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Abstract

This paper presents a three-period model featuring a short-term investor and dealers in an over-the-counter bond market. A short-term investor invests cash in the short term because of a need to pay cash soon. This time constraint lowers the resale price of bonds held by a short-term investor through bilateral bargaining in an over-the-counter market. Ex-ante, this hold-up problem explains the use of a repo by a short-term investor, a positive haircut due to counterparty risk, and the fragility of a repo market. This result holds without any risk to the dividends and principals of underlying bonds or asymmetric information.

JEL: G24.
Keywords: Repo; Over-the-counter market; Securities broker-dealer; Short-term investor; Haircut.

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1 Introduction

Many securities primarily trade in an over-the-counter (OTC) market. A notable example of such securities is bonds.[1] The key feature of an OTC market is that the buyer and the seller in each OTC trade set the terms of trade bilaterally. There has been developed a theoretical literature analyzing the effects of this market structure on spot trading, such as Spulber (1996), Rust and Hall (2003), Duffie, Gârleanu, and Pedersen (2005), Miao (2006), Vayanos and Wang (2007), Lagos and Rocheteau (2010), Lagos, Rocheteau and Weill (2011), and Chiu and Koeppl (2011), for example. This literature uses search models, in which each transaction is bilateral, to analyze various aspects of trading and price dynamics, such as liquidity and bid-ask spread, in OTC spot markets.

This paper analyzes another type of transaction in an OTC market—a repo. A repo is one of the primary instruments in the money market. In this transaction, a short-term investor buys long-term bonds with a repurchase agreement in which the seller of the bonds, typically a securities broker-dealer, promises to buy back the bonds at a later date. From the seller's point of view, this transaction is akin to a secured loan with the underlying bonds as collateral. A question remains, however, regarding why a short-term investor needs a repo when they can simply buy and resell bonds in a series of spot transactions. This paper presents a simple model to show that a short-term investor needs a repo because of the investor's short investment horizon and bilateral bargaining in an OTC bond market. It is not necessary to introduce a search friction, or any other uncertainty or asymmetric information, to obtain this result.

The key factor behind this result is a hold-up problem for a short-term investor in an OTC spot bond market. Typically, a short-term investor stores cash in the short term because the investor must pay out cash in the near future. Therefore, if a short-term investor buys long-term bonds, then the investor needs to resell bonds by the time to pay out cash. Given that the number of trading opportunities per period is finite, this time constraint weakens the bargaining position of the investor against the buyer of the investor's bonds. As a consequence, the buyer can negotiate down the bond price through bilateral bargaining in an OTC market. Ex-ante, this hold-up

[1] See Harris (2003) and Biais and Green (2007) for institutional details of the bond market.

problem lowers the highest spot bond price that a short-term investor can pay to a dealer selling bonds, resulting in no spot transaction between them.

A repo allows a short-term investor to avoid a hold-up problem, because it lets an investor negotiate the initial ask price and the repurchase price of bonds simultaneously with one dealer. If a dealer can commit to an arbitrary repurchase price, then an investor can secure a sufficiently high resale price of the investor's bonds in advance. Even if a dealer cannot commit to such a high repurchase price due to some imperfect enforcement, a dealer can lower the initial ask price of bonds—or raise a haircut—to maintain positive trade surpluses for both parties. This result explains why a short-term investor is the main user of a repo in practice.

The reason behind the need for a repo also explains why a repo market is fragile. If a dealer defaults on a repo, then the short-term investor holding the repo must liquidate bonds at a low price due to the hold-up problem in a spot market. As a result, a short-term investor stops arranging a repo if the exogenous risk of default by a dealer becomes too high. If the default risk is not so high that a short-term investor still arranges a repo, then a haircut increases with the default risk.

1.1 Related literature

The result of fragility is related to a recent turmoil in the U.S. tri-party repo market. In this market, most of underlying bonds are Treasury securities and agency mortgage-backed securities. These securities are government-guaranteed. As described by the Financial Crisis Inquiry Commission (2010), however, the market was about to collapse in the two-week period before the failure of Bear Stearns in 2008. In the literature, Martin, Skeie and von Thadden (2010) show that a repo market can collapse due to coordination failure among investors if a clearing bank unwinds a repo every day as in the U.S. tri-party repo market. Instead of this feature of the market, this paper focuses on the effect of default risk on a repo. The model implies that a sufficiently high risk of default by a dealer, such as Bear Stearns, causes a collapse of a repo market in a unique equilibrium. This result holds without any risk to the dividends and principals of underlying bonds. Thus, it is applicable to a repo backed by government-guaranteed bonds.

This result differs from the analysis by Dang, Gorton, and Holmström (2011). They show that a positive haircut in a repo stems from counterparty risk and asymmetric information. In their model, the lender in a repo faces an adverse selection problem when reselling collateral in case of the borrower's default. Their analysis is linked to Gorton and Metrick (2012), who explain the fragility of a repo market for private-label securities by asymmetric information. In contrast to these papers, asymmetric information plays no role in this paper. All the results are driven by the investment horizon of a short-term investor and bilateral bargaining in an OTC bond market. Thus, this paper adds to the two papers by showing that a repo market can be fragile in a unique equilibrium even without asymmetric information.

The hold-up problem for a short-term investor in the model is related to bid-ask spread in the literature on OTC spot trading described above. In this literature, the motive for an asset sale is typically assumed to be some idiosyncratic shock that raises the seller's asset holding cost or reduces the seller's preference for asset holdings. Given a search friction that delays the seller's contact with another buyer, such a shock lowers the threat point for the seller in a bilateral transaction with a dealer, resulting in a low bid price. In the context of this result in the literature, the novel finding of this paper is a linkage between the investment horizon and a hold-up problem: even without any shock, a short-term investor endogenously falls into a hold-up problem ex-post if buying a long-term bond. This linkage is crucial to explain why a short-term investor is the main user of a repo in practice.

Also, Monnet and Narajabad (2011) consider an asset rental as a repo in a dynamic search model of an OTC market. They show that investors both buy and rent assets in the market if investors have idiosyncratic shocks to their asset holding costs. This paper analyzes different issues than their work. In particular, this paper highlights the effect of an investor's investment horizon rather than an asset holding cost. Furthermore, this paper analyzes both the need for a repo and its fragility, and shows that both of them stem from the same cause.

There exist other related papers in the literature on a repo. Duffie (1996) presents a model to analyze a special repo rate, which is applicable when a security lender lends securities to a short seller through a reverse repo. Vayanos and Weill (2008) analyze the on-the-run premium on Treasury securities by considering reverse repos to short sellers in a dynamic search model. In contrast to these papers, this paper focuses on a repo for a short-term investor.

