frac{\phi^b+\phi_d^b\nu_2}{\chi+\kappa}\Big) - \lambda_1\Big(\frac{\phi^s}{\chi} - \frac{\phi^b+\phi_d^b\nu_1}{\chi+\kappa}\Big)\Big) \equiv \underline{\eta}_1. \tag{58}$$

If the mass of sellers is lower than the bound $\underline{\eta}_1$, a buyer in market 1 would move to market 2 so it violates $\nu_1 = 1$. If $\underline{\eta}_1 > 1$ (equivalently, $\lambda_2(\frac{\phi_2^s}{\chi} - \frac{\phi_2^b}{\kappa+\chi}) - \lambda_1(\frac{\phi_1^s}{\chi} - \frac{\phi_1^b}{\kappa+\chi}) > \lambda_1(\frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\kappa+\chi})$, i.e., ϕ_d^s is smaller than a linear function of ϕ_d^b), then there is no solution.

When $\underline{\eta}_1 \le 1$, the seller's indifference condition is a third-order polynomial for $\eta_1 = 1 - \eta_2$. The monotonicity of sellers' indifference condition gives a sufficient and necessary condition for existence: Given ν_i, there exists a *unique* solution $\eta_1 = 1 - \eta_2 \in [\underline{\eta}_1, 1]$ satisfying (48) if and only if when $\eta_1 = 1 - \eta_2 = \underline{\nu}_1$,

$$\frac{\lambda_1\mu_1^b}{\lambda_2\mu_2^b} \ge \frac{r + \lambda_1\mu_1^s(1-q)}{r + \lambda_2\mu_2^s(1-q)} \quad \text{equivalently,} \quad \lambda_1(\phi_1^b + \phi_d^b) \ge \lambda_2\phi_2^b; \tag{59}$$

and when $\eta_1 = 1$,

$$\frac{\lambda_1\mu_1^b}{\lambda_2\mu_2^b} \le \frac{r + \lambda_1\mu_1^s(1-q)}{r + \lambda_2\mu_2^s(1-q)}, \tag{60}$$

equivalently,

$$\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}\frac{\phi_d^b}{\chi+\kappa} \leq \lambda(1-q)(\overline{\mu}_1^s-\overline{\mu}_2^s)^2+(r+2\lambda(1-q)\overline{\mu}_2^s)(\overline{\mu}_1^s-\overline{\mu}_2^s), \tag{61}$$

where $\overline{\mu}_1^s = \frac{\phi^s+\phi_d^s}{\chi} - \frac{\phi^b+\phi_d^b}{\chi+\kappa} = \overline{\mu}_2^s + \frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi+\kappa}$ and $\overline{\mu}_2^s = \frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}$. If inequality (59) is violated, all sellers enter market 2. If inequality (61) is violated, all buyers and all sellers go to market 1. The inequality (61) gives a lower bounds on the difference between ϕ_d^s and ϕ_d^b:

$$\frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi+\kappa} > \Phi_2(\phi_d^b;\phi^b,\phi^s) \equiv \frac{1}{2D}\Big(-E+\sqrt{E^2+4DF\frac{\phi_d^b}{\chi+\kappa}}\Big),$$

where $D=\lambda(1-q)$, $E=(r+2\lambda(1-q)(\frac{\phi^s}{\chi}-\frac{\phi^b}{\chi+\kappa}))>0$, and $F=(\frac{\phi^s}{\chi}-\frac{\phi^b}{\chi+\kappa})(r+\lambda(1-q)(\frac{\phi^s}{\chi}-\frac{\phi^b}{\chi+\kappa}))\frac{\chi+\kappa}{\phi^b}>0$.

(iii) (Corner Equilibrium) As discussed near equations (47), given $\eta_1 = 1$, ν_1 solving the indifference condition (47) is unique. If there exists a solution $\nu_1 \in (0,1)$ for equation (47), then replacing ν_1 by 1 violates the inequality (57), which is a necessary condition of equilibrium with $\nu_1 = 1$. Hence, an asymmetric equilibrium with $\nu_1 \in (0,1)$ and an asymmetric equilibrium with $\nu_1 = 1$, given $\eta_1 = 1$, cannot coexist because LHS-RHS of equation (47) decreases. Similarly, an asymmetric equilibrium with $\eta_1 \in (0,1)$ and $\eta_1 = 1$, given $\nu_1 = 1$, cannot coexist. When inequalities (55) and (61) are violated, all discretionary buyers and sellers enter market 1. When such asymmetric equilibrium exists, it is unique: i.e., $\eta_1 = 1-\eta_2 = 1$ and $\nu_1 = 1-\nu_2 = 1$.

(4) (Asymmetric Equilibrium is Unique) Now we show that three types of asymmetric equilibria (i), (ii), and (iii) exists exclusively, and so, (a pair of) asymmetric equilibrium is unique.

An asymmetric equilibrium in which discretionary buyers are marginal (i.e., $\nu_1 \in (0,1)$) and all discretionary sellers enter market 1 (i.e., $\eta_1 = 1$) cannot coexist with an asymmetric equilibrium in which all traders choose market 1 (i.e., $\nu_1 = \eta_1 = 1$). This is because, given η_1, the buyer's indifference condition (47) is monotone in $\nu_1 = 1-\nu_2$ and thus it has a unique solution $\nu_1 > 0$. If the solution satisfies $\nu_1 < 1$ then an asymmetric equilibrium with marginal buyers alone exists; if the solution satisfies $\nu_1 \geq 1$ then an asymmetric equilibrium with $\eta_1 = \nu_1 = 1$ alone exists. Similarly, an asymmetric equilibrium with $\eta_1 \in (0,1)$ and $\nu_1 = 1$ cannot coexist with an equilibrium with $\eta_1 = \nu_1 = 1$, due to the monotonicity of the sellers' indifference condition (48) in η_1, given ν_1.

