Journal of Financial Economics 127 (2018) 485–504

Contents lists available at ScienceDirect

Journal of Financial Economics

journal homepage: www.elsevier.com/locate/jfec

Resaleable debt and systemic risk☆

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ARTICLE INFO

Article history:
Received 8 May 2016
Revised 11 August 2016
Accepted 10 October 2016
Available online 20 December 2017

JEL Classification:
G21
G28
G33
K12
K22

Keywords:
Resaleable debt
Systemic risk
Bankruptcy
Repos
Securities law

ABSTRACT

Many debt claims, such as bonds, are resaleable; others, such as repos, are not. There was a fivefold increase in repo borrowing before the 2008–2009 financial crisis. Why? Did banks' dependence on non-resaleable debt precipitate the crisis? In this paper, we develop a model of bank lending with credit frictions. The key feature of the model is that debt claims are heterogenous in their resaleability. We find that decreasing credit market frictions leads to an increase in borrowing via non-resaleable debt. Such borrowing has a dark side: It causes credit chains to form, because, if a bank makes a loan via non-resaleable debt and needs liquidity, it cannot sell the loan but must borrow via a new contract. These credit chains are a source of systemic risk, as one bank's default harms not only its creditors but also its creditors' creditors. Overall, our model suggests that reducing credit market frictions may have an adverse effect on the financial system and even lead to the failures of financial institutions.

1. Introduction

Credit frictions decreased substantially in the decades leading up to the 2008 to 2009 financial crisis.[1] This coincided with the expansion of repo markets, which grew fivefold between 1990 and 2007. Before the crisis, the value of outstanding repos in the US exceeded $5 trillion.[2] The markets appeared to be functioning well, allowing banks to find cheap, short-term liquidity. However, they were harboring systemic risk, because banks were exposed to one another in credit chains: If one bank defaulted, it harmed not only its immediate creditors, but potentially its creditors' creditors as well. This systemic risk manifested itself in the financial crisis, in which shocks to a relatively small set of assets threatened to bring down the entire financial system. Did the buildup of systemic risk relate to the decrease in credit frictions? In general, can a decrease in credit frictions cause an increase in systemic risk?

☆ The support of the Economic and Social Research Council (ESRC) in funding the Systemic Risk Centre is gratefully acknowledged [grant number ES/K002309/1]. Thanks to Gaetano Antinolfi, Bruno Biais, Jen Dlugosz, Armando Gomes, Radha Gopalan, Dalida Kadyrzhanova, Mina Lee, Giorgia Piacentino, Adriano Rampini, Matt Ringgenberg, Edmund Schuster, Ngoc-Khanh Tran, Ed Van Wesep, and Jean-Pierre Zigrand for comments.

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[1] Low credit market frictions in the US before the crisis reflected a number of factors, including advanced information technology for execution and settlement, low transaction costs (Domowitz et al., 2001, Jones, 2002), relatively low information asymmetries (Bai et al., 2016, Greenwood et al., 2013), and a number of potential legal factors, such as privileged bankruptcy treatment of some bank liabilities (Morrison et al., 2014) and required financial disclosure (La Porta et al., 2006).

[2] See Homquist and Gallin (2014).

https://doi.org/10.1016/j.jfineco.2017.12.005
0304-405X/

In this paper, we construct a corporate finance–style model to address this question. We find that the answer is yes. Our main result is that a decrease in credit frictions increases systemic risk. A decrease in credit frictions leads credit chains to become more widespread, and these credit chains harbor systemic risk.

The key novel ingredient in our model is the heterogeneous resaleability of debt claims. For concreteness, consider the salient examples of bonds and repos. Bonds are resaleable and repos are not.[3] As a result, lending via repos leads to credit chains and lending via bonds does not. To see this, suppose you are a lender—you have a loan on the asset side of your balance sheet—and you suddenly need liquidity. Your options for raising this liquidity are different if you hold a bond than if you hold a repo. If you hold a bond, you can sell it in the market. If you hold a repo, you cannot sell it. Hence, you obtain liquidity by borrowing via a new repo. This creates a credit chain, because you are now not only a creditor in the original repo, but a debtor in the new repo as well. In summary, when you hold a non-resaleable instrument such as a repo, the result is a credit chain. This brings with it systemic risk, because defaults can transmit through the chain.

How does a change in credit frictions affect your choice whether to lend with a bond or a repo? In our model, a decrease in credit frictions makes you relatively more likely to lend via a repo. When you are an intermediate link in a credit chain, two contracts must be enforced, one between you and your creditor and another between you and your debtor. Thus, you bear the costs of credit frictions twice, once for each contract. If frictions are high, you have a strong incentive to avoid these double costs. To do this, you lend via resaleable debt such as bonds. In this case, no credit chain is formed and systemic risk is low. If credit frictions are low, you have a weaker incentive to avoid the costs of credit chains. You could prefer to lend via non-resaleable debt such as repos. In reality, you have a strong incentive to use repos instead of bonds, because repos are exempt from the automatic stay in bankruptcy and thus they are effectively super-senior claims. When credit frictions are low, the value of this super-seniority outweighs the cost of the double incidence of credit frictions. As a result, credit chains form and systemic risk is high. This is the essence of our main result: Decreasing credit market frictions can increase systemic risk. Decreasing credit frictions makes it is less likely that banks issue resaleable debt and, hence, more likely that credit chains form.

Model preview. We model the interbank market within a classical corporate finance framework. At the core of the model is one financial institution, Bank A, that needs to raise finance to scale up a project. Bank A borrows from a competitive creditor, Bank B. Bank A can borrow via one of two instruments, a bond or a repo.[4]

The amount that a bank can borrow is limited by the assets it can pledge, via a standard limit to pledgeability. The repayment a bank makes to its creditor cannot exceed a fixed fraction θ of the bank's assets. This fraction θ, which we refer to as the enforceability in the economy, captures credit frictions. An increase in enforceability θ corresponds to a decrease in credit frictions. At an interim date, after Bank B has made the loan to Bank A, it can suffer a liquidity shock, i.e. it suddenly needs cash. If Bank B suffers a liquidity shock, it raises liquidity in the interbank market from a third financial institution, Bank C. Bank B raises this liquidity either by selling Bank A's bond to Bank C or by entering a new repo agreement with Bank C.

Bonds are attractive relative to repos because they are resaleable. However, repos are attractive relative to bonds because they are effectively senior to bonds in bankruptcy. Thus, when Bank A borrows in the interbank market, it trades off the resaleability benefit of bonds against the seniority benefit of repos.

For most of our analysis, we focus on this trade-off in the interbank market, but we consider other applications in Section 4.2. There, we relax the assumption that non-resaleable debt claims (repos) are senior to resaleable debt claims (bonds). We model general debt markets following Kiyotaki and Moore (2005) and show that our main results are broadly applicable. For example, this analysis can cast light on a borrower's choice whether to fund itself via a bank loan (non-resaleable) or long-term bonds (resaleable).

Results preview. Consider the case in which Bank A borrows from Bank B via a bond. When Bank B suffers a liquidity shock, it sells Bank A's bond to Bank C. This sale is depicted in Fig. 1. Bank A now has a debt to Bank C directly. There is no credit chain. There is only one contract to be enforced, the debt from Bank A to Bank C. Credit frictions kick in only once and Bank A's debt capacity is (roughly) proportional to the enforceability θ of this contract.

Now turn to the case in which Bank A borrows from Bank B via a repo. When Bank B suffers a liquidity shock, it must enter into a new contract to find liquidity. Because Bank A's repo debt is not resaleable, Bank B cannot liquidate it in the market. Thus, Bank B borrows from Bank C via a new repo contract. This is depicted in Fig. 2. Bank A has debt to Bank B, and Bank B has debt to Bank C. There is a credit chain. There are two contracts to be enforced. Credit frictions kick in twice, once at each link in the credit chain, and Bank A's debt capacity is (roughly) proportional to the enforceability squared or $\theta \times \theta$. Intuitively, there is one θ for each of the two contracts.

Now consider how an increase in enforceability affects Bank A's choice between bonds and repos. As θ increases, the amount Bank A can borrow with bonds increases linearly and the amount Bank A can borrow with repos increases quadratically. In other words, the sensitivity of

[3] That bonds are resaleable and repos are not is a formal legal property of these claims. Other financial claims, such as derivatives, are also not resaleable; we comment on our model's applicability to derivative markets in Section 1.1.

[4] We use the labels "repo" and "bond" throughout for non-resaleable and resaleable instruments, respectively. For short-term bank funding, the kind of bond we have in mind is commercial paper. We discuss the applicability of our model to short-term bank funding further in Section 1.1 and to more general abstract settings in Section 4.2.

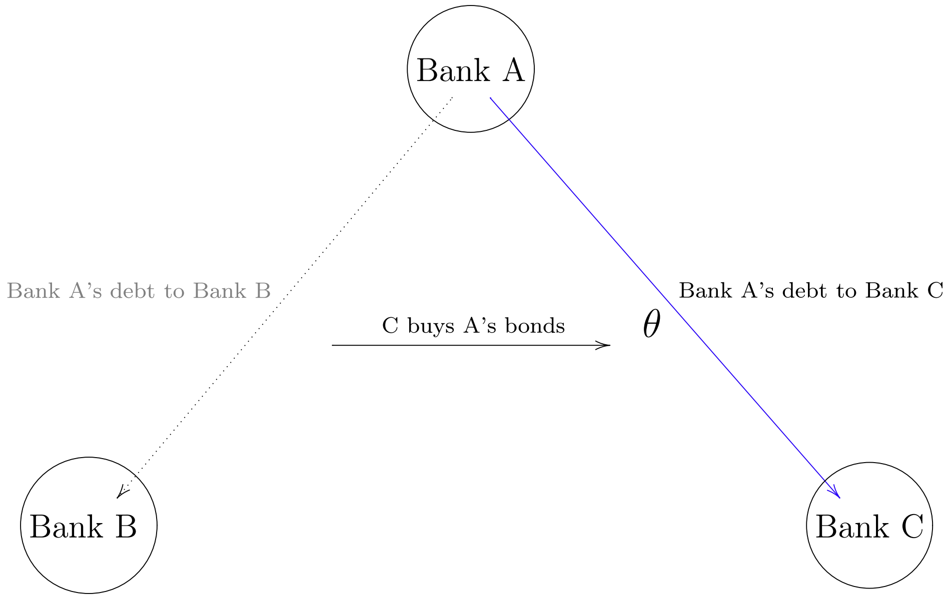

Fig. 1. Bank B's Sale of Bank A's Bonds to Bank C. Because bonds are resaleable, Bank B obtains liquidity by selling Bank A's bonds to Bank C. No credit chain emerges.

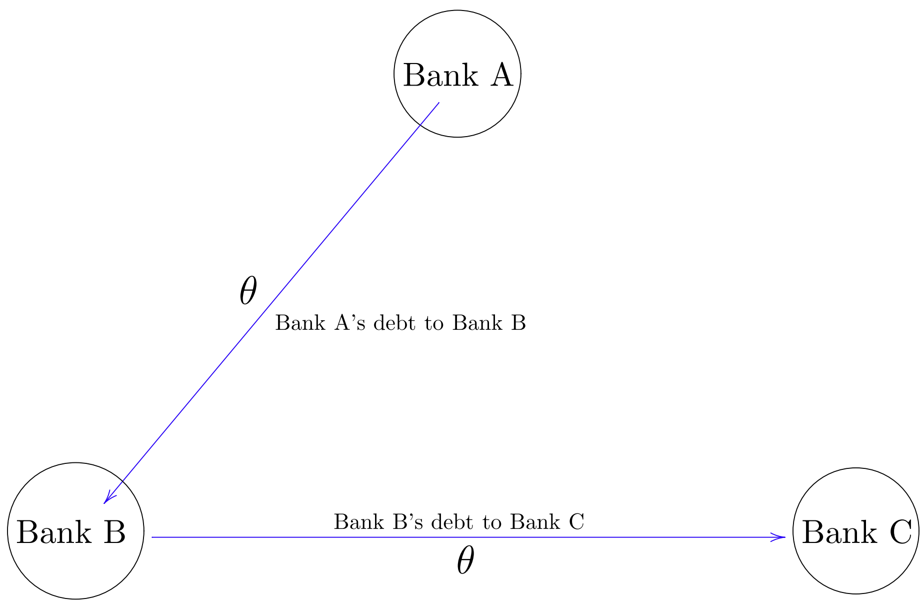

Fig. 2. A credit chain emerges when Bank A borrows from Bank B via repos.

Bank A's debt capacity to enforceability is higher when it borrows via repos than when it borrowers via bonds. Thus, as credit frictions decrease, Bank A switches from bond borrowing to repo borrowing.

What are the implications of increasing enforceability for systemic risk? We have just established that increasing enforceability leads Bank A to borrow via repos and that this, in turn, leads to credit chains. Credit chains harbor systemic risk because if Bank A defaults on its debt to Bank B, Bank B could default on its debt to Bank C. In our model, such default cascades can arise only when enforceability is high, because that is when Bank A funds itself with repos and credit chains emerge. Even though increasing enforceability improves the functioning of each market individually, it could have an adverse effect on the system as a whole, causing an increase in systemic risk.