Antinolfi et al. (2012) characterize a repo as a secured loan, and show that a repo is necessary if there exists the risk of a borrower's default. They analyze the effects of an automatic stay on collateral in defaulted repurchase agreements. Adding to their work, this paper shows that a repo is necessary even in the absence of the risk of a dealer's default, because of bilateral bargaining in an OTC market. From a broader perspective, there exists a theoretical literature on secured loans, such as Kiyotaki and Moore (1997), Geanakoplos (2009), and Brunnermeier and Pedersen (2009). See Krishnamurthy (2010) for a survey of this literature. While this literature typically analyzes a competitive loan market, this paper includes the analysis of imperfect enforcement in an OTC market. It is shown that a repo is robust to imperfect enforcement like a secured loan.

Finally, there exists a literature on analyzing the optimal market mechanism to prevent a hold-up problem. For example, Gehrig (1993) shows that a Bertland competition among dealers through price posting leads to the Walrusian equilibrium price in a search model. Also, Acemoglu and Shimer (1999) show that price posting with directed search prevents hold-up problems for both firms and workers in a labor search model. In contrast to these papers, this paper analyzes an arrangement to avoid a hold-up problem given bilateral bargaining in an OTC market. Even though dealers quote bid and ask prices for their clients in practice, the final terms of trade in each transaction must be determined by bilateral bargaining between a dealer and its client, especially when the client has a large volume of bonds to buy or sell (see Harris 2003, Ch.13). This paper shows that a repo prevents a hold-up problem even without competition through price posting in the bond market.

The remainder of this paper is organized as follows. Section 2 briefly summarizes the stylized features of the repo market in practice. Section 3 presents the baseline model of a spot bond market with a short-term investor and dealers. Section 4 describes a hold-up problem for a short-term investor in the baseline model. In Section 5, the baseline model is extended to introduce a repo. Section 6 analyzes the relationship between a haircut and counterparty risk. Section 7 shows the robustness of a repo to imperfect enforcement. Section 8 introduces sequential bargaining into the model for a robustness check. Section 9 concludes.

2 Features of the repo market in practice

This section briefly summarizes the stylized features of the repo market in practice that motivates the analysis in this paper.

The main repo market in the U.S. is the so-called tri-party repo market.

Table 1: Composition of securities traded in the U.S. tri-party repo market

	Share (%)
Fed-eligible securities	82.7
US Treasury securities	28.9
Agency MBS	36.3
Agency debentures	11.4
Agency REMICs	4.6
Ginnie Mae MBS Pools	1.2
Ginnie Mae REMICs	0.3
Non-Fed eligible securities	17.5

Source: Copeland, Martin and Walker (2010).
Notes: The sample period is from July 2009 to January 2010. Fed-eligible securities are the securities acceptable for the Federal Reserve in its market operations.

In this market, typically a short-term investor, such as a money market mutual fund (MMF), a security lender, a municipal government, or a corporate treasury, buys long-term bonds from a securities broker-dealer through a repo (see Copeland, Martin and Walker 2010).[2] Table 1 reported by Copeland, Martin and Walker shows that most of the underlying bonds in the market are Treasury securities, agency mortgage-backed securities, and agency debt. These securities are government-guaranteed. This observation implies that a short-term investor needs to arrange a repo even without any risk to the dividends and principals of underlying bonds.

Another feature of the repo market is fragility. Despite the government guarantees for underlying bonds, the U.S. tri-party market was about to collapse during the two-week period before the failure of Bear Stearns in March 14, 2008. Even though no public data are available for that period because the market is an OTC market, there exists anecdotal evidence of a turmoil. In the Financial Crisis Inquiry Report, the then Federal Reserve Chairman Ben Bernanke provides his account of the turmoil:

> The $2.8 trillion tri-party repo market had “really [begun] to break down,” Bernanke said. “As the fear increased,” short-term

[2]This market is called “tri-party” because a clearing bank is involved as a third party in a repo. The role of a clearing bank in a repo is beyond the scope of this paper. See Copeland, Martin and Walker (2010) for more details on the role of clearing banks in this market and Martin, Skeie, and von Thadden (2010) for a theoretical analysis on this topic.

> lenders began demanding more collateral, "which was making it more and more difficult for the financial firms to finance themselves and creating more and more liquidity pressure on them. And, it was heading sort of to a black hole." He saw the collapse of Bear Stearns as threatening to freeze the tri-party repo market, leaving the short-term lenders with collateral they would try to "dump on the market. You would have a big crunch in asset prices." (Financial Crisis Inquiry Commission 2010, pp. 290-291.)

Also, Adrian, Burke, and McAndrews (2009) report that haircuts rose significantly across the market during the two-week period before the failure of Bear Stearns.[3] Bear Stearns was one of the large securities broker-dealers participating in the market. Thus, this observation implies that an increase in the risk of default by a dealer, such as Bear Stearns, causes a collapse of a repo market, even if underlying bonds are government-guaranteed.

In addition, Table 2 reported by the Committee on the Global Financial System (2010) compares haircuts in repos with different types of counterparties.[4] A haircut is defined as $1 - v/q$ where v denotes the initial ask price of securities in a repo and q denotes the quoted market value of the securities. The table shows that a haircut is increasing in the risk of default on a repurchase agreement. This tendency became stronger during the recent financial crisis when the risk of default by financial institutions increased. Different haircuts on the same security due to different counterparty risks cannot be

[3]Krishnamurthy, Nagel, and Orlov (2011) construct monthly data of haircuts in repos held by MMFs in the U.S. from Securities and Exchange Commission (SEC) filings. Their data do not show a significant rise in the haircuts on Treasury securities and agency mortgage-backed securities for March 2008. This is because the data are for the end of each month due to the characteristics of SEC filings. Thus, the data indicate that the market turmoil did not last until the end of March 2008. This finding is consistent with the introduction of the Primary Dealer Credit Facility by the Federal Reserve immediately after the failure of Bear Stearns.

[4]A zero haircut on G-7 government bonds in Table 2 differs from a positive haircut on U.S. Treasury securities reported by Copeland, Martin and Walker (2010) and Krishnamurthy, Nagel, and Orlov (2011). They report an around 2% haircut on Treasury securities and agency mortgage-backed securities in the U.S. This discrepancy may be due to a difference in the samples: the sample of Table 2 includes "banks, prime brokers, custodians, asset managers, pension funds and hedge funds in different financial centers" (Committee on the Global Financial System 2010, p.2.), while the other two papers report haircuts in repos held by short-term investors. The existence of a haircut specific to short-term investors is consistent with the result of the model described in Section 6, because the result stems from a hold-up problem specific to a short-term investor.

explained by the standard explanation based on value-at-risk, because value-at-risk should be the same for the same security.[5]

In summary, the features of a repo described here lead to the following questions:

1. Why does a short-term investor need to arrange a repo even without any risk to the dividends and principals of underlying bonds?