Lastly, we show that an asymmetric equilibrium with marginal buyers ($\nu_1 \in (0,1)$ and $\eta_1 = 1$) and an asymmetric equilibrium with marginal sellers ($\eta_1 \in (0,1)$ and $\nu_1 = 1$) do not coexist. We show this by contradiction. Suppose that there exists a parameter set such that both equilibria exists. The necessary condition (55) for equilibrium with marginal buyers and (61) for equilibrium with marginal sellers must hold:

$$\frac{\phi_d^s}{\chi} \geq \frac{(r+(1-q)(\chi+\kappa)+q(\chi+\kappa)\frac{\phi^s}{\chi\overline{\mu}_2^s})}{\overline{\mu}_2^s q(\chi+\kappa)}(\overline{\mu}_1^s-\overline{\mu}_2^s)^2+\frac{((r+(1-q)(\chi+\kappa))\overline{\mu}_2^s+2q(\chi+\kappa)\frac{\phi^s}{\chi})}{\overline{\mu}_2^s q(\chi+\kappa)}(\overline{\mu}_1^s-\overline{\mu}_2^s); \tag{62}$$

$$\frac{\phi_d^b}{\chi+\kappa} \leq \frac{\lambda(1-q)}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}}(\overline{\mu}_1^s-\overline{\mu}_2^s)^2+\frac{(r+2\lambda(1-q)\overline{\mu}_2^s)}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}}(\overline{\mu}_1^s-\overline{\mu}_2^s), \tag{63}$$

where $\overline{\mu}_1^s = \frac{\phi^s+\phi_d^s}{\chi} - \frac{\phi^b+\phi_d^b}{\chi+\kappa}$ and $\overline{\mu}_2^s = \frac{\phi^s}{\chi} - \frac{\phi^b}{\chi+\kappa}$. If both inequalities hold, we get

$$\begin{aligned}(\overline{\mu}_1^s-\overline{\mu}_2^s) \geq\ & \frac{r+(1-q)(\chi+\kappa)+q(\chi+\kappa)\frac{\phi^s}{\chi\overline{\mu}_2^s}}{\overline{\mu}_2^s q(\chi+\kappa)}(\overline{\mu}_1^s-\overline{\mu}_2^s)^2 - \frac{\lambda(1-q)}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}}(\overline{\mu}_1^s-\overline{\mu}_2^s)^2 \\ &+\frac{(r+(1-q)(\chi+\kappa))\overline{\mu}_2^s+2q(\chi+\kappa)\frac{\phi^s}{\chi}}{\overline{\mu}_2^s q(\chi+\kappa)}(\overline{\mu}_1^s-\overline{\mu}_2^s) - \frac{r+2\lambda(1-q)\overline{\mu}_2^s}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}}(\overline{\mu}_1^s-\overline{\mu}_2^s).\end{aligned}$$

Let us denote the quadratic and linear coefficients of the right-hand-side by K and L:

$$K \equiv \frac{r+(1-q)(\chi+\kappa)+q(\chi+\kappa)\frac{\phi^s}{\chi\overline{\mu}_2^s}}{\overline{\mu}_2^s q(\chi+\kappa)} - \frac{\lambda(1-q)}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}}, \tag{64}$$

$$L \equiv \frac{(r+(1-q)(\chi+\kappa))\overline{\mu}_2^s+2q(\chi+\kappa)\frac{\phi^s}{\chi}}{\overline{\mu}_2^s q(\chi+\kappa)} - \frac{r+2\lambda(1-q)\overline{\mu}_2^s}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\chi+\kappa}{\phi^b}}. \tag{65}$$

The inequality has a solution $\overline{\mu}_1^s - \overline{\mu}_2^s = \frac{\phi_d^s}{\chi} - \frac{\phi_d^b}{\chi+\kappa} > 0$, which must be positive by Assumption 1, unless $K \geq 0$ and $L > 1$.

$$K = \frac{r+\chi+\kappa}{\overline{\mu}_2^s q(\chi+\kappa)} + \frac{\lambda(1-q)\frac{\phi^b}{\chi+\kappa}}{\lambda(1-q)(\overline{\mu}_2^s)^2} - \frac{\lambda(1-q)\frac{\phi^b}{\chi+\kappa}}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)} > 0; \tag{66}$$

$$L-1 = \frac{r+\chi+\kappa}{q(\chi+\kappa)} + \frac{2(r+\lambda(1-q)\overline{\mu}_2^s)\frac{\phi^b}{\chi+\kappa}}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)} - \frac{(r+2\lambda(1-q)\overline{\mu}_2^s)\frac{\phi^b}{\chi+\kappa}}{\overline{\mu}_2^s(r+\lambda(1-q)\overline{\mu}_2^s)} > 0. \tag{67}$$

Therefore, the necessary condition (64) for the coexistence of asymmetric equilibrium with marginal buyers and asymmetric equilibrium with marginal sellers never hold. ■

Proof of Lemma 3. In an asymmetric equilibrium in which buyers are marginal and all sellers enter market 1 (i.e., $\nu_1 \in (0,1), \eta_1 = 1$), traders' indifference conditions are written by

$$\frac{\lambda_1\mu_1^s}{\lambda_2\mu_2^s} = \frac{(r+\chi+\kappa)(r+\lambda_1\mu_1^s(1-q))+rq\lambda_1\mu_1^b}{(r+\chi+\kappa)(r+\lambda_2\mu_2^s(1-q))+rq\lambda_2\mu_2^b} < \frac{\lambda_1\mu_1^b}{\lambda_2\mu_2^b}. \tag{68}$$

By Theorem of Equal Ratio, the above condition is simplified into

$$\frac{\lambda_1\mu_1^s}{\lambda_2\mu_2^s} = \frac{r+\chi+\kappa+q\lambda_1\mu_1^b}{r+\chi+\kappa+q\lambda_2\mu_2^b} < \frac{\lambda_1\mu_1^b}{\lambda_2\mu_2^b}. \tag{69}$$

Because the successful selling probability $\lambda_i \mu_i^b$ is positive in equilibrium, the inequality implies that $\frac{\lambda_1 \mu_1^b}{\lambda_2 \mu_2^b} > 1$. Moreover, the equality implies that $\frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s} > 1$. In particular, traders' relative trading probability in market 1 to market 2 satisfies

$$1 < \frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s} < \frac{\lambda_1 \mu_1^b}{\lambda_2 \mu_2^b}$$

in asymmetric equilibrium with marginal buyers and all sellers in market 1.

Similarly, in asymmetric equilibrium in which sellers are marginal and all buyers enter market 1 (i.e., $\eta_1 \in (0,1), \nu_1 = 1$), we get

$$1 < \frac{\lambda_1 \mu_1^b}{\lambda_2 \mu_2^b} < \frac{\lambda_1 \mu_1^s}{\lambda_2 \mu_2^s}.$$

■

B Variable Definition

We exclude the retail transactions (i.e., trading volume less than \$100k) to calculate the following variables. All variables are winsorized at 1^{st} and 99^{th} percentiles.