Further results. In the baseline model, we make the simplifying assumption that Bank A's project itself serves as collateral, even though repos and commercial paper are typically collateralized by financial securities.[5] In an extension, we modify the model so that Bank A pledges securities to fund an illiquid project. We show that our main results are robust to the use of securities as collateral. However, the analysis also raises an important question: Why would Bank A prefer to use the securities as collateral to borrow rather than to sell them in the market, avoiding the effects of credit frictions? We provide a formal explanation based on heterogenous beliefs and find that if Bank A believes the securities are undervalued by the market, it uses them as collateral instead of selling them.[6]

We explore six other extensions of our baseline model. This analysis affirms the robustness of our main findings and provides several new results. First, we show that our model can be applied to many debt markets, not only to the interbank market. Our main results are robust to relaxing the assumption that non-resaleable debt (repos) is senior to resaleable debt (bonds). Second, we consider Bank A's maturity choice in the presence of rollover risk. We find conditions under which Bank A matches the maturity of its liabilities to the maturity of its project, as we assume exogenously in the baseline model. Third, we consider the possibility that credit chains have more than two links. We show that longer chains make repo borrowing relatively less attractive. However, our qualitative findings do not change. Fourth, we ask how systemic risk is affected by a relatively short-term stay on repos, instead of a full exemption from stays. We show that a short-term stay is preferable to an exemption in our setting, but that longer stays for repos are even better. Fifth, we consider how a tax on repo borrowing affects systemic risk. We find that debt capacity is convex in the tax rate, suggesting that a small tax can have a relatively large effect on the volume of repo borrowing. Sixth, we do a reduced-form welfare analysis. If bank default is socially costly, then increasing systemic risk corresponds to decreasing social welfare.

Policy. Our model is stylized but can still cast light on policy debate. Should repos maintain their special treatment in bankruptcy? The exemption from automatic stays for repos makes repos more desirable to Bank A. Thus, the exemption leads Bank A to undertake more repo borrowing and, hence, leads to more credit chains. Because these credit chains are the source of systemic risk in the model, the exemption from the stay exacerbates systemic risk. This finding contrasts with the arguments advanced by proponents of the exemption, who suggest that the safe harbors are "effective in ... limiting [counterparties'] exposure to possibly catastrophic losses from the failure of the debtor. This is the very reason why Congress enacted the safe harbors in the first place" (US House of Representatives, 2014).

Our findings also affirm that regulators must take a macro-prudential approach, as decreasing credit frictions makes every market function better individually but the system as a whole more dangerous.

Layout. The remainder of the paper is organized as follows. There are two remaining subsections in the Introduction, first, a discussion of the realism of our assumptions and the empirical relevance of our results and, second, a review of related literature. Section 2 presents the model. Section 3 contains the formal analysis. In Section 4, we derive further results by extending the model to include the financial securities as collateral, more general instruments, rollover risk, longer chains, short-term stays for repos, taxes on repos, and social costs of bank default. In Section 5, we conclude and consider policy implications. The Appendix contains omitted derivations and proofs.

1.1. Realism and empirical evidence

Our baseline model, while stylized, provides a useful approximation of the interbank market, with reasonable assumptions and predictions. Repos and asset-backed commercial paper (a type of bond) are relatively substitutable instruments for short-term bank funding. They both have relatively short maturities and they are often secured by similar collateral (Krishnamurthy et al., 2014). The bankruptcy advantage of repos is important, as repo volume increased after Congress introduced the safe harbor provision (Garbade, 2006). We emphasize that credit chains are an important feature of the repo market [repo chains are typically associated with the so-called rehypothecation of collateral, see Singh and Aitken (2010) and Singh (2010).[7] Banks assume offsetting long and short repo positions, even though many repos are very short term and it can seem that they should be self-liquidating. This could be because banks manage liquidity over very short time horizons, taking offsetting positions within each day. Another reason for this could be that many repos are of longer maturities, with an estimated 30% of repos having maturity longer than a month (Comotto, 2015). Finally, many repos have open tenors, with no specified maturity. These are typically thought about as overnight contracts, but a lender in an open repo must give its counterparty notice before closing the contract. Sometimes, several weeks' notice is required (Comotto, 2014).

Our baseline model focuses on credit chains in the interbank lending market, but it also can be applied to financial derivatives. In the derivatives market, the analogy to the trade-off between junior, resaleable bonds and senior, non-resaleable repos is the trade-off between standardized, exchange-traded derivatives and specialized, over-the-counter (OTC) derivatives. Exchange-traded derivatives have the advantage of being resaleable. Therefore, they do not lead to the formation of chains of counterparties. In

[5] Our baseline assumption could be realistic if Bank A's project is a financial investment, i.e., if Bank A is buying securities on margin, as discussed in Section 4.1.

[6] There are also institutional reasons that Bank A could prefer to use securities as collateral rather than sell them. For example, it could need to maintain ownership of the securities to meet regulatory liquidity or capital requirements.

[7] Because a repo contract is formally the sale and repurchase of assets, not the pledging (or hypothecating) of collateral, the term "rehypothecation" is not favored by lawyers.

contrast, OTC derivatives have the advantage of being customizable, and they have the potential advantage of providing insurance against specialized risks. Just as decreasing credit frictions makes credit chains relatively less costly in the baseline model, decreasing credit frictions makes risk management chains relatively less costly here. Thus, when credit frictions are low, OTC derivatives are relatively popular and risk management chains are relatively widespread. Decreasing credit frictions can increase systemic risk in derivatives markets just as it can in funding markets.

Further, derivatives markets grew even more dramatically than repo markets in the years before the financial crisis. The notional value of all financial derivatives contracts was estimated at $766 trillion in 2009, a three hundred–fold increase from 30 years earlier (Stulz, 2009). Repos and derivatives often constitute a larger fraction of banks' balance sheets than bonds of all maturities combined. For example, in 2009, over 45% of Barclay's liabilities were listed as "repurchase agreements and stock lending" [199 billion GBP (British pound)] or "derivatives" (403 billion GBP) on its balance sheet.[8]

Our application to the interbank market depends on the assumption that there are frictions in the interbank market. We assume limited enforceability of contracts or, equivalently, limited pledgeability of cash flows. The assumption is standard in the theory literature. For example, Homstrom and Tirole (2011) make the assumption and provide a list of "several reasons why this [limited enforceability] is by and large reality" (p. 3). We think that the realism of the assumption for our application is demonstrated by the importance of collateral in interbank contracts (Bank for International Settlements, 2013). If there were no pledgeablity frictions, banks would not need to post collateral at all. In addition, the years-long bankruptcy proceedings of Lehman Brothers demonstrated that bank creditors can face severe frictions when trying to claim repayment. Further, our model does not rely on the assumption that contractual enforceability is weak, but only on the assumption that it is imperfect, which we believe it is for all contracts in practice.

Finally, reflecting the empirical importance of the problem we study, several papers suggest that the systemic risk that built up in the repo market could have played an important role in the financial crisis of 2008–2009 (Copeland et al., 2014, Gorton and Metrick, 2010, 2012, Krishnamurthy et al., 2014).[9]

1.2. Related literature

Kiyotaki and Moore (2000) analyze how the resaleability of debt claims can mitigate the allocational inefficiencies that stem from limits to enforceability.[10] They demonstrate that a small amount of resaleability (or "multilateral commitment") can substitute for a substantial lack of enforceability (or "bilateral commitment") in a deterministic, infinite-horizon economy. Instead of focusing on allocational efficiency as they do, we study borrowers' endogenous choice of instruments and analyze the implications for systemic risk. Our analysis points to a potential dark side of enforceability that is not present in Kiyotaki and Moore's deterministic setting.

Kiyotaki and Moore (2001b) considers credit chains. Instead of studying, the transferability of debt, that paper shows how chains of bilateral borrowing can emerge and, as such, it constitutes an early contribution to the growing literature on financial networks. Many papers in this literature study systemic risk, including Acemoglu et al. (2015), Allen et al. (2012), Allen and Gale (2000), Blumh et al. (2013), Cabrales et al. (2017), Elliott, Golub et al. (2014), Gale and Kariv (2007), Glode and Opp (2016), Rahi and Zigrand (2013), and Zawadowski (2013). In only a few of these papers, however, is the equilibrium network endogenous. An emerging theory literature takes a detailed approach to modeling credit chains in the repo market specifically, including Kahn and Park (2015), Infante (2015), and Lee (2017).

Numerous other papers study the circulation of private debt, including Gorton and Pennacchi (1990), Gu et al. (2013), Kahn and Roberds (2007), and Townsend and Wallace (2001). These papers typically do not consider debt resaleability as a choice of the borrower and, therefore, they do not study the implications of this choice for systemic risk.

We also hope to contribute to the debate surrounding the bankruptcy seniority of repos and derivatives. Relevant papers in this literature include Antinolfi et al. (2015), Bliss and Kaufman (2006), Duffie and Skeel (2006), Edwards and Morrison (2005), Lubben (2009), Roe (2011), and Skeel and Jackson (2012). Notably, Bolton and Oehmke (2015) bring a corporate finance model to bear on the question of bankruptcy seniority, but they focus on the exemptions for derivatives.

2. Model

In this section, we set up the model, outlining the players and their technologies, the debt instruments by which they can borrow, the specific nature of limited enforcement, and the timing of moves. We also describe several restrictions that we impose on parameters.

2.1. Players and technologies

There is one good called cash and dates: Date 0, Date 1, and Date 2. Cash is the input of production, the output of production, and the consumption good. The main actor in the model is a risk-neutral bank, Bank A. Bank A has an endowment e and a risky constant returns to scale technology. The technology takes two periods to produce, starting at Date 0 and terminating at Date 2. It has random gross

[8] Barclay's annual reports are available online at https://www.home.barclays/barclays-investor-relations/ results-and-reports/annual-reports.html. The Royal Bank of Scotland reports similar numbers (see http://investors.rbs.com/annual-report-subsidiary-results/2010.aspx). The corresponding figures are hard to find for US banks, because they classify their derivatives holdings as risk management instruments and, therefore, are not required to list them on their balance sheets.

[9] These papers differ in their conclusions about the way in which repos contributed to the crisis.

[10] Kiyotaki and Moore develop a framework that they explore further in subsequent work, including Kiyotaki and Moore, 2001a, 2005, and 2012.

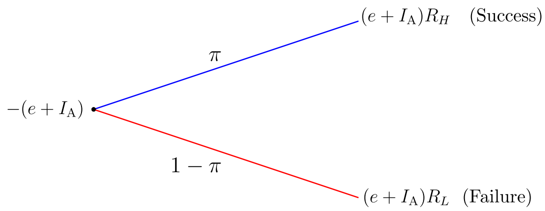

Fig. 3. Depiction of Bank A's technology.

return $\tilde{R}$, which is R_H with probability π and $R_L < R_H$ with probability $1 - \pi$. Fig. 3 depicts the technology. We call the event that $\tilde{R} = R_H$ success and the event that $\tilde{R} = R_L$ failure. Denote the expected return by $\bar{R} := \pi R_H + (1 - \pi)R_L$.[11]

Bank A funds its investment by borrowing capital I from a competitive market of risk-neutral banks. The project is scaleable, so the quantity I is determined in equilibrium. We model the competitive market in reduced form by having Bank A make a take-it-or-leave-it offer to borrow from a second risk-neutral bank, Bank B. Bank B breaks even in expectation, but its preferences are uncertain. With probability $1 - \mu$, Bank B values consumption only at Date 1, and, with probability μ, it values consumption only at Date 2 (all random variables are pairwise independent). With probability $1 - \mu$, Bank B lexicographically prefers Date 1 consumption to Date 2 consumption; with probability μ, Bank B lexicographically prefers Date 2 consumption to Date 1 consumption.[12] We call the event that a bank wishes to consume at Date 1 a liquidity shock. The inclusion of the possibility that a bank is hit by a liquidity shock is a simple way to generate a motive to trade in a secondary market before Bank A's debt matures. When hit by a liquidity shock, Bank B wishes either to resell Bank A's debt or to borrow against Bank A's debt to satisfy its liquidity needs at Date 1. Instead of viewing Date 1 as a fixed point in time that the banks know in advance, we interpret it as a random time at which Bank B needs liquidity. Thus, since the arrival time of Bank B's liquidity shock is uncertain at Date 0, Bank A cannot borrow with a contract that matures exactly when Bank B suffers the liquidity shock.

For simplicity, we assume that Bank B has deep pockets at Date 0. That is, Bank B has sufficient cash to fund Bank A at Date 0, so that Bank A does not need to find a second creditor. If Bank B is hit by a liquidity shock, it uses all this cash to generate liquidity at Date 1.

A competitive interbank market is open at Date 1, in which banks buy and sell bonds in the secondary market as well as borrow and lend among themselves. We model this by allowing Bank B to obtain funds from a third risk-neutral bank, Bank C. Bank B can either sell Bank A's debt or borrow against it. Again, competition is captured by assuming that Bank B makes Bank C a take-it-or-leave it offer, whether to sell bonds or to borrow against repos.

Fig. 4 depicts the timing for the case in which Bank B suffers a liquidity shock (cf. Section 2.4).