2. Why does an increase in the risk of default by a dealer cause a collapse of a repo market, even if there is no risk to the dividends and principals of underlying bonds?

3. Why does a haircut depend on default risk?

This paper presents a simple model to analyze these questions. The model shows that these features of a repo can be explained by the same cause: the short investment horizon of a short-term investor and bilateral bargaining in an OTC bond market.

3 Baseline model

This section describes the baseline model in this paper. The model features a short-term investor and dealers in a spot bond market. In a later section, the model will be extended to introduce a repo.

There are one short-term investor and two dealers living for three discrete periods, 0, 1, and 2. The short-term investor is born with an amount e of cash in period 0 and consume goods in period 1. The price of goods is fixed to unity; thus cash and consumption goods are interchangeable throughout the paper. The investor maximizes its expected consumption.

These assumptions capture a situation in which a short-term investor stores cash until the investor needs to pay cash in the near future. The fixed timing of consumption reflects the rigid due dates for payment obligations in practice. Consumption maximization is equivalent to maximizing the return on cash while storing cash.

The short-term investor has two instruments to store cash. One is a linear storage technology; if the investor invests an amount x of cash into

[5]See Geanakoplos (2009) and Brunnermeier and Pedersen (2009) for an endogenous haircut based on value-at-risk.

Table 2: Typical haircuts in repos (%)

	June 2007			June 2009		
	Type of counterparty			Type of counterparty		
	Prime	Non-prime	Unrated	Prime	Non-prime	Unrated
G-7 government bonds						
Short-term	0	0	0.5	0.5	1	2
Medium-term	0	0	0.5	1	2	3
U.S. agencies						
Short-term	1	2	3	1	2	3
Medium-term	1	2	3	2	5	7
Pfandbriefe	0	0	1	1	2	8
Prime MBS						
AAA-rated	4	6	10	10	20	30-100
AA- and A-rated	8	12	25	100	100	100
Asset-backed securities	10	20	20	25	50	100
Structured products (AAA)	10	15	20	100	100	100
Investment-grade bonds						
AAA- and AA-rated	1	2	5	8	12	15
A- and BBB-rated	4	7	10	10	15	20
High-yield bonds	8	12	20	15	20	40
Equity						
G-7 countries	10	12	20	15	20	25
Emerging economies	15	20	35	20	25	40

Source: Committee on the Global Financial System (2010)
Notes: "Unrated" counterparties include hedge funds and other unrated counterparties. "Pfandbriefe" are covered interest-bearing bonds issued by German banks under the Pfandbrief Act.

this technology in period 0 or 1, then it receives Rx of cash in the following period given a fixed gross rate of return R. Assume that

$$R \geq 1. \tag{1}$$

This technology can be interpreted as a bank deposit or a short-term bill whose interest rate is closely correlated with the policy rate fixed by the central bank.

The other instrument is a long-term discount bond, which returns a unit of cash in period 2. The supply of the bond is fixed to one. The bond is initially held by one of the dealers, called dealer A, who is born with the bond in period 0. The other dealer, called dealer B, has no bond endowment in any period. Each dealer maximizes the expected discounted utility of consumption:

$$c_{j,0} + E_0[\beta c_{j,1} + \beta^2 c_{j,2}], \tag{2}$$

where $c_{j,t}$ is the consumption by dealer j in period t for $j = A, B$, and β is a time discount factor satisfying

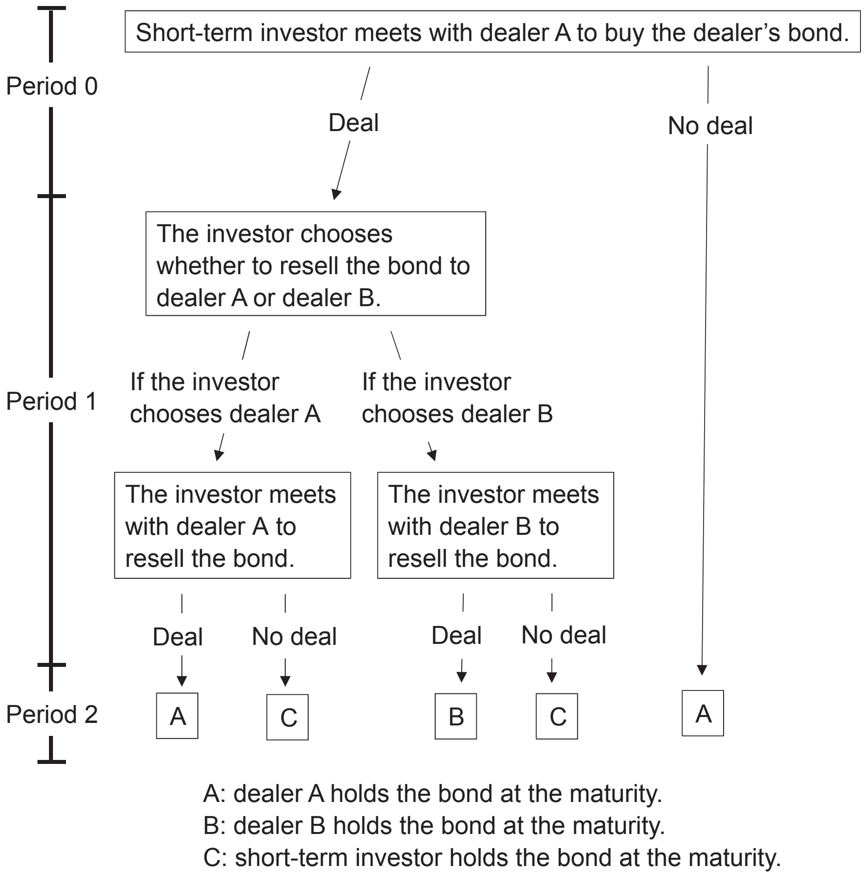
$$\beta \in \left(0,\ \frac{1}{R}\right). \tag{3}$$

This assumption implies that dealers require a higher rate of return on their investments than the short-term investor.

Dealers and the short-term investor can trade the bond in an OTC market. In period 0, the investor meets with dealer A to buy the dealer's bond. If they do not reach any deal, then dealer A retains the bond until period 2 and consumes the return on the bond at maturity. Dealer A does not try to sell the bond to dealer B in this case, because dealers have identical preferences and, therefore, there are no gain from trade between them. If the investor buys the bond from dealer A in period 0, then the investor chooses whether to meet with dealer A or B to resell its bond in period 1. Only spot transactions are considered in the baseline model. See Figure 1 for the tree of events in the bond market. After bond transactions in each period, the short-term investor and dealers can invest their residual cash into the storage technology or consume it.