B.1 *Yield* and *Liquidity Spread*

The yield is yield-to-maturity obtained from the TRACE enhanced database. We follow Bessembinder, Kahle, Maxwell, and Xu (2008) in defining the daily yield. Specifically, we calculate a bond's daily yield as the trading-volume-weighted average yield for each day, after excluding the negative yields. Throughout the paper, we use the matched sample defined in Section 6.1. For the liquid bond i and matched illiquid bond j, we denote the daily yield as $Yield_{i,t}^{(liq)}$ and $Yield_{j,t}^{(illiq)}$, respectively. To be included in our sample, both $Yield_{i,t}^{(liq)}$ and $Yield_{j,t}^{(illiq)}$ for a matched pair should be available in day t. Then, for each day we define *Liquidity Spread* as following:

$$Liquidity\ Spread_{i,j,t} \equiv Yield_{j,t}^{(illiq)} - Yield_{i,t}^{(liq)} \tag{B1}$$

Monthly *Liquidity Spread* is defined as median of the daily *Liquidity Spread* during the month for each matched pair.

B.2 *Amihud*

Amihud is the intraday version of Amihud (2002) illiquidity measure introduced in Dick-Nielsen, Feldhütter, and Lando (2012). Specifically, for each bond i, we calculate the following within day t:

$$Amihud_{i,t} \equiv \frac{1}{N_t} \sum_{k=1}^{N_t} \frac{|r_k|}{Q_k} \tag{B2}$$

where r_k is a return of the k^{th} transaction within day t ($= \frac{p_k - p_{k-1}}{p_{k-1}}$), Q_k is trading volume in \$MM for the k^{th} transaction, and N_t is the number of r_k observations during day t.

B.3 *IRC*

IRC is the imputed roundtrip costs of Feldhütter (2012). For bond i and day t, we call it as the imputed roundtrip trades (IRT) if there exists a group of two or three (and no more than three) transactions that have the same trading volume. Then, we calculate the following daily imputed roundtrip cost:

$$IRC_{i,t} \equiv \frac{1}{N_t} \sum_{k=1}^{N_t} \left[\frac{p_{max} - p_{min}}{p_{max}} \right]_k \tag{B3}$$

where N_t is the number of IRTs for bond i within day t and p_{max} and p_{min} are maximum and minimum transacton prices within each IRT k.

B.4 ***Bid-ask 1***

Bid-ask 1 is the bid-ask spreads calculated by using inter-dealer transaction prices as a reference price, following Choi and Huh (2018). Specifically, we calculate the transaction-level bid-ask spreads for each customer-dealer transaction k of bond i in day t as following:

$$Bid\text{-}ask_k \equiv 2S_k \cdot \frac{p_k - p_k^{reference}}{p_k^{reference}} \tag{B4}$$

where S_k is equal to either $+1$ or -1 if transaction k is a customer-buy or customer-sell from dealers, respectively. The reference price for transaction k, $p_k^{reference}$, is defined as the transaction-volume-weighted average price of interdealer transaction prices for bond i within the same day t after excluding the interdealer trades executed within 15 minutes from the transaction k.

Finally, we define $Bid\text{-}ask\ 1_{i,t}$ as the bond-day level measure of bid-ask spreads by taking the transaction-volume-weighted average of $Bid\text{-}ask_k$ for customer-dealer transactions for bond i during day t.

B.5 ***Bid-ask 2***

For each bond i and day t, we calculate the realized bid-ask spreads similarly to Adrian, Fleming, Shachar, and Vogt (2017). Specifically, we calculate the following:

$$Bid\text{-}ask\ 2_{i,t} \equiv \frac{ask_{i,t} - bid_{i,t}}{(ask_{i,t} + bid_{i,t})/2} \tag{B5}$$

where $ask_{i,t}$ and $bid_{i,t}$ are the transaction-volume-weighted average prices of customer-buy and customer-sell transactions, respectively, for bond i during day t.

B.6 ***Roll***

We calculate the Roll (1984) illiquidity measure, *Roll*, by following Dick-Nielsen, Feldhütter, and Lando (2012). Specifically, for bond i and day t

$$Roll_{i,t} \equiv 2\sqrt{-cov(R_k, R_{k-1})} \tag{B6}$$

where $cov(R_k, R_{k-1})$ is the covariance of consecutive returns calculated based on transaction prices obtained from the TRACE enhanced database. For each day t with at least one transaction, we calculate the measure in a rolling window of 21 trading days. We discard it if the covariance is positive.

B.7 *Dealer Connectedness*

We calculate the connectedness of dealers by computing eignvector centrality of dealer network by following Friewald and Nagler (2019). We define that two dealers are connected if there are at least 50 transactions with each other during a month and we use weight connections by sum of transaction volumes (in par values) between the two dealers. Then, the dealer connectedness for a bond is defined as transaction volume-weighted average of dealer connectedness of dealers who have traded the bond during a month.

B.8 *Prearranged Trading Ratio*

Similar to Schultz (2017), the prearranged trading is defined as a sequence of transactions for a bond that satisfy the following conditions: the transactions are executed within one minute; the transactions have a same trading volume; at least one of the transactions is a customer trade. We define prearranged trading ratio as the fraction of prearranged trading among all transactions for a bond during a month.

B.9 *Volatility of Yield Difference of Matched Bonds*

We define the volatility of yield difference, $Vol(|Yld^T - Yld^C|)$, by calculating previous one year volatility for absolute value of yield differences. The yield difference is calculated as daily yields of the treated bond minus yields of matched control bond at the same day.

B.10 *Flows*

For each fund j and month t, we calculate monthly fund flows as following:

$$Flow_{j,t} \equiv \frac{TNA_{j,t} - TNA_{j,t-1} \cdot (1 + r_{j,t})}{TNA_{j,t-1}} \tag{B7}$$

where $TNA_{j,t}$ is total net assets for fund j at the end of month t and $r_{j,t}$ is monthly return for fund j over month t. The total net assets and monthly returns are obtained from the CRSP survivorship-bias-free mutual fund database. We define corporate bond mutual funds (CBMFs) as funds with the Lipper objective code in (A, BBB, HY, SII, SID, IID) or the CRSP objective code starting with IC. We require that TNA should be at least \$1MM and eliminate overly extreme monthly changes in TNA by requiring $0.5 < \frac{TNA_{j,t}}{TNA_{j,t-1}} < 3$ for fund j and month t. We also require that a fund should have at least one year of the holdings data with at least 10 different holdings at some point in the past.

We calculate the aggregate flows of CBMFs, $Flow_t$, by taking average of individual fund flows ($Flow_{j,t}$) weighted by lagged TNAs ($TNA_{j,t-1}$) using all CBMFs in our sample.