2.2. Borrowing instruments

The crux of the model is the trade-off between borrowing via a bilateral contract called a repo and borrowing via a resaleable instrument called a bond. In the model, two features distinguish repos from bonds. First, bonds are resaleable. A bank that buys a bond can sell it to another bank in the Date 1 market. The issuer of the bond repays its bearer at maturity, regardless of whether this bearer was the original owner at Date 0. Repos, in contrast, are not resaleable. A repo must be settled by the writer and its counterparty. Second, repos are not stayed in bankruptcy.[13] The counterparty to a repo recoups its debt immediately, even if its counterparty defaults. The counterparty to a bond must wait to liquidate until it is awarded the assets in the bankruptcy proceedings.[14] To capture the costs of waiting to liquidate, we normalize bondholders' liquidation value to zero in the event of default.[15] We assume that the realization of $\tilde{R}$ is not verifiable, so state-contingent contracts are impossible.[16] Thus, as in reality, both bonds and repos are debt contracts, i.e., promises to repay a state-independent face value in the future in exchange for cash today. We summarize the dimensions along which repos and bonds differ in Fig. 5.

A main question we ask is under what conditions Bank A funds its Date 0 investment via repos as opposed to bonds. When Bank A determines its funding instrument, it faces a trade-off in borrowing costs. Repos decrease borrowing costs because creditors have higher recovery values in the event of default. Bonds reduce borrowing costs because they can come with a liquidity premium. This liquidity premium is a result of the fact that lenders can sell

[11] We think about π as rather large so that failure is an extreme event. In the repo market, failure should be interpreted as the joint event in which Bank A's project fails and the value of its pledged collateral is not sufficient to cover its loan. We do not model this collateral explicitly here, but we discuss it in the extension in Section 4.1.

[12] The lexicographic preferences are just a modeling device that induces Bank B to have well-defined preference for more to less at Date 2 even if it is hit by a liquidity shock at Date 1. This is important only in the details of micro-founding enforcement constraints (see Section 2.3).

[13] As mentioned in the Introduction, this specific assumption of seniority is not essential for our main results, as we discuss in Section 4.2.

[14] The special treatment of repos is a feature of the US Bankruptcy Code. It is a legal advantage of repos, which are formally not debt contracts but sales and repurchases of securities. In the event of a debtor's bankruptcy, normal creditors are subject to the rules imposed by the court, whereas repo creditors are not. Morrison et al. (2014) provide a detailed legal discussion of this special bankruptcy treatment for repo creditors. They describe the advantages that repo creditors have when a debtor goes bankrupt, pointing out that they can "exercise nearly all out-of-bankruptcy contractual rights.... Other creditors cannot exercise these contractual rights to terminate their contracts with the bankrupt debtor; safe harbored creditors can. They are effectively exempt from bankruptcy" (p. 7). See also the legal opinions available from the Securities Industry and Financial Markets Association at http://www.sifma.org/services/standard-forms-and-documentation/legal-opinions/.

[15] We make this assumption following Bolton and Oehmke (2015), because it provides an easy way to model bankruptcy costs. In our model, it also implies that the value of the bond in the event of default is independent of enforcement frictions. In Section 4.2, we relax this assumption to ensure that it is not driving our results.

[16] We make this assumption only to add realism to our application to the interbank market. Our main mechanism does not depend on it. In particular, in the generalization in Section 4.2, the analysis does not depend on the fact that Bank A's cash flows are not verifiable.

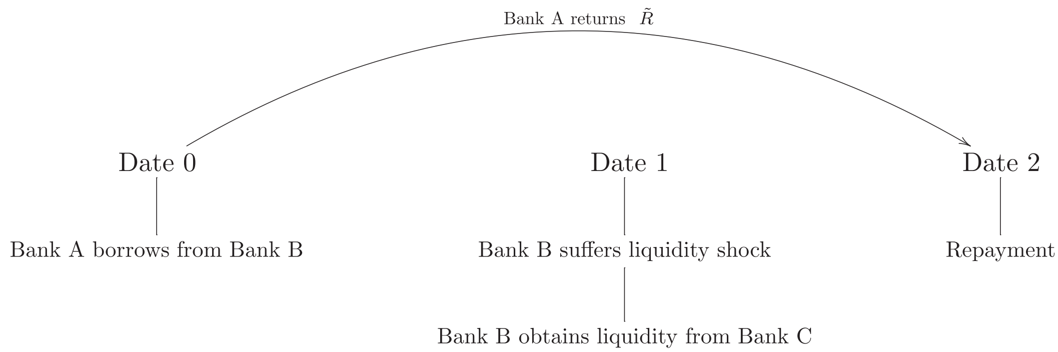

Fig. 4. Timeline when Bank B suffers a liquidity shock.

	Super-senior	Less senior
Resaleable		E.g. bonds, stock
Not resaleable	E.g. repos, derivatives	

Fig. 5. This figure depicts the two dimensions of legal asymmetry we focus on, transferability and bankruptcy treatment. Bonds and stock are resaleable, but they are junior in bankruptcy to non-resaleable instruments such as repos and derivatives.

them at Date 1 to meet their liquidity needs when they suffer liquidity shocks. That is to say, borrowers trade off bonds' resaleability against repos' super-seniority.

2.3. Limited enforcement

The key friction in the economy is limited enforcement. We assume that creditors cannot extract all of a project's surplus when they collect on their debts. An exogenous number $\theta \in (0, 1)$ gives an upper bound on the proportion of assets that a creditor can extract from its debtor, heuristically

$$\text{repayment} \;\leq\; \theta \times \text{assets}. \tag{1}$$

This proportion θ is the same for all debts in the economy. We refer to θ as the enforceability in the economy. θ represents creditors' power to extract repayment from debtors. Developments that we would expect to increase θ include efficient liquidation procedures, strong creditor rights, standardized contracts, technological development for improved record-keeping, and increased accounting transparency.

The formal micro-foundation we provide for the constraint above (inequality (1)) comes from borrowers' incentives to divert assets and abscond. θ is the *pledgeable proportion* of assets. We assume that this fraction θ is not divertable. In other words, a borrower with assets A has the option to divert $(1-\theta)A$ and then default. Thus, a borrower will repay debt with face value F only if the residual value net of repayment exceeds its gain from diverting, or

$$A - F \geq (1-\theta)A. \tag{2}$$

This inequality can be rewritten as

$$F \leq \theta A, \tag{3}$$

which is simply inequality (1) restated symbolically. With this formalism, an increase in enforceability is an increase in the collateralizability or securitizability of assets, which makes it harder for borrowers to divert.

2.4. Timing

We now specify the timing of the extensive game we use to model the economy. Because bonds are resaleable but repos are not, we outline the timing for these two cases separately. We describe first what can happen when Bank A issues bonds at Date 0 and then what can happen when Bank A borrows via repos at Date 0. The repo case is slightly more complicated because credit chains can emerge.

The first move is Bank A's choice of financing instrument. At Date 0, Bank A chooses either bonds or repos. We write the subsequent moves separately for the cases in which Bank A chooses bonds and in which Bank A chooses repos.

Several of the following moves involve one bank making a take-it-or-leave-it offer to another bank. Should the second bank reject the offer, it forgoes the relationship. This captures the idea that the credit market is competitive.

If Bank A issues bonds, the game proceeds as follows: At Date 0, Bank A offers Bank B face value F_A to borrow I_A, and then Bank B accepts or rejects. At Date 1, Bank B is hit by a liquidity shock or not. If Bank B is hit by a liquidity shock, then Bank B offers Bank C a resale price to sell its claim to F_A from Bank A, and Bank C accepts or rejects. At Date 2, the return $\tilde{R}$ on Bank A's project realizes. Bank A either repays F to the bondholder or diverts and defaults. If the debtor defaults the bondholder's payoff is normalized to zero, reflecting the costs of bankruptcy stays.

If Bank A borrows via repos, the game proceeds as follows. At Date 0, Bank A offers Bank B face value F_A to borrow I_A Bank B accepts or rejects. At Date 1, Bank B is hit by a liquidity shock or not. If Bank B is hit by a liquidity shock, then Bank B offers Bank C F_B to borrow I_B from Bank C, and then Bank C accepts or rejects. At Date 2, the return $\tilde{R}$ on Bank A's project realizes. Bank A either repays F_A to Bank B or diverts and defaults. If Bank B has borrowed from Bank C, then Bank B either repays F_B to Bank C or diverts and defaults.

2.5. Assumptions

We make three restrictions on parameters. The first assumption is that Bank A's project is a good investment, even if all revenues are lost due to bankruptcy costs when $\tilde{R} = R_L$. Thus there is no question as to whether the project should go ahead.

Assumption 1.

$$1 < \pi R_H. \tag{4}$$

The second assumption is that the expected project return $\bar{R}$ is not so high that Bank A can lever up infinitely. Limits to enforcement are severe enough (θ is low enough) that Bank A's credit is rationed according to the amount of its own capital that it invests in its project.[17]

Assumption 2.

$$\theta\bar{R} < 1. \tag{5}$$

The third assumption is that the return R_L that realizes in the event of failure is relatively low. The assumption suffices to ensure that Bank A will default in equilibrium whenever its project fails ($\tilde{R} = R_L$).

Assumption 3.

$$R_L < \frac{(\pi R_H - 1)R_H}{R_H - 1}. \tag{6}$$

2.6. Equilibrium concept

The equilibrium concept is subgame perfect equilibrium. We solve the model by backward induction.

3. Results

In this section we solve the model. We first analyze the case in which Bank A borrows via bonds and then the case in which Bank A borrows via repos. We compare Bank A's payoffs from borrowing via each instrument and solve for the equilibrium borrowing instrument. Finally, we study the implications for systemic risk. We show our main result that increasing enforceability increases systemic risk.

3.1. Borrowing via bonds

We now solve for the equilibrium of the subgame in which Bank A issues bonds. We calculate its loan size I_A^b and its Date 0 present value (PV) Π_A^b, where the superscript b indicates that the quantities correspond to the subgame in which Bank A has borrowed via bonds.

To find the amount I_A^b that Bank B is willing to lend to Bank A against a promise to repay F_A^b, we solve the game backward. We begin with the case in which Bank B is not hit by a liquidity shock. It recovers the expected value of Bank A's debt. If there is no default, then Bank B recovers F_A^b; if there is default, it recovers zero. Bank A defaults exactly when it prefers to repay, not to divert capital, or when $\theta(e + I_A^b)R < F_A^b$ for $R \in \{R_L, R_H\}$. It repays zero when it defaults due to the stay in bankruptcy and it repays F_A otherwise.

$$\begin{aligned}\text{expected bond repayment} \\ &= \begin{cases} F_A & \text{if } \theta(e + I_A^b)R_L \geq F_A^b, \\ \pi F_A & \text{if } \theta(e + I_A^b)R_L < F_A^b \leq \theta(e + I_A^b)R_H, \\ 0 & \text{otherwise} \end{cases} \\ &= \pi \mathbf{1}_{\{\theta(e+I_A^b)R_H \geq F_A^b\}} F_A^b + (1 - \pi)\mathbf{1}_{\{\theta(e+I_A^b)R_L \geq F_A^b\}} F_A^b. \end{aligned} \tag{7}$$

When Bank B is hit by a liquidity shock, it sells Bank A's bonds to Bank C in a competitive market. Bank C demands its break-even value, which is the expected value of Bank A's debt. This coincides with Eq. (7) for Bank A's , i.e.,

$$\begin{aligned}\text{bond resale price } &= \pi \mathbf{1}_{\{\theta(e+I_A^b)R_H \geq F_A^b\}} F_A^b \\ &+ (1 - \pi)\mathbf{1}_{\{\theta(e+I_A^b)R_L \geq F_A^b\}} F_A^b.\end{aligned} \tag{8}$$

Thus, when Bank A issues bonds, Bank B's payoff is independent of whether Bank B itself is hit by a liquidity shock. Bank B's condition for accepting Bank A's bond offer, i.e., the contract (F_A, I_A), reduces to the participation constraint that Bank B must make a positive net present value (NPV) investment. This (ex ante) participation constraint takes into account the (ex post) limits to enforcement captured by θ. Hence, we can rewrite the first round of the game in which Bank A determines how much to borrow and invest as a constrained optimization program. Bank A maximizes its profits subject to its borrowing constraints. Lemma 1 states this problem.

Lemma 1. F_A^b and I_A^b are determined to maximize

$$\Pi_A^b = \mathbb{E}\Big[\max\Big\{(e + I)\tilde{R} - F, (1 - \theta)(e + I)\tilde{R}\Big\}\Big] \tag{9}$$

over F and I subject to

$$\pi \mathbf{1}_{\{\theta(e+I)R_H \geq F\}} F + (1 - \pi)\mathbf{1}_{\{\theta(e+I)R_L \geq F\}} F \geq I. \tag{10}$$

The program has a convex objective with a piecewise linear constraint, so it has a corner solution. There are three possible solutions: (1) Bank A does not borrow at all, (2) Bank A borrows as much as it can while ensuring it will never default, i.e., ensuring it can repay F even when $\tilde{R} = R_L$, or (3) Bank A borrows as much as it can, accepting that it will default when it fails but that it will still be able to repay when it succeeds, i.e., ensuring it can repay F when $\tilde{R} = R_H$. Lemma 2 states that, given the assumptions in Section 2.5, this third possibility obtains in equilibrium, i.e., Bank A will always lever up so much that it will default when its project fails.