Each bilateral transaction in the bond market is characterized by Nash bargaining. The bargaining power of dealer j against the short-term investor

Figure 1: Bond market events in the baseline model



in each period is denoted by α_j ($\in (0,1)$) for $j = A, B$. Assume that

$$\alpha_A > \alpha_B, \tag{4}$$

which implies that dealer B becomes the best counterparty for the short-term investor in period 1.[6] This assumption captures the fact that securities broker-dealers offer different bid prices in practice.[7] For simplicity, the inequality (4) is assumed to hold with probability one. The result of the model is robust as long as the inequality holds with some positive probability.

Each dealer has a cash endowment e in period 1. Assume that

$$e > 1, \tag{5}$$

so that the short-term investor and dealers have enough cash to buy the bond in each period given the assumptions (1) and (3). To motivate bond trade between the short-term investor and dealers, also assume that the investor does not have ability to provide an unsecured loan to dealers against their cash endowments in period 1.[8] See Table 3 for a summary of the timing of endowments and consumption and the returns on financial instruments.

Given the parameter values, (e, β, R), and the tree of events shown in Figure 1, an equilibrium is a sub-game perfect equilibrium characterized by the short-term investor's consumption-maximizing decision on whether to meet with dealer A or B in period 1 and the solution to Nash bargaining for each bond transaction.[9]

In the baseline model, the number of the short-term investor's trading opportunities in period 1 is set to one for simplicity. In Section 8, the number of trading opportunities is extended to an arbitrarily large finite integer. The result of the model shown below is robust even in such a case.

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[6] With this assumption, dealers do not gain if dealer A sells its bond to dealer B in period 0 so that dealer B bargains with the short-term investor on behalf of dealer A. Thus, dealer A meets directly with the investor in the period.

[7] See Harris (2003).

[8] This assumption does not imply that dealers in practice cannot borrow an unsecured loan from any lender. Instead, it captures the fact that some investors do not have enough capacity to provide unsecured loans to some borrowers.

[9] These variables are sufficient to pin down the residual cash that the short-term investor invests into the storage technology and also the consumption by each dealer and the investor in each period.

Table 3: The timing of endowments and consumption and the returns on financial instruments in the baseline model

		Period		
		0	1	2
Utility of consumption	Short-term investor		c	
	Dealer A	c	βc	$\beta^2 c$
	Dealer B	c	βc	$\beta^2 c$
Endowments	Short-term investor	e		
	Dealer A	one bond	e	
	Dealer B		e	
Returns on financial instruments	Bond			1 per bond
	Storage		R per cash invested in period 0	R per cash invested in period 1

Notes: "c" represents the amount of goods consumption by each agent in each period. "β" is the time discount factor for dealers. "e", "R", and "1" appearing as the return per bond are the amounts of cash. Goods and cash are interchangeable as the price of goods is one.

4 Hold-up problem for a short-term investor in an OTC spot market

For a wide range of parameter values, the short-term investor does not buy the bond in the spot market because its investment horizon is shorter than the maturity of the bond. To see this result, solve the baseline model backward.

4.1 Hold-up problem for a short-term investor holding a bond

Suppose that the short-term investor holds the bond at the beginning of period 1. Whether the investor chooses to resell its bond to dealer A or B, the bargaining problem between the investor and a dealer is

$$\max_{p_{j,1}} (\beta - p_{j,1})^{\alpha_j} (p_{j,1} - 0)^{1-\alpha_j}, \tag{6}$$

for $j = A, B$, where $p_{j,1}$ is the price of the investor's bond paid by dealer j. The left and the right parentheses are the trade surpluses for the dealer and the investor, respectively. In the right parenthesis, a zero appears as the investor's payoff in case of no deal, because the investor will miss the opportunity of consumption if it retains the bond until period 2. In the left parenthesis, β is the present discounted value of the return on the bond in period 2 for the dealer.

The solution to the bargaining problem is

$$p_{j,1} = (1 - \alpha_j)\beta. \tag{7}$$

Given $\alpha_A > \alpha_B$ as set by the assumption (4), $p_{A,1} < p_{B,1}$. Thus, the short-term investor chooses to sell its bond to dealer B for a higher bond price.

This result has two implications. First, it captures the feature of a spot market that an investor can switch to the best counterparty freely at each point of time. Thus, once a dealer sells a bond to an investor in a spot market, the bond may not come back to the dealer. Second, the short-term investor has to accept a low resale price if holding a bond in period 1, unless the value of α_B is unrealistically close to zero.[10] This hold-up problem is due

[10] Such an assumption would imply that a dealer does not have a good negotiation skill, which is unrealistic.

to the time constraint that the investor must resell the bond within period 1, given its timing of consumption. This constraint weakens the bargaining position of the investor and allows the buyer of the bond to negotiate down the bond price.

4.2 No spot bond purchase by a short-term investor

Now move back to period 0. In this period, the short-term investor meets with dealer A to buy the dealer's bond. The bargaining problem takes the following form:

$$\max_{p_0}(p_0 - \beta^2)^{\alpha_A}(p_{B,1} - Rp_0)^{1-\alpha_A}, \tag{8}$$

where p_0 denotes the price of the dealer's bond to be paid by the investor. The left and the right parentheses are the trade surpluses for the dealer and the investor, respectively. In the right parenthesis, Rp_0 is the opportunity cost for the investor to pay p_0. If incurring this cost, the investor can resell the bond at $p_{B,1}$ in period 1, as shown above. In the left parenthesis, the total revenue from the bond sale for dealer A is just p_0, because the investor will not come back to the dealer in period 1. The second term, β^2, is the present discounted value of the bond for the dealer in case that the dealer holds the bond until the maturity in period 2. This term is the opportunity cost for the dealer to sell the bond in period 0.

The bargaining problem (8) implies that dealer A and the short-term investor agree on a deal in period 0 if and only if

$$\frac{p_{B,1}}{R} \geq \beta^2, \tag{9}$$

because otherwise there is no value of p_0 that generates non-negative trade surpluses for both parties. Substituting Eq. (7) into Eq. (9) yields a closed form of Eq. (9):

Proposition 1. In the baseline model, the short-term investor buys the bond from dealer A in period 0 if and only if

$$1 - \alpha_B \geq \beta R. \tag{10}$$

Otherwise, they make no deal in period 0.