B.11 *Trade*

We define mutual fund trading, $Trade_{i,j,t}$, for each bond i, fund j, and quarter t as following:

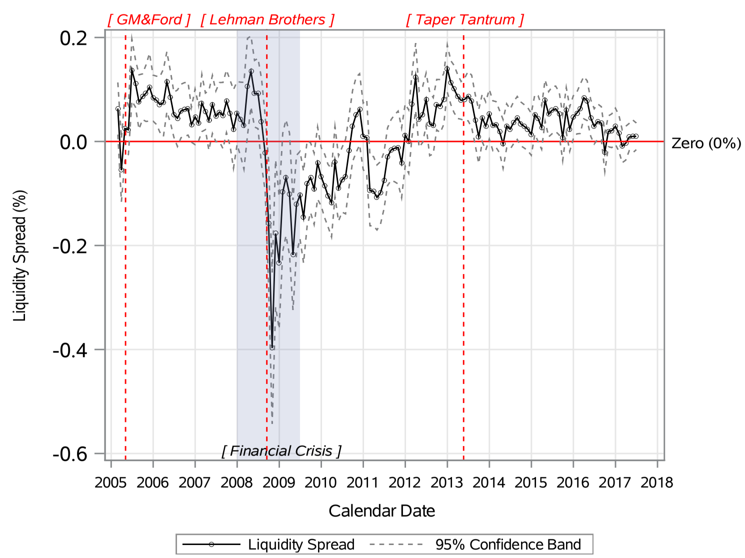
$$Trade_{i,j,t} \equiv \frac{AmtHold_{i,j,t}}{AmtHold_{i,j,t-1}} - 1 \tag{B8}$$

where $AmtHold_{i,j,t}$ is the dollar par-value amount of bond i held by fund j at the end of quarter t. We obtain the quarterly holdings of CBMFs from the Morningstar database.

Figure 5. Time Series of Average Monthly Liquidity Spread

This figure depicts the time series of the liquidity spread. The *LiquiditySpread* is defined as illiquid bond yields minus matched liquid bond yields. Specifically, we match two bonds issued by a same firm with difference in liquidity but with same credit rating and seniority, and very similar time-to-maturity. The matching is detailed in Section 6.1. We calculate the spread each day if both yields from liquid and matched illiquid bonds are available for the same day. For each liquid–illiquid bond pair, the monthly liquidity spread is defined as a median of daily liquidity spread during the month. We plot the average of monthly liquidity spread. The sample period runs from February 2005 through June 2017. In Panel A, we use all matched bond pairs. The circles connected by black solid line represent the average monthly liquidity spread and the dashed lines represent the 95% confidence interval. In Panel B, we separately calculate *LiquiditySpread* by using investment grade (IG) and high yield (HY) matched bonds separately. In Panel B, the circles connected by solid line and the triangles connected by dashed line represent the average monthly liquidity spread of IG and HY matched bonds, respectively. Dashed vertical lines indicate the GM&Ford downgrades (May 2005), Lehman Brothers Bankruptcy (September 2008), and Taper Tantrum (May 2013). The grey shade area represents the 2008 financial crisis period (January 2008 to June 2009) is denoted by grey shades. The x-axis represents calendar dates and the y-axis represents yield spreads in percentages.

Panel A. All Sample



Panel B. IG and HY Sample

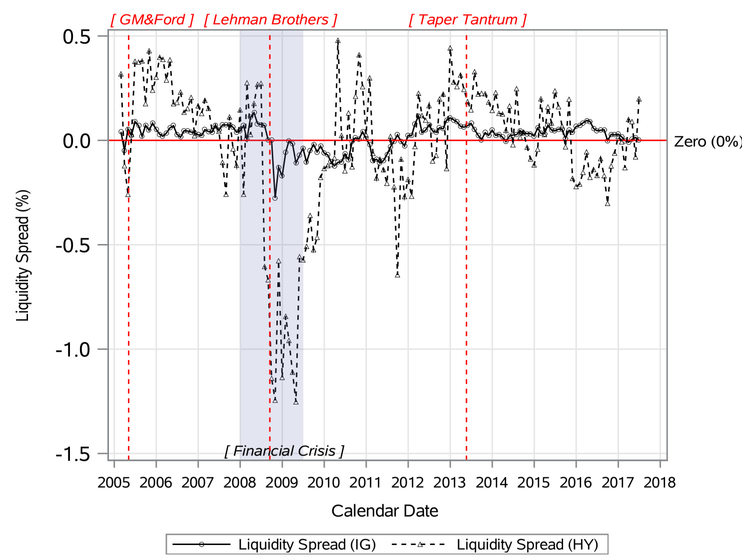
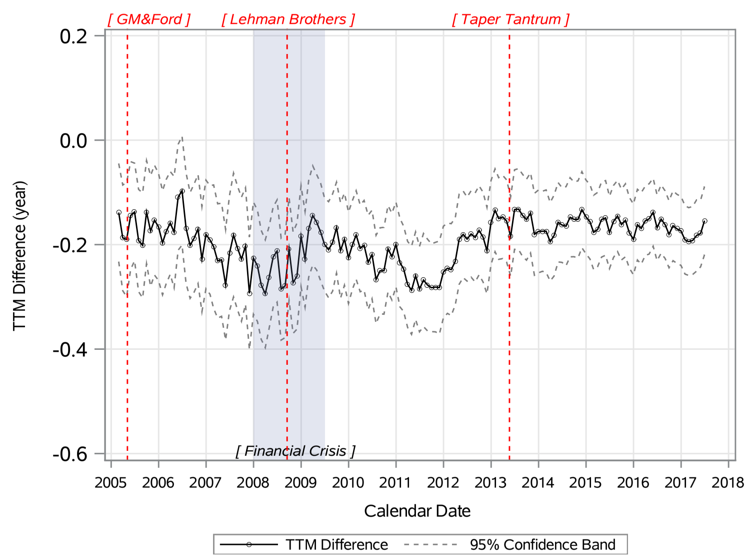


Figure 6. Differences in Time-to-maturity and Age of Matched Bond Pairs

This figure provides the time series of average differences in time-to-maturity (Panel A) and age (Panel B) between the matched bonds. The differences are calculated as time-to-maturity (or age) of the illiquid (i.e., older) bond minus those of the matched liquid (i.e., younger) bond. The monthly time-series are calculated similarly to the monthly liquidity spread in Figure 5. The sample period runs from February 2005 through June 2017. Dashed vertical lines indicate the GM&Ford downgrades (May 2005), Lehman Brothers Bankruptcy (September 2008), and Taper Tantrum (May 2013). The grey shade area represents the 2008 financial crisis period (January 2008 to June 2009) is denoted by grey shades. The circles connected by black solid lines represent the average differences in time-to-maturity (or age) and the dashed lines represent the 95% confidence interval. The x-axis represents calendar dates and the y-axis represents differences in time-to-maturity (Panel A) and age (Panel B) in years.