Lemma 2.

$$F_A^b = \theta\Big(e + I_A^b\Big)R_H. \tag{11}$$

Proof. See Appendix Section A.1 □

[17] The alternative assumption that Bank A's project has decreasing returns to scale would also prevent the project from becoming infinitely big. We choose the decreasing returns to scale because it is a tractable way to capture the economic mechanism we wish to study.

Date 0

Assets	Liabilities
Debt from Bank A	All equity

$\longrightarrow$

Date 1

Assets	Liabilities
Cash	All equity

Fig. 6. Bank B's balance sheet composition when it sells Bank A's bonds. When Bank B sells Bank A's bonds to Bank C, it does not assume a new liability.

Because competition is perfect in the Date 1 market, Bank B sells Bank A's bonds at fair value if it suffers a liquidity shock at Date 1. As a result, Bank B's Date 1 payoff is unaffected by the liquidity shock and Bank B's Date 0 break-even condition reads

$$\begin{aligned} I_{\rm A}^{\rm b} &= \pi F_{\rm A}^{\rm b} \\ &= \pi\theta\left(e + I_{\rm A}^{\rm b}\right)R_H, \end{aligned} \tag{12}$$

having taken into account that the recovery value for Bank B is zero due to the stay in bankruptcy. This says that

$$I_{\rm A}^{\rm b} = \frac{\pi\theta e R_H}{1-\pi\theta R_H}. \tag{13}$$

Before Bank B is hit by a liquidity shock, Bank B has Bank A's debt on the assets side of its balance sheet. In response to the liquidity shock, Bank B sells Bank A's bonds, replacing this asset with cash on its balance sheet. This is depicted in Fig. 6. Bank B only ever has equity on the right-hand side of its balance sheet. When Bank B funds Bank A via bonds, its balance sheet does not expand.

Now we can calculate Bank A's expected equity value when it issues bonds. With probability π, it succeeds and repays $F_{\rm A}^{\rm b} = \theta\left(e + I_{\rm A}^{\rm b}\right)R_H$. With probability $1-\pi$, it fails and diverts capital $(1-\theta)(e+I_{\rm A}^{\rm b})$. Thus,

$$\begin{aligned} \Pi_{\rm A}^{\rm b} &= \pi\left((e+I_{\rm A}^{\rm b})R_H - F_{\rm A}^{\rm b}\right) + (1-\pi)(1-\theta)\left(e+I_{\rm A}^{\rm b}\right)R_L \\ &= \pi(1-\theta)\left(e+I_{\rm A}^{\rm b}\right)R_H + (1-\pi)(1-\theta)\left(e+I_{\rm A}^{\rm b}\right)R_L \\ &= (1-\theta)\left(e+I_{\rm A}^{\rm b}\right)\bar{R} \\ &= \frac{(1-\theta)e\bar{R}}{1-\pi\theta R_H}. \end{aligned} \tag{14}$$

3.2. Borrowing via repos

We now solve for the equilibrium of the subgame in which Bank A issues repos. We calculate its loan size $I_{\rm A}^{\rm r}$ and its Date 0 PV $\Pi_{\rm A}^{\rm r}$, where the superscript r indicates that the quantities correspond to the subgame in which Bank A has borrowed via repos.

Again, we solve the game backward to determine the amount $I_{\rm A}^{\rm r}$ that Bank B is willing to lend to Bank A against the promise to repay $F_{\rm A}^{\rm r}$. When Bank B is not hit by a liquidity shock, it holds Bank A's repos to maturity and recovers the expected value of Bank A's debt. If there is no default, Bank B receives $F_{\rm A}^{\rm r}$; if there is default, it recovers $\theta(e+I_{\rm A}^{\rm r})R$ for $R \in \{R_L, R_H\}$. As before, Bank A defaults exactly when it prefers to repay than to divert capital, or when $\theta(e+I_A^{\rm r})R < F_{\rm A}^{\rm b}$. In contrast to the case of bonds, when Bank A defaults, its repo creditors are not subject to the bankruptcy stay and, hence, they recover the fraction of assets that Bank A does not divert.

$$\begin{aligned} &\text{expected repo repayment} \\ &= \pi\left[\mathbf{1}_{\{\theta(e+I_{\rm A}^{\rm r})R_H \ge F_{\rm A}^{\rm r}\}} F_{\rm A}^{\rm r} + \mathbf{1}_{\{\theta(e+I_{\rm A}^{\rm r})R_H < F_{\rm A}^{\rm r}\}}\,\theta(e+I_{\rm A}^{\rm r})R_H\right] \\ &\quad + (1-\pi)\left[\mathbf{1}_{\{\theta(e+I_{\rm A}^{\rm r})R_L \ge F_{\rm A}^{\rm r}\}} F_{\rm A}^{\rm r} + \mathbf{1}_{\{\theta(e+I_{\rm A}^{\rm r})R_L < F_{\rm A}^{\rm r}\}}\,\theta(e+I_{\rm A}^{\rm r})R_L\right] \\ &= \pi \min\left\{\theta(e+I_{\rm A}^{\rm r})R_H, F_{\rm A}^{\rm r}\right\} + (1-\pi)\min\left\{\theta(e+I_{\rm A}^{\rm r})R_L, F_{\rm A}^{\rm r}\right\} \\ &= \mathbb{E}\left[\min\left\{\theta(e+I_{\rm A}^{\rm r})\tilde{R}, F_{\rm A}^{\rm r}\right\}\right]. \end{aligned} \tag{15}$$

When Bank B is hit by a liquidity shock, it must find liquidity in the interbank market at Date 1. In contrast to the case of bond-borrowing considered in Section 3.1, Bank A's debt to Bank B is not resaleable. Instead of liquidating Bank A's bond in the interbank market as before, now Bank B must borrow from Bank C to obtain liquidity. It does so by borrowing $I_{\rm b}$ in exchange for the promise to repay $F_{\rm b}$. But, Bank C must anticipate the enforcement frictions it faces with Bank B: Bank B will divert if its promised repayments to Bank C are too high. Bank B diverts if it profits more from diverting its repayment from Bank A than it profits from making its promised repayment $F_{\rm b}$ to Bank C. This gives the condition that Bank B diverts whenever

$$\theta \min\left\{\theta(e+I_{\rm A}^{\rm r})\tilde{R}, F_{\rm A}^{\rm r}\right\} < F_{\rm B}. \tag{16}$$

If Bank B does divert and default on its debt to Bank C, then Bank C seizes Bank B's assets and recovers $\theta\min\{\theta(e+I_{\rm A}^{\rm r})\tilde{R}, F_{\rm A}^{\rm r}\}$. Because the interbank market is competitive (Bank B makes Bank C a take-it-or-leave-it offer), Bank B always borrows an amount $I_{\rm B}$ equal to its expected repayment (given the face value $F_{\rm B}$), so

$$\begin{aligned} I_{\rm B} &= \text{expected repayment from Bank B to Bank C} \\ &= \mathbb{E}\left[\min\left\{\theta\min\left\{\theta(e+I_{\rm A}^{\rm r})\tilde{R}, F_{\rm A}^{\rm r}\right\}, F_{\rm B}\right\}\right]. \end{aligned} \tag{17}$$

Further, because Bank B has been hit by a liquidity shock, it values Date 1 consumption infinitely more than Date 2 consumption. Thus, it sets $F_{\rm B}$ to maximize $I_{\rm B}$ in Eq. (17). Because the expectation is weakly increasing in $F_{\rm B}$, it is without loss of generality to set $F_{\rm B} = \infty$. Thus,

$$I_{\rm B} = \theta\,\mathbb{E}\left[\min\left\{\theta(e+I_{\rm A}^{\rm r})\tilde{R}, F_{\rm A}^{\rm r}\right\}\right]. \tag{18}$$

Before Bank B is hit by a liquidity shock, it has Bank A's debt on the assets side of its balance sheet. In response to the liquidity shock, Bank B borrows from Bank C, adding cash as an asset on its balance sheet. This is depicted in Fig. 7. In contrast with the bond case depicted in Fig. 6, Bank B now has debt on both sides of its balance sheet. It has debt from Bank A on the assets side and debt to Bank

Date 0

Assets	Liabilities
Debt from Bank A	All equity

$\longrightarrow$

Date 1

Assets	liabilities
Cash	Debt to Bank C
Debt from Bank A	Equity

Fig. 7. Bank B's balance sheet expands when it holds Bank A's repos. If Bank A borrows via repos and Bank B needs liquidity at the interim date, then Bank B borrows from Bank C. Bank B's balance sheet thus expands, as it holds debt on both sides of its balance sheet.

C on the liabilities side. In other words, Bank B is a link in a credit chain. When Bank B lends via repos, its balance sheet blows up when it needs liquidity.

We now calculate Bank B's expected payoff given that it holds Bank A's repo with face value F_{A}. To do so, we take the expectation of the value of the repo to Bank B across the case in which it is not hit by a liquidity shock and holds Bank A's repo until maturity and the case in which it is hit by a liquidity shock and borrows from Bank C:

$$\begin{aligned}\text{value of Bank A's repo}\\ &= \mu\mathbb{E}\Big[\min\Big\{\theta(e+I_{\mathrm{A}}^{\mathrm{r}})\tilde{R}, F_{\mathrm{A}}^{\mathrm{r}}\Big\}\Big]\\ &\quad+(1-\mu)\theta\mathbb{E}\Big[\min\Big\{\theta(e+I_{\mathrm{A}}^{\mathrm{r}})\tilde{R}, F_{\mathrm{A}}^{\mathrm{r}}\Big\}\Big]\\ &= \big(\mu+(1-\mu)\theta\big)\mathbb{E}\Big[\min\Big\{\theta(e+I_{\mathrm{A}}^{\mathrm{r}})\tilde{R}, F_{\mathrm{A}}^{\mathrm{r}}\Big\}\Big]. \end{aligned} \tag{19}$$

Bank A determines its repo contract $(F_{\mathrm{A}}^{\mathrm{r}}, I_{\mathrm{A}}^{\mathrm{r}})$ to maximize its present value $\Pi_{\mathrm{A}}^{\mathrm{r}}$. It does so by making Bank B a take-it-or-leave-it offer such that the value of the contract expressed in Eq. (19) just induces Bank B to accept the offer. Thus, we can rewrite Bank A's choice of contract as a constrained maximization problem in which the objective is Bank A's PV and the constraint is that Bank B must (weakly) prefer the repo promise $F_{\mathrm{A}}^{\mathrm{r}}$ to its cash $I_{\mathrm{A}}^{\mathrm{r}}$. We can now rewrite Bank A's choice of repo contract as an optimization program.

Lemma 3. $F_{\mathrm{A}}^{\mathrm{r}}$ and $I_{\mathrm{A}}^{\mathrm{r}}$ are determined to maximize

$$\Pi_{\mathrm{A}}^{\mathrm{r}} = \mathbb{E}\Big[\max\Big\{(e+I)\tilde{R}-F,\,(1-\theta)(e+I)\tilde{R}\Big\}\Big] \tag{20}$$

over F and I subject to

$$\big(\mu+(1-\mu)\theta\big)\mathbb{E}\Big[\min\Big\{\theta(e+I)\tilde{R}, F\Big\}\Big] \geq I. \tag{21}$$

As in the program in Lemma 1 above for the bond borrowing case, there is a corner solution. Lemma 4 now states that in equilibrium either Bank A does not borrow at all or it exhausts its debt capacity completely, promising the maximum repayment.