This condition is violated unless the value of α_B is unrealistically close to zero. For example, suppose that $\alpha_B = 0.5$, so that dealer B and the short-term investor have equal bargaining power. In such a case, the condition is violated even under a mild assumption such as $\beta R > 0.5$.[11]

This result is due to the hold-up problem for the short-term investor described above. Expecting this hold-up problem in period 1, the short-term investor can pay only a low bond price in period 0. In a wide range of parameter values, the dealer does not accept such a low spot price for its bond because the bond would not come back to the dealer once sold in a spot transaction.

In summary, three factors play roles in the result of the baseline model: bilateral bargaining in an OTC market, the short investment horizon of a short-term investor, and the feature of a spot market that an investor can freely resell a bond to the best counterparty at each point of time.

5 Use of a repo and its fragility

5.1 Extension of the baseline model

In this section, extend the baseline model to introduce a repo. Assume that the short-term investor can buy the bond from dealer A in period 0 with a repurchase agreement in which the dealer will buy back the bond at a pre-specified repurchase price in period 1.

Also, introduce an exogenous risk of default on a repurchase agreement which cannot be controlled by the terms of a repo. Assume that dealer A goes bankrupt exogenously in period 1 with probability μ ($\in [0, 1)$). In case of bankruptcy, dealer A must stop all cash payments; thus it must default on a repurchase agreement. In this case, the short-term investor can meet only with dealer B in period 1. Bankruptcy does not have any other effect.[12]

[11] This assumption implies that the excess rate of return required by the dealer for its investment, $1/\beta - R$, is less than 100% given the rate of return on the storage technology, R, as the benchmark.

[12] If dealer A does not sell the bond in period 0, then dealer A can receive the return on the bond at maturity in period 2 regardless of bankruptcy. Thus, bankruptcy only stops cash payments by the dealer and does not force the dealer to sell its assets immediately. The interpretation of this assumption is that a dealer always maximizes the return on its assets, whether it is for the dealer's original owner or for a bankruptcy estate. For simplicity, the model abstracts from inefficient asset management due to bankruptcy

See Figure 2 for the event tree in the extended model. The other part of the model remains as same as in the baseline model.

5.2 Bargaining problem with a repo and a default risk

Now put these new assumptions into a mathematical form. The baseline bargaining problem between dealer A and the short-term investor in period 0, Eq. (8), is modified to

$$\begin{aligned}
\max_{d,v_0,v_1,p_0} \quad & \{[v_0 + (1-\mu)\beta(\beta - v_1)]d + p_0(1-d) - \beta^2\}^{\alpha_A} \\
& \cdot \{[\mu p_{B,1} + (1-\mu)v_1 - Rv_0]d + (p_{B,1} - Rp_0)(1-d)\}^{1-\alpha_A}, \quad (11) \\
\text{s.t.} \quad & d \in \{0,\ 1\}, \quad (12) \\
& \beta - v_1 \geq 0, \quad (13)
\end{aligned}$$

where dealer A and the investor decide whether to arrange a repo ($d = 1$) or not ($d = 0$), as indicated by the first constraint. Note that the bargaining problem is as same as in the baseline model if $d = 0$. If $d = 1$, then dealer A and the investor negotiate the initial ask price v_0 and the repurchase price v_1 of the bond jointly.

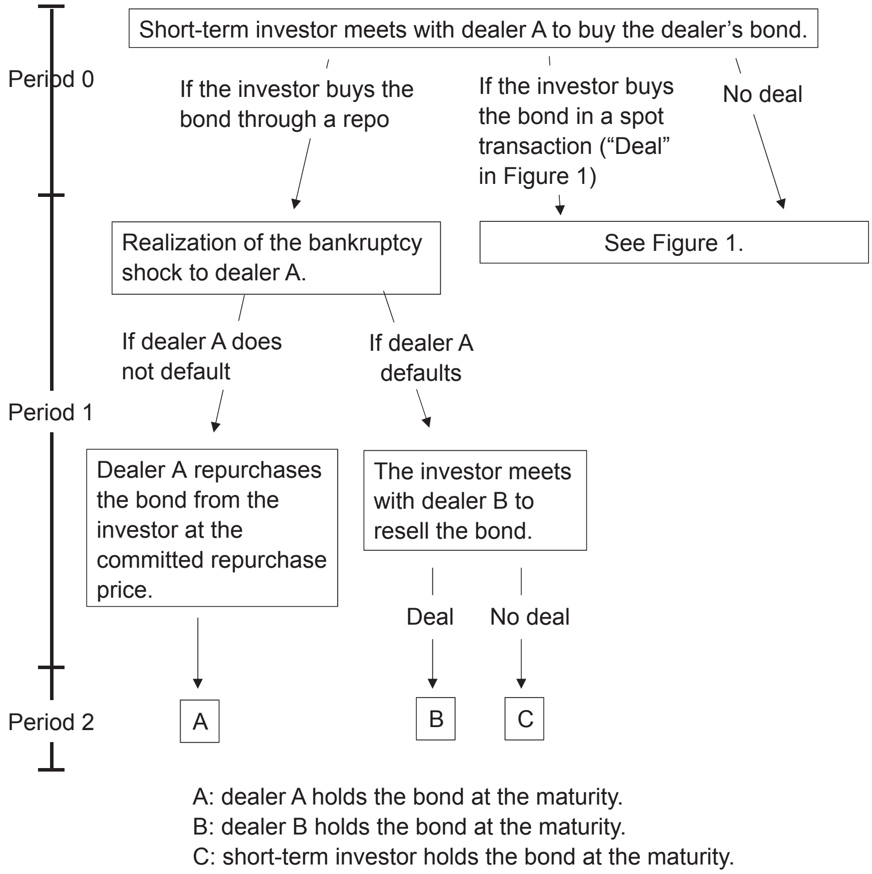
The left and the right curly bracket are the trade surpluses for dealer A and the short-term investor, respectively. In the right curly bracket, $\mu p_{B,1} + (1-\mu)v_1$ is the expected resale bond price for the investor arranging a repo. With probability μ, dealer A defaults, and the investor must resell its bond to dealer B. The bond price in this case equals $p_{B,1}$ as shown in the baseline model. In the other probability, dealer A repurchases the bond at the repurchase price v_1. The opportunity cost for the investor to arrange a repo is Rv_0.

In the left curly bracket, v_0 is dealer A's revenue from a repo in period 0. In the next term, $(\beta - v_1)$ is the ex-post profit for dealer A from a repo in period 1, in which β is the present discounted value of the return on the bond at maturity for dealer A in period 1 and v_1 is the cost of repurchasing the bond in that period. This profit is discounted by β in period 0. Also, the survival probability of dealer A, $1 - \mu$, is multiplied to the profit, because dealer A cannot obtain the profit if defaulting on a repurchase agreement.[13]

procedure.