Panel A. Difference in Time-to-maturity



Panel B. Difference in Age

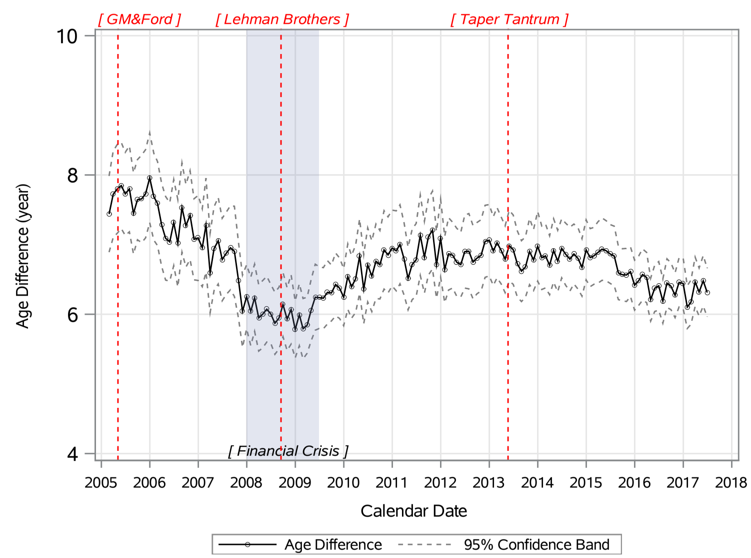


Figure 7. Monthly Mutual Fund Investor Flows and the Liquidity Spread

This figure plots monthly mutual fund flows (grey vertical bars) along with the monthly average liquidity spread (black solid line). The monthly mutual fund flows are defined as capital flows to corporate bond mutual funds (CBMF) in percentages of total net assets. Corporate bond mutual funds are defined as the Lipper objective code is in (A, BBB, HY, SII, SID, IID) or the CRSP objective code starts with ”IC”. We use all CBMF in CRSP mutual fund database. The monthly average liquidity spread is same as in Figure 5. The sample period runs from February 2005 through June 2017. Dashed vertical lines indicate the GM&Ford downgrades (May 2005), Lehman Brothers Bankruptcy (September 2008), and Taper Tantrum (May 2013). The x-axis represents calendar dates. The left y-axis represents yield spreads in percentages and the right y-axis represents the mutual fund flows in percentage.

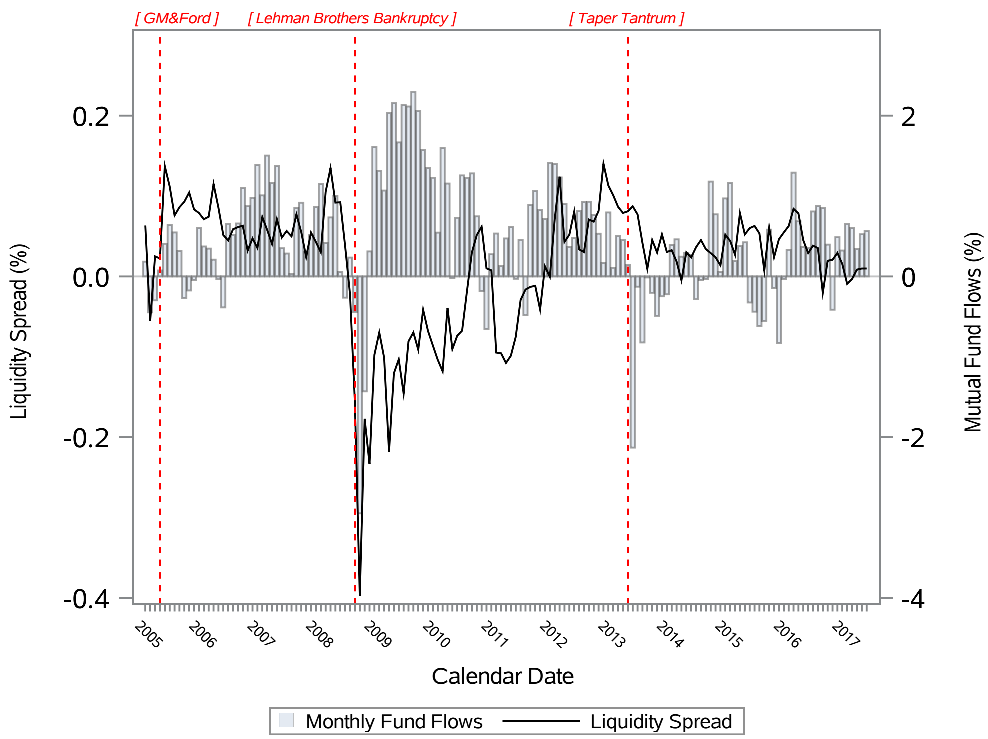


Figure 8. Trading of Liquid and the Matched Illiquid Bonds by Distressed Mutual Funds

This figure shows relationship between mutual fund flows and their trading (*Trade*) of the liquid and illiquid bonds in a matched pair during the distressed periods. Specifically, we plot fitted lines from non-parametric regressions of *Trade* on quarterly fund flows for the post Lehman crisis period (2008 Q3 through 2009 Q2) and the Taper Tantrum period (2013 Q2 through 2013 Q4). $Trade \equiv AmtHold_{i,j,t}/AmtHolt_{i,j,t-1}$ is the percentage trading by mutual fund j in quarter t where $AmtHold_{i,j,t}$ is par-value amounts of holdings in corporate bond i of fund j at the end of quarter t. We standardize *Trade* using the entire sample period. We only use actively managed corporate bond funds (i.e., index funds, exchange-traded funds, exchange-traded notes are excluded) that hold both liquid and illiquid bonds in a matched pair at the beginning of each quarter. For the non-parametric regression, we use kernel-weighted local polynomial smoothing with the Epanechnikov kernel function in, e.g., Fan (1992) and Fan and Gijbels (1996). Black solid line represents trade–flow relationship of liquid bonds and gray dashed line represents those of illiquid bonds. The vertical dashed lines represent the 95% confidence bands.