Lemma 4. In equilibrium, Bank A either does not borrow, $F_{\mathrm{A}}^{\mathrm{r}} = I_{\mathrm{A}}^{\mathrm{r}} = 0$, or sets $F_{\mathrm{A}}^{\mathrm{r}}$ large enough to induce the maximum repayment,[18]

$$F_{\mathrm{A}}^{\mathrm{r}} = \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H. \tag{22}$$

Proof. See Appendix Section A.2. □

If Bank A borrows (i.e. if $I_{\mathrm{A}}^{\mathrm{r}} \neq 0$), then we can plug $F_{\mathrm{A}}^{\mathrm{r}} = \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$ from Lemma 4 into the binding constraint in Lemma 3 to recover the following equation for $I_{\mathrm{A}}^{\mathrm{r}}$:

$$I_{\mathrm{A}}^{\mathrm{r}} = \theta\big(\mu+(1-\mu)\theta\big)\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)\bar{R}. \tag{23}$$

The enforceability parameter θ appears in Eq. (23) twice, because enforceability kicks in twice, once at each link in the credit chain. Bank B has to enforce its contract with Bank A, and Bank C has to enforce its contract with Bank B. We can solve this equation for $I_{\mathrm{A}}^{\mathrm{r}}$ to recover

$$I_{\mathrm{A}}^{\mathrm{r}} = \frac{\theta\big(\mu+(1-\mu)\theta\big)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}}, \tag{24}$$

which allows us to write down an expression for the PV of Bank A when it funds itself with repos. When $\tilde{R} = R_H$, Bank A repays its debt $F_{\mathrm{A}}^{\mathrm{r}} = \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$; when $\tilde{R} = R_L$, Bank A diverts a proportion $1-\theta$ of its assets. Thus, if Bank A borrows

$$\begin{aligned}\Pi_{\mathrm{A}}^{\mathrm{r}} &= \pi\Big((e+I_{\mathrm{A}}^{\mathrm{r}})R_H - F_{\mathrm{A}}^{\mathrm{r}}\Big) + (1-\pi)(1-\theta)\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_L\\ &= \pi\Big((e+I_{\mathrm{A}}^{\mathrm{r}})R_H - \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H\Big)\\ &\quad+(1-\pi)(1-\theta)\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_L\\ &= (1-\theta)\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)\bar{R}\\ &= \frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}}. \end{aligned} \tag{25}$$

Bank A could prefer not to borrow and to invest just its inside equity e into its project, in which case $\Pi_{\mathrm{A}}^{\mathrm{r}} = e\bar{R}$. Thus, the value of borrowing via repos is the greater of the value of not borrowing and borrowing with face value $F_{\mathrm{A}}^{\mathrm{r}} = \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$, or

$$\Pi_{\mathrm{A}}^{\mathrm{r}} = \max\left\{e\bar{R},\ \frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}}\right\}. \tag{26}$$

3.3. Equilibrium borrowing instrument

Our main theoretical result is that increasing enforceability θ leads Bank A to favor repos and thereby leads to credit chains. Bank C lends to Bank B, which lends to Bank A.

To determine when Bank A borrows via bonds and when it borrows via repos, we compare its PV its in the

[18] Whenever $F_{\mathrm{A}}^{\mathrm{r}} > \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$, the repayment does not depend on $F_{\mathrm{A}}^{\mathrm{r}}$, i.e., $\min\big\{\theta(e+I_{\mathrm{A}}^{\mathrm{r}})R, F_{\mathrm{A}}^{\mathrm{r}}\big\} = \theta(e+I_{\mathrm{A}}^{\mathrm{r}})R$. Hence, any face value $F_{\mathrm{A}}^{\mathrm{r}} > \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$ is equivalent to $F_{\mathrm{A}}^{\mathrm{r}} = \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$ in the sense that it induces the same transfers for each realization of $\tilde{R}$. If $I_{\mathrm{A}}^{\mathrm{r}} \neq 0$, we focus on $F_{\mathrm{A}}^{\mathrm{r}} = \theta\big(e+I_{\mathrm{A}}^{\mathrm{r}}\big)R_H$ without loss of generality.

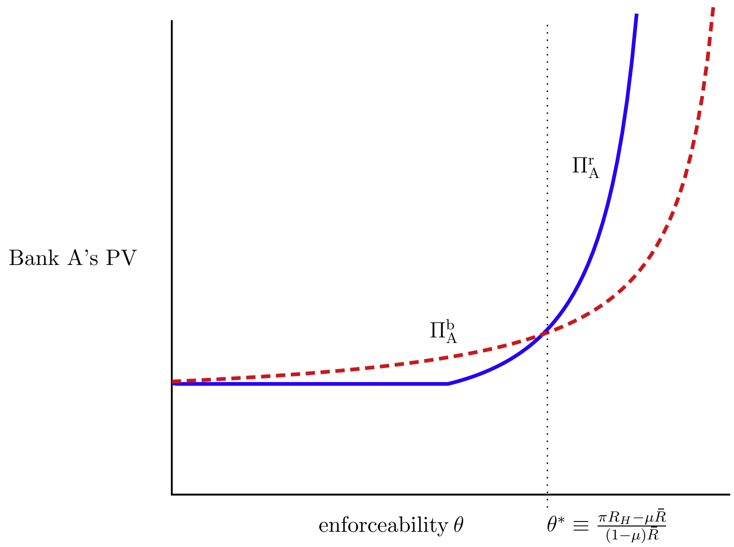

Fig. 8. Bank A's PV from Issuing bonds and repos as a function of enforceability. When enforceability is low ($\theta \le \theta^*$) Bank A's PV is higher from issuing bonds; when enforceability is high ($\theta > \theta^*$) Bank A's PV is higher from issuing repos. The parameters used to make the plot are $e = 1, \bar{R} = 1.4, \pi R_H = 1.2$, and $\mu = 1/2$.

bond-borrowing case, Π_A^b in Eq. (14) with its PV in the repo-borrowing case, Π_A^r in Eq. (25). This comparison is illustrated in Fig. 8. Bank A borrows via bonds whenever $\Pi_A^b \ge \Pi_A^r$ or

$$\frac{(1-\theta)e\bar{R}}{1-\pi\theta R_H} \ge \frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}}, \tag{27}$$

which can be written as

$$\pi R_H \ge \big(\mu + (1-\mu)\theta\big)\bar{R}. \tag{28}$$

With Eq. (28), we derived that increased enforceability leads Bank A to prefer repos.

Proposition 1. Bank A borrows via bonds only if

$$\theta \le \theta^* := \frac{\pi R_H - \mu\bar{R}}{(1-\mu)\bar{R}} \tag{29}$$

and borrows via repos otherwise.

This result is the key result behind our main finding that increasing enforceability can increase systemic risk, as more enforceability leads banks to rely more on non-resaleable instruments—on repos—and borrowing via non-resaleable instruments leads to credit chains.

3.4. Implications for systemic risk

We now analyze the effect of increasing enforceability on risk in the financial system as a whole, considering when risk on the balance sheet of a single institution can spread beyond that institution's immediate creditors, in particular, when one bank's default causes the default of other banks. This is our notion of systemic risk, a default cascade.

Definition 1. A default cascade is an event in which a bank fails as a consequence of another bank's failure. In the model, this occurs whenever Bank B fails (which occurs only because its debtor, Bank A, has failed).

Bank B can fail only when it has debt to default on. Bank B has debt only when it borrows from Bank C to satisfy its liquidity needs. This occurs only when Bank A borrows via repos. In this case, because repos are not resaleable, Bank B cannot find liquidity by selling Bank A's debt in the market. As a result, Bank B borrows from Bank C creating a credit chain. Hence, Bank A's default can lead to Bank B's default; i.e., default cascades can occur only when Bank A borrows via repos. The next result is that default cascades only happen when enforceability is high. This follows as a corollary of Proposition 1.

Corollary 1. Default cascades occur only when enforceability is high, specifically when

$$\theta > \theta^* \equiv \frac{\pi R_H - \mu\bar{R}}{(1-\mu)\bar{R}}. \tag{30}$$

Increasing enforceability increases systemic risk in the sense that increasing enforceability can cause default cascades. With repo borrowing, a credit chain emerges in which Bank A borrows from Bank B and Bank B borrows from Bank C. When its project fails, Bank A defaults on its debt to Bank B. This depletes the left-hand side of Bank B's balance sheet, so Bank B cannot cover its debt to Bank C and Bank B also defaults.

4. Generalizations, extensions, and robustness

In this section, we extend the analysis in seven ways.

First, we explicitly incorporate securities as collateral into our model. Second, we consider a more general version of our model and argue that our results can hold in many debt markets, not only the interbank market. Third, we consider the possibility that Bank A borrows via one-period debt and rolls over at Date 1. Fourth, we allow for credit chains with more than two links. Fifth, we consider the effects of a short-term stay for repos, instead of an all-out exemption. Sixth, we consider the effects of a tax on repo borrowing. Seventh, we consider implications for social welfare, not just systemic risk. Our results are robust to all these extensions.

4.1. Role of collateral

Repos and asset-backed commercial paper are collateralized by financial securities. In our model, we assume that Bank A's project serves as collateral for its debt. In this subsection, we argue that our main results are robust to the use of securities as collateral. We do this in two ways. First, we argue that Bank A's project can be interpreted as an investment in financial securities, in which Bank A borrows from Bank B to buy the securities on margin. With this interpretation, our model captures the use of securities as collateral as is. Second, we modify the model so that Bank A pledges liquid securities to fund an illiquid project and show that our results are robust. We also discuss both economic and institutional reasons that Bank A could prefer to raise capital by using its securities as collateral rather than selling them in the market.

Investment as buying on margin. So far, we have viewed Bank A's project as an investment in a real technology. However, given that it has constant returns to scale, we can also view it as a financial investment in securities. With this interpretation, Bank A wishes to invest in securities because it believes they are undervalued, i.e., Bank A has the view that the securities will generate high returns and is willing to pay interest to Bank B to borrow and invest in them. Bank A borrows I from Bank B and invests $e+I$ in the securities, pledging the securities as collateral to Bank B. This corresponds to Bank A buying the securities on margin from Bank B, and Bank A's endowment e serves as the haircut. Given this interpretation, our model already captures the use of securities as collateral in interbank markets.

Collateralizing other securities. Consider the following twist on the baseline model, which gives a role for securities to be used as collateral. In addition to its endowment and its project, Bank A holds securities that have Date 2 payoff $\tilde{s} \in \{s_L, s_H\}$, where $s_L < s_H$. Denote the probability that $\tilde{s} = s_H$ by $p := \mathbb{P}\{\tilde{s} = s_H\}$ and the expected value of the securities by $\bar{s} := ps_H + (1-p)s_L$. Here, we assume that only securities are pledgeable. Enforceability is zero for the cash flows that Bank A gets from its project and θ for securities.[19] Thus, Bank A must use its securities as collateral to borrow and invest in its project. We assume that s_L is low enough that Bank A prefers to lever up and default if $\tilde{s} = s_L$ (this is the analogy of Assumption 3, which states that R_L is low). This assumption may seem not to apply to safe collateral such as government bonds. However, the results in this section hold even if the probability $1-p$ that the securities decline in value is very small, and realistically even safe securities can lose value quickly with some probability. Finally, we assume that, as in the baseline model, bond creditors recover nothing in bankruptcy and that repo creditors still recover the proportion θ of the collateral, where here the collateral constitutes the securities $\tilde{s}$.

Consider the case in which Bank A borrows via bonds. Given that the securities $\tilde{s}$ are serving as collateral, these bonds can represent asset-backed commercial paper or short-term covered bonds. We can write Bank A's borrowing constraint analogously to Eq. (12): Due to the bankruptcy costs associated with bonds, the amount that Bank B is willing to lend to Bank A is limited by a proportion θ of its repayment in the event that $\tilde{s} = s_H$,

$$I^{\text{b,coll.}} \le p\theta s_H. \tag{31}$$

This constraint binds at the optimum and Bank A's PV is[20]

$$\begin{aligned}\Pi_{\text{A}}^{\text{b,coll.}} &= \left(e + I^{\text{b,coll.}}\right)\bar{R} + (1-\theta)\bar{s} \\ &= (e + p\theta s_H)\bar{R} + (1-\theta)\bar{s}.\end{aligned} \tag{32}$$

In the case in which Bank A borrows via repos, we can write Banks A's borrowing constraint analogously to Eq. (23): Because repos are not resaleable, the amount that Bank B is willing to lend takes into account the fact that Bank B could have to borrow against Bank A's repo in the event that Bank B suffers a liquidity shock,

$$\begin{aligned}I_{\text{A}}^{\text{r,coll.}} &\le \mu\theta\bar{s} + (1-\mu)\theta^2\bar{s} \\ &= \theta\big(\mu + (1-\mu)\theta\big)\bar{s}.\end{aligned} \tag{33}$$

This constraint binds at the optimum and Bank A's PV is

$$\begin{aligned}\Pi_{\text{A}}^{\text{r,coll.}} &= \left(e + I^{\text{r,coll.}}\right)\bar{R} + (1-\theta)\bar{s} \\ &= \Big(e + \theta\big(\mu + (1-\mu)\theta\big)\bar{s}\Big)\bar{R} + (1-\theta)\bar{s}.\end{aligned} \tag{34}$$

Comparing this expression with $\Pi_{\text{A}}^{\text{b,coll.}}$ gives Proposition 2, which confirms that the main results of the model are robust to the case in which securities must be used as collateral.

Proposition 2. Bank A borrows via bonds only if enforceability θ is below a threshold, i.e., if $\theta \le \theta^s$, where

$$\theta^s = \frac{ps_H - \mu\bar{s}}{(1-\mu)\bar{s}}. \tag{35}$$

Thus, credit chains emerge and default cascades can occur for only high levels of enforceability.

Proof. See Appendix Section A.3. □

Reasons to use securities as collateral rather than sell them. We assume that Bank A uses it securities $\tilde{s}$ as collateral to raise capital, abstracting from the possibility that Bank A could sell its securities in the market at Date 0

[19] The idea that assets are pledgeable but cash flows are not is common in the literature. See, for example, Hart and Moore (1998) or the Tirole (2006) textbook, which says that "collateral pledging makes up for a lack of pledgeable cash.... [B]orrowers must borrow against assets" (p. 169).

[20] Because the project's cash flows are not pledgeable, the amount that Bank A repays is independent of the realization of its return $\tilde{R}$.

and invest the proceeds in its project, thereby avoiding the frictions in the credit market. This restriction can be justified if institutional arrangements prevent Bank A from liquidating its securities even when it is efficient. For example, it can hold securities on behalf of clients that it is not free to sell but is still allowed to use as collateral. Alternatively, it could need to hold the securities for regulatory reasons, for example to meet liquidity or capital requirements. However, Bank A may also prefer to hold its securities to maturity rather than to liquidate them because it places a higher value on the securities than it can obtain in the market.