[13]The default risk does not affect dealer A's payoff in case of no deal, β^2, in the left curly bracket, because bankruptcy does not constrain the dealer from managing its assets optimally, as assumed above. See footnote 12 for a further explanation of the assumption.

Figure 2: Bond market events when a repo is added to the baseline model



The second constraint (13) implies that v_1 cannot be set higher than β. The underlying assumption behind this constraint is that a dealer cannot commit to such a repurchase price that the dealer has to incur an ex-post loss in period 1 to repurchase the bond. This assumption is consistent with the assumption that the short-term investor cannot provide an unsecured loan to a dealer.

5.3 Dominance of a repo over a spot transaction

The solution to the bargaining problem between dealer A and the short-term investor in period 0, Eqs. (11)-(13), implies that:

Proposition 2. If a repo is available, then the short-term investor buys the bond through a repo from dealer A in period 0 (i.e., $d = 1$) if and only if

$$1 - \mu\alpha_B \geq \beta R. \tag{14}$$

The terms of a repo in this case are

$$v_0 = \frac{\alpha_A(1 - \mu\alpha_B)\beta}{R} + (1 - \alpha_A)\beta^2, \tag{15}$$

$$v_1 = \beta. \tag{16}$$

Dealer A and the short-term investor make no deal in period 0 if the inequality (14) is violated.

Proof. If a spot transaction is chosen ($d = 0$), then the solution to the bargaining problem in Eqs. (11)-(13) is the same as that to the baseline model as shown above. Now derive the solution with a repo ($d = 1$) and compare it with the solution with $d = 0$.

Given the assumption (3), the short-term investor's outside option—that is, investing into the storage technology—has a lower rate of return, R, than the time preference rate of the dealer, $1/\beta$. Thus, they are mutually better off if the investor pays a higher initial ask price v_0 in period 0 in exchange for an increase in the repurchase price v_1 in period 1. As a result, dealer A and the short-term investor maximize the repurchase price v_1, if $d = 1$. Given the constraint (13), the maximization of v_1 implies Eq. (16).

Given $d = 1$ and this value of v_1, the trade surpluses for dealer A and the short-term investor can be non-negative if and only if

$$\frac{\mu p_{B,1} + (1 - \mu)v_1}{R} \geq \beta^2. \tag{17}$$

Otherwise, there is no value of v_0 that generates non-negative trade surpluses for both of them. Substituting Eq. (7) into the inequality (17) yields the inequality (14). If this condition is satisfied, then the solution to the initial ask price of the bond, v_0, is the sum of the left- and the right-hand side of the inequality (17) weighted by α_A and $1-\alpha_A$, respectively. Hence, Eq. (15) holds if $d = 1$.

To compare the trade surpluses between $d = 0$ and $d = 1$, suppose that $v_0 = p_0$ in a repo (i.e., $d = 1$), so that the investor pays the same bond price to the dealer as in a spot transaction (i.e., $d = 0$). Both the dealer and the investor still gain higher trade surpluses in a repo, because $v_1 = \beta > p_{B,1} = (1 - \alpha_B)\beta$ as implied by Eqs. (7) and (16). Thus, they always have a more surplus to split with $d = 1$ than with $d = 0$. $\square$

The inequality (14) is strictly weaker than the inequality (10) given the assumption that the probability of default by dealer A, μ, is less than one. Especially, the inequality (14) is always satisfied if $\mu = 0$, given $\beta R < 1$ as implied by the assumption (3). In contrast, the inequality (10) is violated unless α_B or β is extremely low, as described in the baseline model. Thus, the short-term investor can buy the bond only through a repo in a wide range of parameter values.

The key effect of a repo behind this result is that a repo lets the short-term investor negotiate the repurchase price in advance when buying the bond from dealer A in period 0. Thus, the investor can avoid the hold-up problem when reselling the bond in period 1.

5.4 Fragility of a repo market

The inequality (14) is violated if the probability of default by the dealer, μ, is sufficiently high. In this case, the inequality (10) must be also violated. Thus:

Corollary 1. The short-term investor does not arrange a repo in period 0, if $\mu > (1 - \beta R)/\alpha_B$. In this case, the short-term investor invests all of its cash into the storage technology in the period.

The probability of default matters for the short-term investor because of the hold-up problem for the investor in a spot market. If dealer A defaults, then the short-term investor arranging a repo must resell its bond to dealer B in period 1. In such a case, the investor suffers a low resale bond price,

$p_{B,1}$, because its bargaining position is weakened by the time constraint that it must sell the bond within period 1, as described in the baseline model. Fearing this hold-up problem, or a fire sale, the investor cannot pay a sufficiently high price for dealer A to sell the bond in period 0 if the probability of default by dealer A is too high.

This result is relevant to the U.S. tri-party repo market. In this market, most of underlying securities are government-guaranteed bonds, as described in Section 2. Despite no change in this characteristic of underlying securities, however, the market was about to collapse in the run-up to the failure of Bear Stearns in March 2008. The result of the model indicates that an increase in the risk of default by counterparties in a repo market, such as Bear Stearns, can cause a collapse of a repo market without any risk to the dividends and principals of underlying bonds or asymmetric information.

6 Default risk and a haircut

The short-term investor's fear of the hold-up problem in case of dealer A's default also explains why a haircut is increasing in default risk, as indicated by Table 2.

As described above, the definition of a haircut is $1-v_0/q_0$, where v_0 is the initial ask price of the bond in a repo and q_0 denotes the quoted market value of the bond. The simplest way to see the relationship between a haircut and default risk is to consider some exogenous spot bond price as q_0. Given q_0, a haircut is increasing in the probability of default on a repurchase agreement, μ, because v_0 is decreasing in μ as implied by Eq. (15).

This result can be formally confirmed by calculating an equilibrium spot bond price. Suppose that the investor in the baseline model consumes goods in period 2 rather than period 1. For comparison purpose, keep unchanged the other assumptions in the baseline model. This investor is a long-term investor who can hold the bond until maturity. It can be shown that the spot bond price paid by the long-term investor is

$$q_0 = \frac{\alpha_A}{R^2} + (1-\alpha_A)\beta^2. \tag{18}$$

See Appendix A for the proof. The right-hand side is a weighted average of the indifference values of the bond for the investor ($1/R^2$) and dealer A (β^2) in period 0. Given the assumption (3), q_0 falls between the two indifference values, providing positive trade surpluses for both the dealer and the long-term investor. Thus, the long-term investor can buy the bond from dealer A in a spot transaction in period 0.