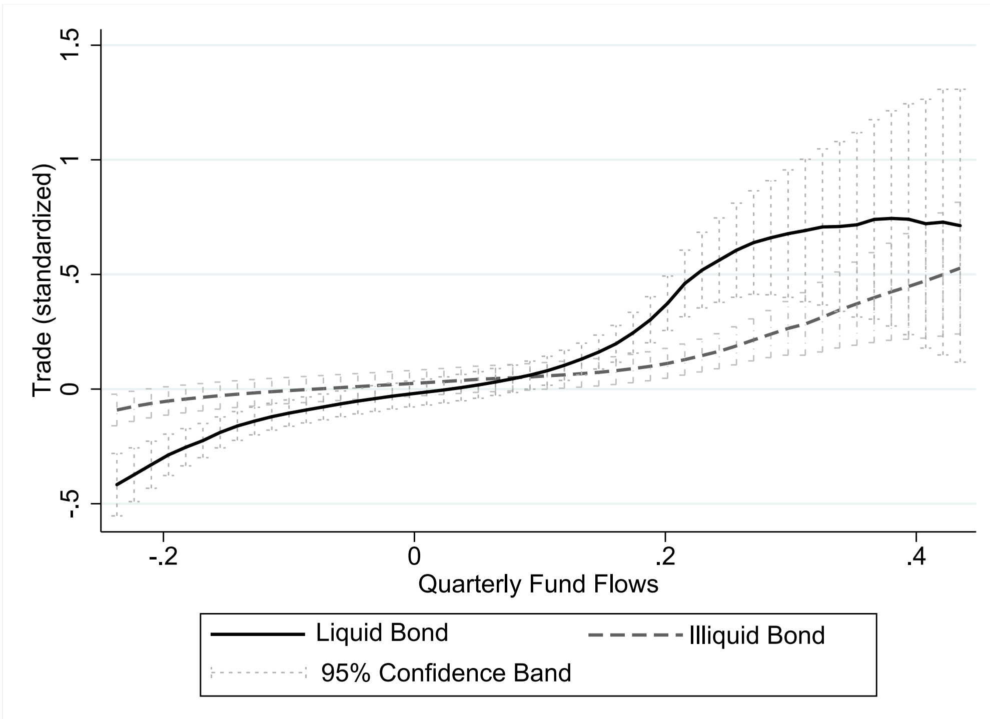


Table 1. Descriptive Statistics of Matched Bonds

This table provides descriptive statistics for 2,142 unique matching pairs of the young and the old bonds in our sample from February 2005 through June 2017. The sample consists of matching bond pairs issued by a same issuer with same credit rating and seniority, and very similar time-to-maturities (less than one year difference), but different ages. *Age* is defined as years passed after the issuance. We define young bond as bonds with age less than 3 years and pick a matched bond with a maximum age differences having age of at least 5 years. time-to-maturity (TTM) are remaining years to the maturity. We also report the dollar amount outstandings (*Amtout*). *Rating* is the S&P credit rating of bonds where we assign 21 to AAA rating and so on. The rating is reported just once because the young and old bonds in a matched pair have exactly same rating. The reported variables are calculated when the bond pairs are first appeared on our sample. We report the number of observations (N), mean, standard deviation (Std.), and 5%, 25%, 50% (median), 75%, and 95% quantiles.

	N (1)	Mean (2)	Std. (3)	5% (4)	25% (5)	50% (6)	75% (7)	95% (8)
Age (year), Young Bond	2,142	0.947	0.989	0.005	0.038	0.553	1.843	2.757
Age (year), Old Bond	2,142	7.515	3.727	5.002	5.046	5.921	8.129	16.674
TTM (year), Young Bond	2,142	4.574	3.403	0.583	2.919	4.427	5.024	9.949
TTM (year), Old Bond	2,142	4.425	3.455	0.427	2.42	4.23	4.999	9.895
Amtout ($MM), Young Bond	2,142	838.4	623.9	200	400	650	1,100	2,240
Amtout ($MM), Old Bond	2,142	765.0	735.0	100	250	500	1,000	2,500
Rating	2,140	15.11	3.031	10	13	15	17	21

Table 2. Mean Difference Tests of Matched Bonds

This table provides the results of difference tests on means between young and old bonds in the matched pair. The sample is consist of 63,052 monthly bond-level observations from 2,142 unique pairs during our sample period from February 2005 through June 2017. We examine times passed after the issuance, *Age*; remaining times to the maturity, *TTM*; and par-value dollar amount outstandings, *Amtout*. We also include various measures of illiquidity such as the Amihud (2002) illiquidity, *Amihud*; imputed round-trip costs of Feldhütter (2012), *IRC*; two measures of Bid-ask spreads, *Bid-ask 1* and *Bid-ask 2*, calculated following in Choi and Huh (2018) and Adrian, Fleming, Shachar, and Vogt (2017), respectively; and Roll (1984) illiquidity, *Roll*; All measures are calculated daily basis following Dick-Nielsen, Feldhütter, and Lando (2012) and Schestag, Schuster, and Uhrig-Homburg (2016) and each month we take median of daily measures during previous six months. Definitions for all variables are detailed in the Appendix B. Column (1) reports the number of observations used. Columns (2) and (3) report mean of each variable for the young bonds and the matched old bonds, respectively. Column (4) reports mean differences. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The numbers in parentheses (Column 5) are the standard errors two-way clustered at the issuer and month levels.

	N (1)	Young (2)	Old (3)	Difference (4)	*s.e.* (5)
Age (year)	63,052	1.547	8.317	-6.770***	(0.240)
TTM (year)	63,052	3.841	3.655	0.186***	(0.019)
Amtout ($MM)	63,052	940.4	878.2	62.19*	(36.86)
Amihud	62,106	0.468	0.633	-0.166***	(0.027)
IRC	61,693	0.076	0.108	-0.032***	(0.004)
Bid-ask 1	59,852	0.262	0.402	-0.140***	(0.013)
Bid-ask 2	60,157	0.223	0.313	-0.090***	(0.011)
Roll	61,553	0.459	0.576	-0.117***	(0.011)

Table 3. Difference-in-Differences Regressions: Yields around Market-wide Distress Events

This table provides the difference-in-difference regression results for the following model:

$$Yield_{i,t} = \alpha + \beta_1 Treat_i \cdot Post_t + \beta_2 Treat_i + ctrls_{i,t} + \varepsilon_t$$