Suppose that Bank A believes that its securities are more valuable than Bank B and Bank C believe they are. Also, suppose that Bank A believes that the probability that $\tilde{s} = s_H$ is $p + \Delta_p$, and Bank B and Bank C believe this probability is p. Formally, $\Delta_p > 0$ captures Bank A's relative optimism, but it could also stand in for other benefits that Bank A receives from holding the securities $\tilde{s}$. For example, if the securities are shares, then Bank A could have private benefits of control from holding them. Alternatively, the securities could be useful for risk management, hedging against risks that Bank A holds elsewhere in its portfolio.

We now solve for a sufficient condition for Bank A to prefer to use its securities as collateral rather than to sell them in the market. If Bank A sells its securities to invest in its project, it raises their fair value $\bar{s} \equiv ps_H + (1-p)s_L$ in capital, so its PV is

$$\Pi_{\text{A}}^{\text{sell coll.}} = (e + \bar{s})\bar{R}. \tag{36}$$

We now compare this to Bank A's PV if it issues bonds under its own beliefs. Modifying Eq. (32) to account for Bank A's optimistic beliefs gives

$$\begin{aligned}\Pi_{\text{A}}^{\text{b,optimistic}} &= \left(e + I^{\text{b,coll.}}\right)\bar{R} + (1-\theta)\big((p+\Delta_p)s_H \\ &\quad + (1-p-\Delta_p)s_L\big) \\ &= \left(e + I^{\text{b,coll.}}\right)\bar{R} + (1-\theta)\big(\bar{s} + (s_H - s_L)\Delta_p\big).\end{aligned} \tag{37}$$

If this expression is greater than the payoff $\Pi_{\text{A}}^{\text{sell coll.}}$ from selling securities, then Bank A always prefers to use its securities as collateral rather than liquidate in the market.[21] Proposition 3 gives a condition under which Bank A will always use its securities as collateral instead of selling them in the market.

Proposition 3. Bank A uses collateral as long as its optimism Δ_p is above a threshold, i.e., if $\Delta_p \geq \Delta_p^*$, where

$$\Delta_p^* := \frac{(\bar{s} - \theta p s_H)\bar{R} - (1-\theta)\bar{s}}{(1-\theta)(s_H - s_L)}. \tag{38}$$

Proof. See Appendix Section A.4. □

4.2. More general instruments

So far, we focus on the trade-off between borrowing via bonds (commercial paper) and repos in the interbank market. In this subsection, we argue that our main result—that increasing enforceability leads to credit chains and, therefore, increases systemic risk—generalizes to other markets. The basic mechanism can be at work in nearly all debt markets, even absent the formal, legal differences in resaleability and bankruptcy seniority that exist between repos and bonds. The reason is as follows. In addition to legal non-resaleability, fundamental economic frictions such as adverse selection can inhibit the resaleability of debt.[22] A debt issuer can mitigate these frictions at a cost, for example, by using securitization to combat the lemons problem, and thereby make debt resaleable or liquid in secondary markets. When enforceability increases, however, the relative benefits of resaleability decrease and, as a result, issuers are not willing to pay the cost to issue resaleable debt. Thus, for high enforceability, creditors, unable to sell their assets, could enter into new debt contracts to meet liquidity needs. This is the creation of a credit chain, which harbors systemic risk, just as in our baseline analysis. We formalize this argument below. The analysis in this subsection does not depend on the assumption that bankruptcy is costly or the assumption that the outcome R of Bank A's project is non-contractable. We make these assumptions above only for realism of the application to interbank loan markets.

Here we abstract from legal asymmetries. We follow Kiyotaki and Moore (2005) and assume that adverse selection frictions inhibit the resale of debt in the secondary market, but that an issuer can pay an upfront cost to mitigate these frictions.[23] Specifically, we modify the model above in the following way. When Bank A borrows from Bank B, it can pay a proportional cost c to securitize its project. That is, if Bank A securitizes its project, its returns are decreased by the proportion c to $(1-c)R$, $R \in \{R_L, R_H\}$. Securitization circumvents the adverse selection friction, making Bank A's debt resaleable. There are no bankruptcy costs. We now analyze when Bank A chooses to securitize its project, forfeiting some returns but making its debt liquid/resaleable.

Consider first the case in which Bank A does not securitize its project. Its PV is simply the repo PV expression in Eq. (26):

$$\Pi_{\text{A}}^{\text{no sec.}} = \max\left\{e\bar{R}, \frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu + (1-\mu)\theta\big)\bar{R}}\right\}. \tag{39}$$

Now turn to the case in which Bank A securitizes its project. Securitization lowers the returns on its project but eliminates the cost associated with the liquidity shock. This observation allows us to write Bank A's PV in this no-securitization case immediately. We simply scale down the returns by a factor $1-c$ and replace the probability $1-\mu$

[21] Whereas this condition implies that Bank A prefers to borrow via bonds than to sell its securities, it is not a sufficient condition for it to borrow via bonds. It could still prefer to borrow via repos.

[22] See Kiyotaki and Moore (2002) for a list of reasons that "between the date of issue and the date of delivery, an initial creditor C may not be able to resell [the debtor] D's paper on to a third party ... insofar as D gets locked in with C ex post" (p. 62).

[23] See page 703 of Kiyotaki and Moore (2005) for a discussion of this adverse selection–based micro-foundation. Kiyotaki and Moore (2000, 2001a, 2012) make similar assumptions.

of a liquidity shock with zero:

$$\Pi_A^{\text{sec.}} = \max\left\{e(1-c)\bar{R}, \frac{(1-\theta)e(1-c)\bar{R}}{1-\theta(1-c)\bar{R}}\right\}. \tag{40}$$

Now, Bank A securitizes only when $\Pi_A^{\text{sec.}} \geq \Pi_A^{\text{no sec.}}$. This inequality leads to the main result of this subsection, that Bank A securitizes only below a threshold level of enforceability θ^{**}. Thus, credit chains emerge only for high levels of enforceability and, therefore, increasing enforceability increases systemic risk as in Section 3.4. We summarize this in Proposition 4.

Proposition 4. Bank A securitizes its debt only if enforceability θ is below a threshold, i.e., if $\theta \leq \theta^{**}$, where

$$\theta^{**} := \frac{1}{2}\left(-1 + \sqrt{1 + \frac{4c}{(1-\mu)(1-c)\bar{R}}}\right). \tag{41}$$

Thus, credit chains emerge and default cascades can occur for only high levels of enforceability.

Proof. See Appendix Section A.5. □

This result demonstrates that our finding that increasing enforceability can increase systemic risk is not specific to the interbank market. Instead, the interbank market is just an environment in which systemic risk arising from credit chains is especially important and in which formal legal asymmetries make the trade-offs between resaleable debt such as commercial paper and non-resaleable debt such as repos especially stark.

4.3. Rollover and the timing of the liquidity shock

In the baseline model, we assume that Bank A can borrow only via a two-period debt. Thus, when Bank B suffers a liquidity shock at Date 1, there is still one period before Bank A's debt matures and Bank B must raise liquidity from Bank C. If Bank A could borrow via one-period debt, would it do away with the frictions in our model? That is, would Bank A borrow via one-period debt from Bank B from Date 0 to Date 1 and from a new creditor, Bank B′, from Date 1 to Date 2, eliminating the need for Bank B to resell Bank A's debt at Date 1? In this subsection, we briefly analyze two extensions to argue that such an arrangement could be infeasible. First, we explain how Date 1 should represent the random arrival time of Bank B's liquidity shock, not a fixed time. With this interpretation, Bank A cannot write debt maturing at Date 1, because it does not know when Date 1 will arrive. Second, we extend the model to include rollover risk for Bank A. Bank A could fail to find credit from Bank B′ at Date 1 and be forced to liquidate its project.

Random arrival of liquidity shock. Suppose that time is continuous in the interval between Date 0 and Date 2 and Bank B's liquidity shock arrives at a Poisson rate $(1-\mu)/2$. Thus, the probability that Bank B suffers a liquidity shock at some time $\tau \in [0, 2]$ is $1-\mu$. In other words, Bank B suffers a liquidity shock with the same probability as in the baseline model, and the time τ corresponds to Date 1 in the baseline model. Because τ is random, Bank A cannot borrow from Bank B via a debt contract with maturity τ. Thus, Bank A cannot employ a rollover strategy, whereby it borrows short-term twice, first from Bank B and then from Bank B′.

In practice, many repo contracts are short term. This may reflect banks' attempting to allow their creditors to close contracts easily if they need liquidity at an unexpected date. However, in practice it seems like overnight is the shortest possible debt maturity and, as a result, banks use offsetting repos to manage liquidity intraday. Further, many repos have much longer maturities. This likely reflects the fact that rolling debt over is risky.

Rollover risk. Suppose that Bank A may face rollover risk at Date 1. At Date 0, Bank A can borrow from Bank B via a one-period repo. In this case, Bank A must borrow from Bank B′ at Date 1, to fulfill its obligation to Bank B. With probability ρ, Bank A borrows from Bank B′ successfully and rolls over its repo position. But with probability $1-\rho$, Bank A is not able to borrow from Bank B′ in time to pay its debt to Bank B, so it must liquidate its project to pay Bank B. We assume that the Date 1 liquidation value of Bank A's project is a fraction θ of its expected payoff, i.e., exactly the pledgeable fraction θ of the project is recoverable in liquidation. This assumption simplifies the analysis, because it implies that if Bank A fails to roll over its debt, Bank B is still repaid in full, but Bank A is left with no assets. As a result, if Bank A borrows via one-period repos, it captures the entire NPV of its project with probability ρ (with one-period repos, it borrows at the fair price because it avoids the cost of both credit chains and of bankruptcy), but with probability $1-\rho$, it receives payoff zero (it fails to roll over its debt and liquidates). Thus, the PV of borrowing via one-period repos is ρ times what the PV of the project would be if it were funded with two-period repos, but the probability of a liquidity shock were zero ($\mu = 1$). From the expression for Π_A^r in Eq. (26), we have the PV of Bank A's project from borrowing via one-period repos with rollover risk:

$$\Pi_A^{\text{rollover}} = \rho \Pi_A^r|_{\mu=1} = \rho \max\left\{e\bar{R}, \frac{(1-\theta)e\bar{R}}{1-\theta\bar{R}}\right\}. \tag{42}$$

Comparing this expression with the Π_A^r gives Proposition 5.

Proposition 5. As long as rollover risk is not too small, Bank A prefers to borrow via two-period repos than one-period repos. That is, as long as ρ is below a threshold ρ^*, Bank A never borrows via one-period repos, where ρ^* is given by

$$\rho^* := \frac{1-\theta\bar{R}}{1-\theta^2\bar{R}}. \tag{43}$$

This proposition says that the analysis of our baseline model is valid even if Bank A has the option of borrowing via one-period repos, as long as one-period repos come with some rollover risk.

Proof. See Appendix Section A.6. □

4.4. Longer chains

So far, we focus on credit chains with only two links: between Bank A and Bank B and between Bank B and Bank C. In this subsection, we extend the model to include longer credit chains. We consider the possibility that liquidity shocks hit not only Bank A's immediate creditor, but also its creditor's creditor, its creditor's creditor's creditor, and so on. Thus, credit chains can become arbitrarily long.

We extend the model to include a sequence of competitive creditors. We refer to the nth creditor in the sequence as Bank B_n, so Bank B_1 is Bank A's immediate creditor and, generally, Bank B_{n+1} is Bank B_n's creditor. With this notation in the baseline model, Bank B would be called Bank B_1 and Bank C would be called Bank B_2. Each Bank B_n suffers a liquidity shock with probability $1-\mu$, in which case it borrows from Bank B_{n+1}. For simplicity, we assume that all liquidity shocks occur between Date 1 and Date 2, but that Bank B_n borrows from Bank B_{n+1} before Bank B_{n+1} suffers a liquidity shock. We consider the possibility of borrowing either via repos or via bonds. The problem is stationary—Bank B_n's problem of borrowing from Bank B_{n+1} coincides with B_{n+1}'s problem of borrowing from B_{n+2}—we restrict attention to the cases in which all banks borrow via bonds and all banks borrow via repos.

Consider first the case in which banks borrow via bonds. Because the bond is perfectly resaleable, the credit chain does not affect its value. Thus, Bank A's PV is simply the bond PV expression in Eq. (14):

$$\Pi_{\mathrm{A}}^{\mathrm{b},\infty} = \frac{(1-\theta)e\bar{R}}{1-\pi\theta R_H}. \tag{44}$$

In the case in which banks borrow via repos, if Bank B_n needs liquidity, it cannot sell Bank B_{n-1}'s debt but must borrow from Bank B_{n+1}, extending the credit chain. Each bank extends the chain if and only if it suffers a liquidity shock, which occurs with probability μ. Thus, the length of the credit chain is geometrically distributed with mean $1/\mu$, i.e., the chain has length one with probability μ, length two with probability $(1-\mu)\mu$, length three with probability $(1-\mu)^2\mu$, and length n with probability $(1-\mu)^{(n-1)}\mu$.