Eq. (18) confirms that q_0 is independent of μ. Also, q_0 always greater than v_0 under the assumption (3):

$$q_0 - v_0 \; = \frac{\alpha_A}{R^2} \left[1 - (1 - \mu\alpha_B)\beta R\right]. \tag{19}$$

Thus, a haircut, $1 - v_0/q_0$, is positive and increasing in μ. The intuition for this result is simple. Because of the hold-up problem in a spot market, the short-term investor must resell its bond at a low price if dealer A defaults on its repurchase agreement. Ex-ante, the expected loss from this fire sale lowers the initial ask price of the bond paid by the short-term investor in a repo, v_0. In contrast, this problem does not affect the long-term investor, because the long-term investor can hold the bond until maturity. Thus, an increase in default risk in a repurchase agreement increases a haircut through a decline in v_0.

7 Robustness of a repo to imperfect enforcement

The remaining part of the paper considers alternative assumptions in the model to discuss the robustness of a repo. Hereafter, set the probability of default by dealer A, μ, to zero to simplify the presentation.

7.1 Imperfect enforcement

While a repo combines a spot bond transaction and a future contract for a repurchase agreement, it is also regarded as a secured loan. In a secured loan, the pledgeable future cash repayment by the borrower is constrained by the value of collateral due to some imperfect enforcement. To introduce such a feature into a repo, suppose that dealer A can commit to a repurchase price only up to the spot market value of the bond for the short-term investor in period 1, $p_{B,1}$. Thus, the following constraint on the repurchase price, v_1, is added to the bargaining problem between dealer A and the short-term investor in period 0, Eqs. (11)-(13):

$$v_1 \leq p_{B,1}. \tag{20}$$

With this constraint, a repo does not change the bond price received by the short-term investor in period 1. Hence, the robustness of a repo is tested under the minimal commitment ability of dealer A.

The constraint (20) makes a repo resemble a secured loan, as the market value of collateral for the lender (i.e., the short-term investor) constrains the pledgeable future cash payment by the borrower (i.e., dealer A). This constraint is the same type of borrowing constraint as in the secured-loan literature reviewed by Krishnamurthy (2010).[14]

7.2 Robustness of a repo

A repo is robust to imperfect enforcement:

Proposition 3. Suppose that $\mu = 0$ and that a repo is available with the constraint (20). The short-term investor always buys the bond through a repo from dealer A in period 0 (i.e., $d = 1$) under the assumption (3). The terms of a repo are

$$v_0 = \left[\frac{\alpha_A}{R} + (1-\alpha_A)\beta\right] p_{B,1}, \tag{21}$$

$$v_1 = p_{B,1}. \tag{22}$$

Proof. Guess and verify that $d = 1$. Given the assumption (3), it is optimal to maximize v_1. Thus, the constraint (20) holds with equality. Substituting this equality into the bargaining problem yields Eq. (21). The set of (v_0, v_1) implied by Eqs. (21) and (22) provides positive trade surpluses for both dealer A and the short-term investor, given $\mu = 0$ and $\beta R < 1$ as implied by the assumption (3).

To show that $d = 1$ dominates $d = 0$, suppose $v_0 = p_0$. Given the constraint (20) with equality, this value of v_0 makes the trade surplus for the short-term investor equal between the two values of d. Also, the trade

[14]The constraint (20) can be formally derived as a result of imperfect enforcement. Following Hart and Moore (1994), suppose that dealer A can threat to cancel a repurchase agreement to renegotiate the repurchase price at the beginning of period 1, if the contracted repurchase price is not renegotiation-proof. Assume that dealer A has all bargaining power in a renegotiation. In this case, dealer A can commit only to $p_{B,1}$ as the renegotiation-proof repurchase price. Note that $p_{B,1}$ is the threat point for the short-term investor in a renegotiation, because the outside option for the investor is to sell the bond to dealer B at the spot price $p_{B,1}$ in period 1. A renegotiation does not actually take place on the equilibrium path, if the constraint (20) is satisfied.

surplus for dealer A with $v_0 = p_0$ is greater if $d = 1$ than if $d = 0$, because $p_{B,1} < \beta$ as implied by Eq. (7). Thus, the optimized trade surpluses are higher if $d = 1$ than if $d = 0$. □

The key reason for the robustness of a repo is that the bond will be ultimately returned to dealer A. Because of this feature of a repo, only the ratio between the initial ask price, v_0, and the repurchase price, v_1—that is, the yield—matters for dealer A and the short-term investor. Thus, dealer A can lower v_0 to offer a sufficiently high yield for the short-term investor, even if the dealer cannot commit to a high value of v_1. Given the spot bond price paid by a long-term investor in period 0, q_0, this result implies that a repo can be made robust to imperfect enforcement by raising a haircut, $1 - v_0/q_0$.

8 Effect of more trading opportunities in a spot market

For simplicity, the baseline model allows the short-term investor to deal with a dealer only once in period 1. Thus, the dealer transacting with the short-term investor in that period can enjoy monopoly. Does the hold-up problem for the short-term investor, and hence the need for a repo, disappear if there is more competition among dealers? To investigate this question, extend the baseline model to give the short-term investor more trading opportunities with dealers in period 1 through sequential bargaining.

The need for a repo remains even in this case:

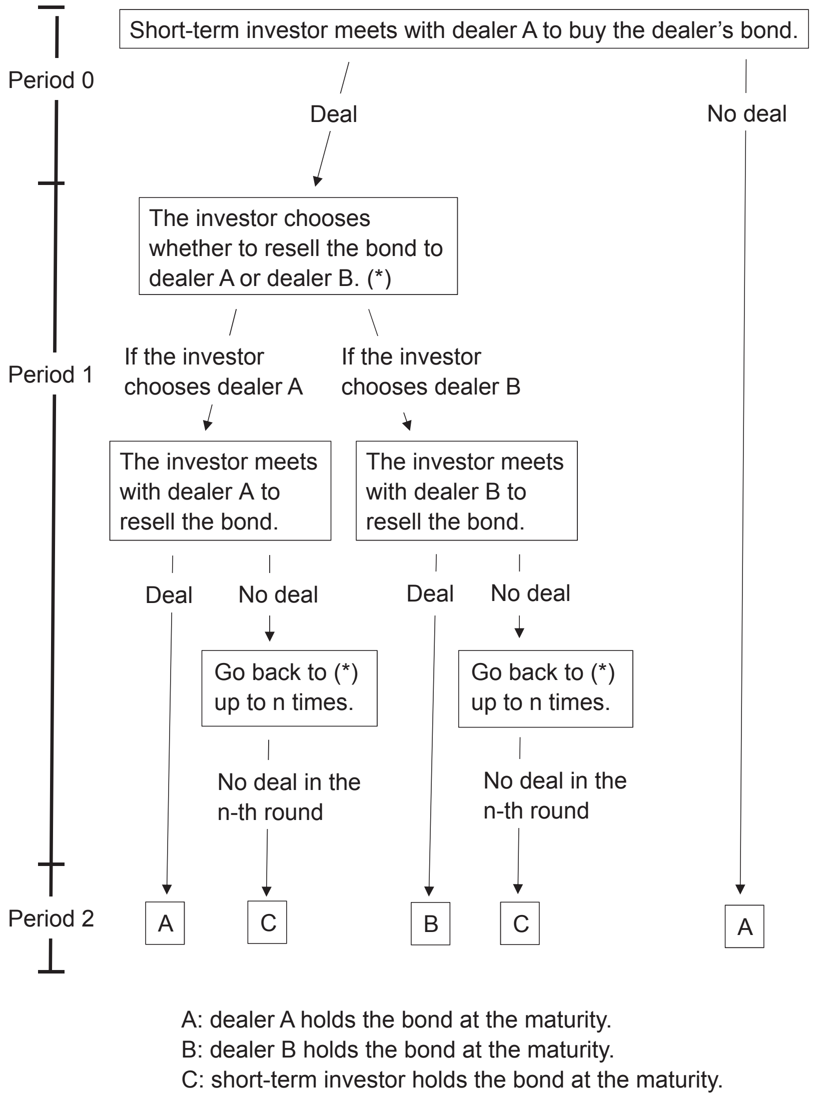
Proposition 4. Suppose that the short-term investor in the baseline model can meet with a dealer up to n rounds in period 1 until the investor sells its bond. In each round, the short-term investor can choose between dealer A and B. See Figure 3 for the event tree.

For all $n \in \mathbf{N}^+$, the short-term investor buys the bond from dealer A in a spot transaction in period 0 if and only if

$$(1 - \alpha_B) \sum_{s=0}^{n-1} \alpha_B^s \geq \beta R. \tag{23}$$

Proof. See Appendix B. □

Figure 3: Bond market events when sequential trades in period 1 are added to the baseline model



Thus, compared to the case with $n = 1$ in the baseline model, more trading opportunities in period 1 allow the short-term investor to buy the bond in a spot transaction in period 0 in a wider range of parameter values. The left-hand side of the inequality (23), however, is less than one for any finite n. Hence, there still remains a parameter range with no bond trade under the assumption (3). This result holds because the short-term investor's payoff from not selling the bond in the n-th round of trades in period 1 is still zero. The effect of this hold-up problem in the last round lowers the threat point for the short-term investor, and hence the spot price of the investor's bond, in earlier rounds.

In contrast, a repo always allows the short-term investor to buy the bond in period 0 under the assumption (3) and $\mu = 0$, as implied by the inequality (14). Thus, the need for a repo remains even if the short-term investor can have an arbitrarily large finite number of trading opportunities in period 1.

9 Conclusions

This paper has presented a simple model featuring a short-term investor and dealers in an OTC bond market. The model illustrates that the short investment horizon of a short-term investor and bilateral bargaining in an OTC market cause a hold-up problem for a short-term investor in a spot bond market. The hold-up problem explains the use of a repo by a short-term investor as well as the fragility of a repo market. This result holds without any risk to the dividends and principals of underlying bonds or asymmetric information.

In this paper, it is taken as given that the bond market is an OTC market. A question remains regarding the optimal market design, such as whether to introduce a centralized bond market. Also, it remains an issue to introduce a repo into a richer model of a bond market. This paper keeps the model as simple as possible to analyze the reason for the use and fragility of a repo. The remaining issues are left for future research.

A Baseline model with a long-term investor

A.1 Modification of the baseline model

Suppose that the investor in the baseline model consumes goods in period 2 rather than period 1. Thus, if the investor buys the bond from dealer A in period 0, then it retains the bond until period 2. If dealer A retains the bond in period 0, then the dealer holds the bond until period 2, as in the baseline model. Call the investor in this model a long-term investor to distinguish it from the short-term investor arranging a repo.

A.2 Proof for Eqs. (18) and (19)

This model with the long-term investor consists only of the bargaining problem between dealer A and the long-term investor in period 0. The bargaining problem is

$$\max_{q_0}(q_0 - \beta^2)^{\alpha_A}(1 - R^2 q_0)^{1-\alpha_A}, \tag{24}$$

where q_0 denotes the spot price of the dealer's bond paid by the long-term investor. The left and the right parentheses are the trade surpluses for the dealer and the long-term investor, respectively. In the right parenthesis, the investor's payoff in case of buying the bond is one, because the investor consumes the return on the bond at the maturity in that case. The opportunity cost for the investor to pay the bond price is $R^2 q_0$, because the investor's outside option in period 0 is to invest cash in the storage technology twice until period 2. In the left parenthesis, β^2 is the opportunity cost for the dealer to sell the bond. The solution to the bargaining problem is Eq. (18). Because $1/R^2 > \beta^2$ as implied by the assumption Eq. (3), the long-term investor and dealer A always trade the bond at q_0 with positive trade surpluses in period 0.

Now compare the spot bond price paid by the long-term investor, q_0, and the initial ask price paid by the short-term investor in a repo, v_0. Eqs. (15) and (18) imply Eq. (19). Given the assumption (3), the haircut, $1 - v_0/q_0$, is always positive. $\square$

B Proof for Proposition 4

Given the assumption that dealer B's bargaining power is less than dealer A's (the inequality 4), the short-term investor chooses to meet with dealer B in each round. The bargaining problem between dealer B and the short-term investor in the i-th round can be specified as

$$\max_{p(i)_{B,1}} (\beta - p(i)_{B,1})^{\alpha_B} (p(i)_{B,1} - p(i+1)_{B,1})^{1-\alpha_B}, \tag{25}$$

for $i = 1, 2, ..., n$ with

$$p(n+1)_{B,1} \equiv 0, \tag{26}$$

where $p(i)_{B,1}$ denotes the spot bond price paid by dealer B in the i-th round. Solving the sequential bargaining backward implies that

$$p(i)_{B,1} = \alpha_B p(i+1)_{B,1} + (1-\alpha_B)\beta = (1-\alpha_B)\beta \sum_{s=0}^{n-i} \alpha_B^s. \tag{27}$$

for $i = 1, 2, ..., n$. If dealer B and the short-term investor agree on a spot transaction, it takes place in the first round. Thus, substitute $p(1)_{B,1}$ into $p_{B,1}$ in the bargaining problem between dealer A and the short-term investor in period 0 (Eq. 8). The bargaining problem implies that there exists such a value of p_0 that generates non-negative trade surpluses for dealer A and the short-term investor in period 0, if and only if the inequality (23) is satisfied. □

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