where $Yield_{i,t}$ is monthly (or daily) yields in percentage on bond i. Monthly yields are defined as median of daily yields of bonds during the month. We only use yields where both liquid and matched illiquid bonds of a pair have available yields at the same day. $Treat_i$ is a time-invariant indicator variable for the young bonds of matched pairs. In Panel A, we employ two market-wide events: the Lehman Brothers bankruptcy during 2008 financial crisis (September 14, 2008) and the Taper Tantrum episode in 2013 (May 22, 2013). $Post_t$ is a dummy variable indicating months of event and afterwards (in Columns 1 and 3) or days after the event date (in Columns 2 and 4). The sample period runs from January 2008 through June 2009 for Columns (1) and (2) and from January 2013 through December 2013 for Columns (3) and (4). In Panel B, we use the monthly data around the Lehman Brothers bankruptcy. We further divide the sample into two subgroups based on the following variables related to the search friction and limits to arbitrage. In Columns (1) through (4), we use search friction variables to measure relative search frictions of treated bonds and matched control bonds. In Columns (1) and (2), we use differences in the dealer connectedness, measured by eigenvector centrality of dealer networks. Specifically, we calculate eigenvector centrality of dealer networks for treated bonds minus those for matched control bonds. Higher eignvector centrality implies better connectedness. Thus, the large difference of connectedness means the higher search friction of control bonds relative to treated bonds. In Columns (3) and (4), we similarly define the relative strength of search friction by calculating the prearranged trading ratio of control bonds minus those of treated bonds. Higher prearranged trading means higher search friction. Thus, the larger difference means the higher search friction of control bonds relative to treated bonds. We also examine the amount outstanding of treated and control bonds. $Vol(|Yld^T - Yld^C|)$ is the volatility of yield differences between matched bonds by using daily yields of previous one year. In Columns (1) through (10), We form two subgroups based on the median of each variable measured prior to the Lehman Brothers bankruptcy. In Columns (11) and (12), HY and IG represent the high yield and investment grade bonds, respectively. The control variables, $ctrls$, include logged time-to-matured, TTM, and logged amount outstandings, $Amtout$. Definitions for all variables are detailed in Appendix B. We also include issuer-times-month fixed effects. The sample bonds contain all matched bonds during the sample periods and the matching process is detailed in Section 6.1. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The numbers in parentheses are standard errors two-way clustered at the issuer and time levels.

Panel A: Market-wide Distress Events

	2008 Financial Crisis		2013 Taper Tantrum	
	Monthly	Daily	Monthly	Daily
	(1)	(2)	(3)	(4)
$Treat \cdot Post$	0.342***	0.266***	0.058***	0.067***
	(0.118)	(0.096)	(0.018)	(0.016)
$Treat$	-0.139***	-0.123***	-0.155***	-0.159***
	(0.043)	(0.025)	(0.018)	(0.015)
TTM	1.125***	1.283***	1.332***	1.408***
	(0.245)	(0.313)	(0.112)	(0.058)
$Amtout$	-0.032	0.034	-0.116***	-0.003
	(0.061)	(0.058)	(0.020)	(0.029)
Issuer · Time F.E.	Y	Y	Y	Y
N	5,510	37,170	5,604	40,116
Adj R^2	0.954	0.955	0.906	0.936

Panel B: Search Friction and Limits to Arbitrage (2008 Financial Crisis)												
	Search Friction (*Dealer Connectedness*)		Search Friction (*Prearranged Trading*)		Amount Outstanding (*Treated Bonds*)		Amount Outstanding (*Control Bonds*)		Limits to Arbitrage ($Vol(\|Yld^T - Yld^C\|)$)		*Credit Rating*	
	High (1)	Low (2)	High (3)	Low (4)	Small (5)	Large (6)	Small (7)	Large (8)	High (9)	Low (10)	HY (11)	IG (12)
$Treat \cdot Post$	0.547**	0.205	0.499**	0.246**	0.386**	0.280**	0.413**	0.254*	0.742***	0.043	1.280***	0.263**
	(0.207)	(0.157)	(0.184)	(0.102)	(0.166)	(0.112)	(0.168)	(0.123)	(0.244)	(0.061)	(0.360)	(0.103)
$Treat$	-0.278***	-0.058	-0.211***	-0.084	-0.152***	-0.163***	-0.116	-0.101**	-0.146*	-0.106***	0.072	-0.158***
	(0.060)	(0.052)	(0.057)	(0.057)	(0.041)	(0.047)	(0.093)	(0.046)	(0.074)	(0.021)	(0.338)	(0.038)
TTM	1.154***	1.295***	1.325***	1.150***	1.096***	1.297***	1.300***	1.176***	1.002***	1.263***	1.950**	1.087***
	(0.304)	(0.219)	(0.221)	(0.187)	(0.157)	(0.261)	(0.243)	(0.332)	(0.279)	(0.231)	(0.905)	(0.242)
$Amtout$	0.029	-0.053	0.002	0.055	-0.095	0.043	-0.090	0.046	-0.073	0.008	0.007	-0.040
	(0.073)	(0.077)	(0.080)	(0.097)	(0.129)	(0.042)	(0.097)	(0.088)	(0.076)	(0.059)	(0.136)	(0.062)
Issuer · Time F.E.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	2,170	2,404	2,534	2,522	2,752	2,758	2,844	2,666	2,238	2,260	413	5,004
Adj R^2	0.954	0.961	0.961	0.952	0.956	0.960	0.956	0.956	0.956	0.965	0.894	0.952

Table 4. Effects of Market Liquidity on Yields and Funding Liquidity

This table provides the regression results for the following model:

$$Yield_{i,t} \quad = \quad \alpha + \beta_1 Illiq_{i,t-1} \cdot TED_t + \beta_2 Illiq_{i,t-1} + ctrls_{i,t} + \varepsilon_t$$

where $Yield_{i,t}$ is monthly yields in percentage defined as median of daily yields of bond i during month t. We only use yields where both liquid and matched illiquid bonds of a pair have available yields at the same day. *Illiq* represents one of the five measures of illiquidity described in Table 2 (*Amihud*, *IRC*, *Bid-ask 1*, *Bid-ask 2*, and *Roll*). All illiquidity measures are standardized. TED is the TED spreads (%) obtained from Federal Reserve Bank of St. Louis. The control variables, $ctrls$, include logged time-to-matured, TTM, and logged amount outstandings, *Amtout*. Definitions for all variables are detailed in Appendix B. We also include issuer-times-month fixed effects. The sample contains all matched pairs of bonds from February 2005 through Jun 2017. The matching process is detailed in Section 6.1. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The numbers in parentheses are standard errors two-way clustered at the issuer and month levels.