Repos are senior in bankruptcy and thus, given the analysis in Section 3.2, Bank A repays Bank B a fraction θ of the value of its asset value in every state. Likewise, Bank B_n repays Bank B_{n+1} a fraction θ of its own value, which is a fraction θ^n of Bank A's asset value. This observation allows us to write down the analogy of Eq. (19) for the value of Bank A's repo.

Assuming that Bank A borrows and denoting the amount Bank A borrows from Bank B_1 by $I_{\mathrm{A}}^{\mathrm{r},\infty}$, we have

$$\begin{aligned}
&\text{value of A's repo}\\
&= \Big(\mu + (1-\mu)\mu\theta + (1-\mu)^2\mu\theta^2 + \cdots\Big)\theta\Big(e + I_{\mathrm{A}}^{\mathrm{r},\infty}\Big)\bar{R}\\
&= \mu\theta\Big(e + I_{\mathrm{A}}^{\mathrm{r},\infty}\Big)\bar{R}\sum_{n=0}^{\infty}\Big((1-\mu)\theta\Big)^n\\
&= \frac{\mu\theta\Big(e + I_{\mathrm{A}}^{\mathrm{r},\infty}\Big)\bar{R}}{1-(1-\mu)\theta}.
\end{aligned} \tag{45}$$

To find the PV of Bank A's project when it borrows via repos, we proceed by analogy with the baseline model (Section 3.2). Bank B_1's indifference condition implies that the amount of capital it provides equals the repo value of Bank A's repo above, or

$$I_{\mathrm{A}}^{\mathrm{r},\infty} = \frac{\mu\theta\Big(e + I_{\mathrm{A}}^{\mathrm{r},\infty}\Big)\bar{R}}{1-(1-\mu)\theta}, \tag{46}$$

which implies

$$I_{\mathrm{A}}^{\mathrm{r},\infty} = \frac{\mu\theta\bar{R}e}{1-(1-\mu)\theta-\mu\theta\bar{R}}, \tag{47}$$

if Bank A borrows and $I_{\mathrm{A}}^{\mathrm{r},\infty} = 0$ otherwise. This allows us to express the PV of Bank A's project as

$$\begin{aligned}
\Pi_{\mathrm{A}}^{\mathrm{r},\infty} &= \max\Big\{e\bar{R},\ (1-\theta)\Big(e + I_{\mathrm{A}}^{\mathrm{r},\infty}\Big)\bar{R}\Big\}\\
&= \max\left\{e\bar{R},\ \frac{(1-\theta)\Big(1-(1-\mu)\theta\Big)e\bar{R}}{1-\Big(1-\mu(1+\bar{R})\Big)\theta}\right\}.
\end{aligned} \tag{48}$$

For the equilibrium borrowing instrument. Bank A borrows via bonds as long as $\Pi_{\mathrm{A}}^{\mathrm{r},\infty} \geq \Pi_{\mathrm{A}}^{\mathrm{b},\infty}$. This inequality leads to the main result of this subsection, that Bank A borrows via bonds only above a threshold level of enforceability θ^∞.

Proposition 6. Bank A borrows via bonds only if enforceability θ is below a threshold, i.e., Bank A borrows via bonds if $\theta \leq \theta^\infty$, where

$$\theta^\infty := \frac{\pi R_H - \mu\bar{R}}{\pi(1-\mu)R_H} \tag{49}$$

and borrows via repos otherwise. Thus, credit chains emerge and default cascades can occur for only high levels of enforceability.

Proof. See Appendix Section A.7. □

This result confirms our main finding of the baseline model; that is, credit chains emerge only for high levels of enforceability and, therefore, increasing enforceability increases systemic risk as in Section 3.4. It also leads to an additional result. Comparison of the threshold θ^∞ above and the threshold θ^* in the baseline model reveals that the possibility of longer credit chains make repo borrowing relatively less attractive.

Corollary 2. In the extension with longer credit chains, the threshold above which Bank A borrows via repos is higher than the threshold in the baseline model,

$$\theta^\infty > \theta^*, \tag{50}$$

as defined in Proposition 1 and Proposition 6.

Proof. See Appendix Section A.8. □

The intuition behind this result is that if Bank A borrows via repos, then credit frictions θ kick in at each link in the chain. If chains become arbitrarily long, this amplifies credit frictions, making bond borrowing relatively more attractive.

4.5. Short-term stay for repos

Currently, repos and derivatives are exempt from bankruptcy stays, and bonds and bank loans are subject to a stay of indefinite length, determined by the bankruptcy court. We consider the effects of a fixed-term stay for repos. We suppose that, in the default state, repo creditors receive a proportion λ of the value of the debtor's pledgeable assets.[24] λ represents the inverse length of the stay. $\lambda = 1$ represents the case in which repos are exempt from the stay, and $\lambda = 0$ represents the stay of indefinite length, as in the case of bonds. We show that increasing the length of the stay for repos, increases the likelihood that credit chains form.

To find the PV of Bank A's project if it borrows via repos with a short-term stay, we proceed by analogy with the analysis of repo borrowing in Section 3.2. The amount I^{λ} that Bank A can borrow via repos with the inverse length of stay λ is given by the analog of Eq. (23). We simply replace R_L with λR_L, as a creditor's recovery value is reduced by λ in the default state

$$\begin{aligned} I_{\mathrm{A}}^{\lambda} &= \theta\big(\mu + (1-\mu)\theta\big)\big(e + I_{\mathrm{A}}^{\mathrm{r}}\big)\big(\pi R_H + (1-\pi)\lambda R_L\big) \\ &= \theta\big(\mu + (1-\mu)\theta\big)\big(e + I_{\mathrm{A}}^{\mathrm{r}}\big)R^{\lambda}, \end{aligned} \tag{51}$$

where $R^{\lambda} := \pi R_H + (1-\pi)\lambda R_L$. Thus we have that

$$I_{\mathrm{A}}^{\lambda} = \frac{\theta\big(\mu + (1-\mu)\theta\big)eR^{\lambda}}{1 - \theta\big(\mu + (1-\mu)\theta\big)R^{\lambda}}. \tag{52}$$

Now we compute the PV of Bank A's project. As in the baseline analysis, Bank A retains a fraction $1-\theta$ of the asset value, so

$$\begin{aligned} \Pi_{\mathrm{A}}^{\lambda} &= \pi(1-\theta)(e + I_{\mathrm{A}}^{\lambda})R_H + (1-\pi)(1-\theta)(e + I_{\mathrm{A}}^{\lambda})R_L \\ &= \frac{(1-\theta)e\bar{R}}{1 - \theta\big(\mu + (1-\mu)\theta\big)R^{\lambda}}. \end{aligned} \tag{53}$$

Comparison of this expression with the expression for the PV of Bank A's project if it borrows via bonds (Eq. (14) gives the threshold θ^{λ} above which Bank A borrows via repos. Thus, we have the analog of Proposition 1 given a stay of inverse length λ.

Proposition 7. Bank A borrows via bonds only if enforceability θ is below a threshold, i.e., if $\theta \le \theta^{\lambda}$, where

$$\theta^{\lambda} = \frac{\pi R_H - \mu R^{\lambda}}{(1-\mu)R^{\lambda}}. \tag{54}$$

Thus, credit chains emerge and default cascades can occur for only high levels of enforceability.

Proof. See Appendix Section A.9. □

This result confirms that our main result is robust to the possibility that repos are subject to a short-term stay. It also allows us to analyze how Bank A's choice of borrowing instrument depends on the length of the stay.

Corollary 3. The threshold above which Bank A borrows via repos is decreasing in the length of the stay on repo assets, i.e., θ^{λ} is increasing in λ,

$$\frac{\partial\theta^{\lambda}}{\partial\lambda} > 0. \tag{55}$$

Proof. See Appendix Section A.10. □

[24] Throughout this analysis, we assume that Bank A chooses to borrow enough that it defaults if $\tilde{R} = R_L$, i.e., Lemma 4 holds. This is the case as long as π is sufficiently large.

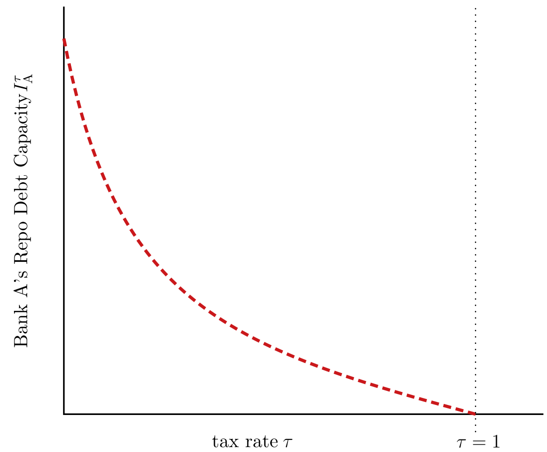

Fig. 9. Bank A's repo debt capacity as a function of the tax rate τ. The amount Bank A can borrow via repos is decreasing and convex τ. The parameters used to make the plot are $e = 1, \bar{R} = 1.4, \theta = 0.7$ and $\mu = 0$.

This corollary suggests that the length of the stay for repos can mitigate systemic risk. Thus, policy makers should be concerned not only with the question of whether repos should be stayed in bankruptcy, but also with how long they should be stayed for. In the context of the model, a short-term stay for repo collateral can decrease systemic risk, while still maintaining repos' effective seniority over other instruments such as bonds.

4.6. Taxation of repos

We now turn to the effects of taxing repos. We find that, because each link in a credit chain is taxed, the amount Bank A can borrow is convex in the tax rate. Thus, a small tax can have a relatively large effect on the volume of repo borrowing.

Suppose that there is a proportional tax τ on repo borrowing, so that if a bank borrows I, the government takes τI, leaving the bank to invest the remaining $(1-\tau)I$. We also make the following assumption to prevent the equations from becoming too complicated: Bank B always suffers a liquidity shock at Date 1, i.e., $\mu = 0$.[25] In this case, Bank A's maximum expected repayment to Bank B is given by the analogy of Eq. (15):[26]

$$\text{max expected repo repayment } = \theta\big(e + (1-\tau)I_{\mathrm{A}}^{\tau}\big)\bar{R}. \tag{56}$$

Because Bank B is always hit by the liquidity shock, it anticipates that it must borrow from Bank C, at which point

[25] This is effectively the same as the assumption that there are overlapping generations of short-lived creditors in Dang et al. (2017). In that model, the initial creditor dies at the interim date so it has to obtain liquidity from a second creditor to consume before it dies. In other words, suffering a liquidity shock with certainty at Date 1 is equivalent to dying with certainty at Date 1.

[26] More precisely, this is the analogy to Eq. (15) with $F_{\mathrm{A}}^{\mathrm{r}} = \infty$. As in the baseline model, this is without loss of generality whenever repo borrowing is profitable, because there are no bankruptcy costs for repos (cf. Lemma 4).

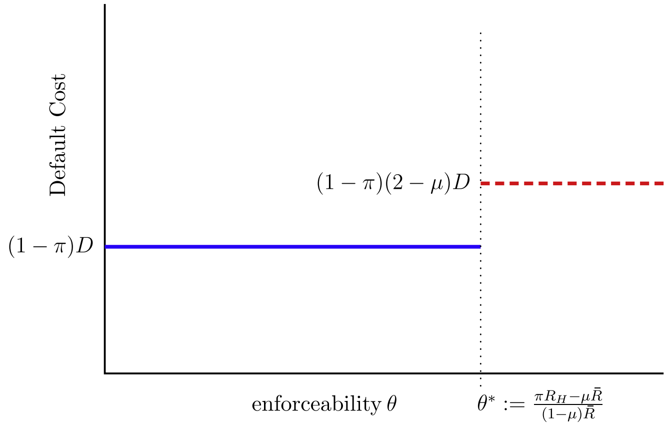

Fig. 10. Social costs of default as a function of enforceability. When enforceability is low, Bank A funds itself via bonds and the social costs of default are low. When enforceability is high, Bank A funds itself via repos and the social costs of default are high. The parameters used to create the plot are $(1-\pi)D = 100$, and $\mu = 1/2$.

it is taxed. Thus, the amount it is willing to lend to Bank A is given by

$$\begin{aligned} I_{\mathrm{A}}^{\tau} &= (1-\tau)\theta \; \times \; \text{max expected repo repayment} \\ &= (1-\tau)\theta^2(e + (1-\tau)I_{\mathrm{A}}^{\tau})\bar{R}. \end{aligned} \tag{57}$$

Hence, the amount Bank A can borrow is given by

$$I_{\mathrm{A}}^{\tau} = \frac{(1-\tau)\theta^2 e}{1-(1-\tau)^2\theta^2\bar{R}}. \tag{58}$$

The effect of the tax rate on the amout I_{A}^{τ} that Bank A can borrow via repos is depicted in Fig. 9 and summarized in Proposition 8.

Proposition 8. The amount I_{A}^{τ} that Bank A can borrow via repos is decreasing and convex in the tax rate τ on repo borrowing. Further, it is continuous and approaches zero as the tax rate approaches one. Thus, for a sufficiently high tax rate, Bank A always borrows via bonds and no credit chains form.

Proof. See Appendix Section A.11. □

The novel element of this proposition is that the amount Bank A can borrow via repos is convex in the tax rate. This is a result of the fact that each link in the credit chain is taxed. If there are two links in the chain, the tax is effectively squared. This finding implies that the effect of an increase in taxes is largest when the tax rate is low. Thus, implementing even a small tax on repos can have a relatively large effect on repo borrowing.

4.7. Welfare consequences of systemic risk

Our analysis focuses on systemic risk and how to mitigate it. Whereas many regulations aim expressly to decrease systemic risk, we believe that it is important to acknowledge that decreasing systemic risk is just one component of a regulator's objective function and that some policies that reduce systemic risk can have other costs. In this subsection, we argue that, in our model, decreasing systemic risk increases social welfare under reasonable assumptions.

We assume that there is a fixed social cost of each bank's default.

Assumption 4. Each bank's default has social cost *D*.

This assumption leads immediately to the result that the social costs of bank default are higher when Bank A borrows via repos than when Bank A borrows via bonds.

Lemma 5. The social costs of default are higher when Bank A has borrowed via repos than when Bank A has borrowed via bonds, i.e.,

$$(1-\pi)(2-\mu)D > (1-\pi)D, \tag{59}$$

where $(1-\pi)D$ is the expected social cost of bank default when Bank A borrows via bonds and $(1-\pi)(2-\mu)D$ is the expected social cost of bank default when Bank A borrows via repos.

Proof. See Appendix Section A.12. □

Viewed in conjunction with Proposition 1, Lemma 5 implies that decreasing credit market frictions can decrease welfare.[27] Fig. 10 depicts the social costs of default as a function of enforceability θ.

Corollary 4. Decreasing credit frictions (i.e. increasing enforceability θ) can decrease welfare. Increasing θ from below θ^* to above θ^* leads to an increase in the social costs of default from $(1-\pi)D$ to $(1-\pi)(2-\mu)D$.

5. Conclusions

Paper review. In this paper, we develop a model to analyze the connection between credit market frictions and systemic risk. We argued that a decrease in credit market

[27] Decreasing credit frictions also has a positive effect on welfare. It allows Bank A to scale up its project further. Thus, away from the cutoff θ^*, increasing enforceability has the standard positive effect. However, we emphasize here the negative effect of increasing enforceability around θ^*.

frictions can lead to an increase in systemic risk and a decrease in welfare. Even though a decrease in credit market frictions makes each market function better in isolation, it can harm the financial system as a whole. In markets with low credit market frictions, financial institutions are likely to borrow via non-resaleable debt (e.g., repos) instead of resaleable debt (e.g., bonds), and borrowing via non-resaleable debt leads to credit chains, which harbor systemic risk.

Policy. Our model is stylized, but we hope that it draws attention to some features of debt claims and financial markets that could deserve more attention in the policy debate. Most notably, borrowing via resaleable instruments mitigates systemic risk. Therefore, a regulator aiming to combat systemic risk should encourage financial institutions to fund themselves via resaleable instruments. Our model suggests that improvements in financial markets that mitigate credit frictions (e.g., improving creditor rights) could have the unintended consequence of undermining this goal: Lowering credit frictions could induce financial institutions to borrow via non-resaleable debt, increasing systemic risk. The exemption to the automatic stay for repos appears to have had unintended consequences, increasing repo borrowing, which led to credit chains, consistent with the predictions of the model.

Appendix A. Omitted derivations and proofs

A.1. Proof of Lemma 2

Because the program in Lemma 1 is linear, it must have a corner solution. Thus, there are three possible solutions: Bank A either borrows nothing, borrows the maximum so that it never defaults, or borrows the maximum so that it defaults only when it fails. The case in which it borrows the maximum so that it defaults only when it fails is analyzed in the main text and yields expected equity value given in Eq. (14),

$$\Pi_{\mathrm{A}}^{\mathrm{b}}\Big|_{\text{repay if } \tilde{R}=R_H} = \frac{(1-\theta)e\bar{R}}{1-\pi\theta R_H}. \tag{60}$$

If it borrows nothing its expected equity value is

$$\Pi_{\mathrm{A}}^{\mathrm{b}}\Big|_{\text{borrow nothing}} = e\bar{R}. \tag{61}$$

Now, $\Pi_{\mathrm{A}}^{\mathrm{b}}\big|_{\text{repay if } \tilde{R}=R_H} > \Pi_{\mathrm{A}}^{\mathrm{b}}\big|_{\text{borrow nothing}}$ if and only if $\pi R_H > 1$, which is guaranteed by Assumption 1. Thus, it remains only to compare the case in which Bank A defaults only when it fails with the case in which Bank A never defaults.

If Bank A never defaults, it borrows as much as it can given that it does not default in the event that $\tilde{R} = R_L$. Thus, it borrows

$$I_{\mathrm{A}} = F_{\mathrm{A}} = \theta(e+I_{\mathrm{A}})R_L \tag{62}$$

and its expected equity value is

$$\begin{aligned}
&\Pi_{\mathrm{A}}\big|_{\text{never default}}\\
&= \pi\big((e+I_{\mathrm{A}})R_H - F_{\mathrm{A}}\big) + (1-\pi)(1-\theta)(e+I_{\mathrm{A}})R_L\\
&= \Big(\pi(R_H-\theta R_L) + (1-\pi)(1-\theta)R_L\Big)(e+I_{\mathrm{A}})\\
&= \Big(\pi\big((1-\theta)R_H - (1-\theta)R_H + R_H - \theta R_L\big)\\
&\quad +(1-\pi)(1-\theta)R_L\Big)(e+I_{\mathrm{A}})\\
&= \Big((1-\theta)\bar{R} + \pi\theta(R_H-R_L)\Big)(e+I_{\mathrm{A}})\\
&= \frac{\big((1-\theta)\bar{R}+\pi\theta(R_H-R_L)\big)e}{1-\theta R_L}.
\end{aligned} \tag{63}$$

Assumption 3 ensures that this expression is always smaller than $\Pi_{\mathrm{A}}^{\mathrm{b}}\big|_{\text{repay if } \tilde{R}=R_H}$ from Eq. (14). Therefore, Bank A always sets $F_{\mathrm{A}} = \pi\theta(e+I_{\mathrm{A}})R_H$, as in the case analyzed in the main text. □

A.2. Proof of Lemma 4

Because there are no inefficiencies from default in the repo case, if Bank A borrows it is without loss of generality to assume that Bank A defaults whenever it borrows, i.e. that $F=\infty$ if $I>0$ or, alternatively, because $R \le R_H$, that $F = \theta(e+I)R_H$ whenever $I>0$. Thus it suffices to consider $F = \theta(e+I)R_H$ and $F=0$, as stated in the lemma.

Note that a more explicit computational proof could also be done in exact analogy with Lemma 2, but we omit it here. □

A.3. Proof of Proposition 2

The result follows directly from the comparison of $\Pi_{\mathrm{A}}^{\text{b,coll.}}$ and $\Pi_{\mathrm{A}}^{\text{r,coll.}}$ in Eqs. (32) and (34). □

A.4. Proof of Proposition 2

The result follows directly from the comparison of $\Pi_{\mathrm{A}}^{\text{b,sell coll.}}$ and $\Pi_{\mathrm{A}}^{\text{b,optimistic}}$ in Eqs. (36) and (37). □

A.5. Proof of Lemma 4

Bank A borrows via non-securitized debt if and only if $\Pi_{\mathrm{A}}^{\text{no sec.}} \ge \Pi_{\mathrm{A}}^{\text{sec.}}$. From the expressions for $\Pi_{\mathrm{A}}^{\text{no sec.}}$ and $\Pi_{\mathrm{A}}^{\text{sec.}}$ in Eqs. (39) and (40), we see that a necessary condition for this is that the

$$\frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}} \ge \frac{(1-\theta)e(1-c)\bar{R}}{1-\theta(1-c)\bar{R}} \tag{64}$$

or, rewriting, that

$$\theta^2 + \theta - \frac{c}{(1-\mu)(1-c)\bar{R}} \ge 0. \tag{65}$$

Thus, Bank A securitizes only if

$$\begin{aligned}
&\frac{1}{2}\left(-1-\sqrt{1+\frac{4c}{(1-\mu)(1-c)\bar{R}}}\right) \le \theta\\
&\quad \le \frac{1}{2}\left(-1+\sqrt{1+\frac{4c}{(1-\mu)(1-c)\bar{R}}}\right).
\end{aligned} \tag{66}$$

Because the lower root is negative whenever it exists and $\theta \in (0, 1)$, this is equivalent to saying that Bank A securitizes only if

$$\theta \le \theta^{**} := \frac{1}{2}\left(-1+\sqrt{1+\frac{4c}{(1-\mu)(1-c)\bar{R}}}\right). \tag{67}$$

The proposition follows. □

A.6. Proof of Proposition 5

As long as $\Pi_A^{\text{rollover}} < \Pi_A^{\text{r}}$, Bank A never borrows via one-period repos. From the expression for Π_A^{rollover} in Proposition 5 and the expression for Π_A^{r} in Eq. (26), this says Bank A never borrows via one-period repos as long as

$$\frac{\rho(1-\theta)e\bar{R}}{1-\theta\bar{R}} < \frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}} \tag{68}$$

or

$$\rho < \frac{1-\theta\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)\bar{R}}. \tag{69}$$

The right-hand side above is decreasing in μ, so if it holds for $\mu = 0$, it holds for all μ. This implies that Bank A never borrows via one-period repos as long as

$$\rho < \frac{1-\theta\bar{R}}{1-\theta^2\bar{R}} \equiv \rho^*, \tag{70}$$

as in the statement of the proposition. □

A.7. Proof of Proposition 6

The result follows directly from the comparison of $\Pi_A^{\text{b},\infty}$ and $\Pi_A^{\text{r},\infty}$ in Eqs. (44) and (48). □

A.8. Proof of Corollary 2

The result follows directly from the comparison of θ^* in Proposition 1 and θ^∞ in Proposition 6, using the fact that $\pi R_H < \bar{R} \equiv \pi R_H + (1-\pi)R_L$. □

A.9. Proof of Proposition 7

Given that repos are subject to a stay with inverse length λ, Bank A borrows via bonds whenever Π_A^{b} is greater than Π_A^{λ} or, substituting from Eqs. (14) and (53),

$$\frac{(1-\theta)e\bar{R}}{1-\pi\theta R_H} \le \frac{(1-\theta)e\bar{R}}{1-\theta\big(\mu+(1-\mu)\theta\big)R^\lambda}. \tag{71}$$

Simplifying this inequality gives

$$\theta \ge \frac{\pi R_H - \mu R^\lambda}{(1-\mu)R^\lambda} \equiv \theta^\lambda \tag{72}$$

as stated in the proposition. □

A.10. Proof of Corollary 3

We can restrict attention to the case in which $\theta^\lambda > 0$. Otherwise, Bank A always borrow via bonds. Differentiating gives

$$\frac{\partial\theta^\lambda}{\partial\lambda} = -\frac{(1-\mu)\big(\mu R^\lambda + (\pi R_H - \mu R^\lambda)\big)}{(1-\mu)^2(R^\lambda)^2}\frac{\partial R^\lambda}{\partial\lambda}. \tag{73}$$

This is negative because $\theta^\lambda > 0$ implies $\pi R_H - \mu R^\lambda > 0$ and

$$\frac{\partial R^\lambda}{\partial\lambda} = (1-\pi)R_L > 0. \tag{74}$$

□

A.11. Proof of Proposition 8

Immediately from differentiation of

$$I_A^\tau = \frac{(1-\tau)\theta^2 e}{1-(1-\tau)^2\theta^2\bar{R}}, \tag{75}$$

we have that

$$\frac{\partial I_A^\tau}{\partial\tau} = -\frac{\big(1+\theta^2(1-\tau)\bar{R}\big)\theta^2 e}{\big(1-\theta^2(1-\tau)^2\bar{R}\big)^2} < 0 \tag{76}$$

and

$$\frac{\partial^2 I_A^\tau}{\partial\tau^2} = \theta^4 e\bar{R}\left(\frac{1+4(1-\tau)+3\theta\bar{R}(1-\tau)^2}{\big(1-\theta^2(1-\tau)^2\bar{R}\big)^3}\right) > 0, \tag{77}$$

so I_A^τ is a decreasing convex function of τ. □

A.12. Proof of Lemma 5

Bank A defaults with probability $1-\pi$. Because no other bank ever defaults if Bank A has borrowed via bonds, the expected social costs of default are simply $(1-\pi)D$ if Bank A has borrowed via bonds.

If Bank A has borrowed via repos, and only if Bank A has borrowed via repos, Bank B defaults if and only if Bank A defaults and Bank B itself has been hit by a liquidity shock. This liquidity shock occurs with independent probability $1-\mu$. Thus, the expected social costs of default are

$$(1-\pi)D + (1-\pi)(1-\mu)D = (1-\pi)(2-\mu)D. \tag{78}$$

Because $\mu < 1$, the social costs are greater when Bank A has borrowed via repos. □

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