	All					Excluding TED Spikes (2007 Q3 – 2009 Q2)				
Illiquidity Measure	*Amihud* (1)	*IRC* (2)	*Bid-ask 1* (3)	*Bid-ask 2* (4)	*Roll* (5)	*Amihud* (6)	*IRC* (7)	*Bid-ask 1* (8)	*Bid-ask 2* (9)	*Roll* (10)
$Illiq \cdot TED$	-0.085**	-0.073***	-0.050***	-0.089***	-0.150***	-0.264**	-0.261***	-0.164**	-0.175*	-0.615***
	(0.039)	(0.022)	(0.014)	(0.021)	(0.029)	(0.108)	(0.071)	(0.080)	(0.104)	(0.188)
Illiq	0.079***	0.060***	0.060***	0.081***	0.147***	0.114***	0.105***	0.091***	0.105***	0.266***
	(0.020)	(0.014)	(0.012)	(0.018)	(0.021)	(0.034)	(0.021)	(0.024)	(0.033)	(0.057)
TTM	1.189***	1.191***	1.181***	1.180***	1.151***	1.212***	1.211***	1.200***	1.197***	1.179***
	(0.053)	(0.051)	(0.051)	(0.050)	(0.051)	(0.054)	(0.053)	(0.052)	(0.052)	(0.053)
Amtout	-0.081***	-0.078***	-0.081***	-0.074***	-0.065***	-0.094***	-0.089***	-0.084***	-0.076***	-0.076***
	(0.021)	(0.023)	(0.022)	(0.020)	(0.023)	(0.019)	(0.020)	(0.023)	(0.021)	(0.023)
Issuer · Time F.E.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	61,871	61,289	58,801	59,282	61,236	55,146	54,677	52,496	52,894	54,562
Adj R^2	0.973	0.973	0.974	0.974	0.973	0.968	0.969	0.969	0.970	0.969

Table 5. Effects of Market Liquidity on Yields and Investor Outflows from Corporate Bond Mutual Funds

This table provides the regression results for the following model:

$$Yield_{i,t} \quad = \quad \alpha + \beta_1 Illiq_{i,t-1} \cdot Outflows_t + \beta_2 Illiq_{i,t-1} + ctrls_{i,t} + \varepsilon_t$$

where $Yield_{i,t}$ is monthly yields in percentage defined as median of daily yields of bond i during month t. We only use yields where both liquid and matched illiquid bonds of a pair have available yields at the same day. *Illiq* represents one of the five measures of illiquidity described in Table 2 (*Amihud*, IRC, *Bid-ask 1*, *Bid-ask 2*, and *Roll*). All illiquidity measures are standardized. All illiquidity measures are standardized. $Outflows$ is investor capital outflows of corporate bond mutual funds (CBMFs) defined as $-min(flow, 0)$ where $flow$ is capital flows of CBMFs as percentage of their assets under managements. The control variables, *ctrls*, include logged time-to-matured, TTM, and logged amount outstandings, *Amtout*. Definitions for all variables are detailed in Appendix B. We also include issuer-times-month fixed effects. The sample contains all matched pairs of bonds from February 2005 through Jun 2017. The matching process is detailed in Section 6.1. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The numbers in parentheses are standard errors two-way clustered at the issuer and month levels.

Dependent Variable: Monthly Yields					
Illiquidity Measure	*Amihud* (1)	IRC (2)	*Bid-ask 1* (3)	*Bid-ask 2* (4)	*Roll* (5)
$Illiq \cdot Outflows$	-0.135***	-0.081***	-0.042***	-0.064**	-0.148***
	(0.030)	(0.022)	(0.015)	(0.030)	(0.046)
Illiq	0.043***	0.029**	0.036***	0.035**	0.076***
	(0.015)	(0.014)	(0.010)	(0.014)	(0.015)
TTM	1.192***	1.193***	1.184***	1.187***	1.163***
	(0.053)	(0.051)	(0.051)	(0.050)	(0.051)
Amtout	-0.084***	-0.080***	-0.084***	-0.078***	-0.070***
	(0.022)	(0.023)	(0.023)	(0.021)	(0.024)
Issuer · Time F.E.	Y	Y	Y	Y	Y
N	61,871	61,289	58,801	59,282	61,236
Adj R^2	0.973	0.973	0.973	0.974	0.973

Table 6. Difference-in-Differences Regressions: Issuer-level Outflow Shocks from Downgrade Events

This table provides the difference-in-difference regression results for the following model:

$$Yield_{i,t} \quad = \quad \alpha + \beta_1 Treat_i + \beta_2 Treat_i \cdot w_{[-10,-1]} + \beta_3 Treat_i \cdot w_{[0,9]} + ctrls_{i,t} + \varepsilon_t$$

where $Yield_{i,t}$ is daily yields in percentage on bond i and day t. $Treat_i$ is a time-invariant indicator variable for the young bonds of matched pairs. We employ downgrade of bond credit ratings as events for difference-in-difference regressions. We define the downgrade event as the first downgrade announcement date by S&P, Moody's, or Fitch (i.e., downgrade that changes the lowest rating of the three ratings). We only include downgrades where two bonds in the matched pairs are downgraded at the same day. If there are multiple consecutive downgrade events within a month, we only include the first event Similarly, $w_{[-10,-1]}$ is a dummy variable indicating days between -10 and -1 weeks from the event date. Similarly, $w_{[0,9]}$ is a dummy variable indicating days between 0 and 9 weeks from the event date. The sample consists of daily yields from 30 weeks before and 10 weeks after the event. In Column (1), we include all downgrade events between February 2005 and June 2017. In Columns (2) and (3), we use downgrade events during the normal and distressed periods, respectively, where we define the distressed periods as the post Lehman Brothers bankruptcy crisis periods (September 2008 through June 2009) and the Taper Tantrum periods (May 2013 through December 2013). In Columns (4), (5), and (6), we use downgrades from investment grades (IG) to IG, from IG to high yields (HY), and from HY to HY, respectively. The control variables, $ctrls$, include logged time-to-maturity, TTM, and logged amount outstandings, $Amtout$. We also include issuer-times-month fixed effects. The sample consists of the matched bonds and we detailed the matching process in Section 6.1. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The numbers in parentheses are standard errors two-way clustered at the issuer and month levels.

	All	Normal	Distressed	IG → IG	IG → HY	HY → HY
	(1)	(2)	(3)	(4)	(5)	(6)
$Treat$	-0.078	-0.108**	0.012	-0.113***	0.227	0.169
	(0.049)	(0.044)	(0.091)	(0.027)	(0.233)	(0.204)
$Treat \cdot w_{[-10,-1]}$	0.161***	0.111**	0.282***	0.080*	0.189	0.632***
	(0.045)	(0.046)	(0.083)	(0.041)	(0.216)	(0.208)
$Treat \cdot w_{[0,9]}$	0.332***	0.160***	0.709***	0.214***	0.835*	0.822***
	(0.062)	(0.053)	(0.174)	(0.045)	(0.426)	(0.275)
TTM	1.332***	1.293***	1.355***	1.323***	0.168	2.338
	(0.189)	(0.230)	(0.288)	(0.161)	(0.841)	(1.555)
$Amtout$	-0.024	-0.066	0.076	0.024	-0.405	-0.386***
	(0.071)	(0.073)	(0.111)	(0.029)	(0.309)	(0.125)
Issuer · Time F.E.	Y	Y	Y	Y	Y	Y
N	74,760	52,266	22,494	59,302	4,196	11,262
Adj R^2	0.976	0.977	0.973	0.973	0.929	0.943