Collateral as Hostage, Risk Taking, and Repo Runs *

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Abstract

When banks borrow through repurchase agreements (repo) for margin trading, the repo collateral serves as a hostage that incentivizes banks to repay. As some banks become poorly capitalized, the repo margin depends not only on collateral risk but also on counterparty risk. A small increase in collateral risk or counterparty risk, or a self-fulfilling belief shock, can lead to a large decrease in asset price and repo financing, which resembles the market crash and repo run episode of the 2007-08 financial crisis. Repo runs occur because of upward-sloping asset demand: a decrease in asset price makes risk-taking more profitable for banks, reducing their incentive to repay. Expecting this heightened counterparty risk, lenders set a higher repo margin, which can depress asset demand and result in a further decrease in asset price. In a repo run, the effectiveness of intervention policies depends on the reason for the run as well as the design of the policies.

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1 Introduction

Before the 2007-08 financial crisis, repurchase agreements, or repos, were widely believed to be a stable funding source for investment banks. As a short-term collateralized loan, repos are often over-collateralized by a margin that insulates repo lenders from collateral risk. Besides, repos are exempt from automatic stay. This allows repo lenders to immediately seize the collateral when cash borrowers default. Because of over-collateralization and special treatment in default, repos are generally considered as safe investments for cash lenders, especially when the repos are collateralized by relatively safe assets. As a result, repo lenders were believed to have little incentive to cut off repo funding during stress times.

However, such a belief was proven wrong when repo lenders refused to roll over funding to risky borrowers, Bear Stearns and Lehman Brothers, during the financial crisis. This happened even when the funding seemed to be well over-collateralized against relatively safe assets (Ball (2018)). After Lehman lost its repo funding and declared bankruptcy, repo lenders pulled out repo funding from other borrowers for fears of counterparty risk, leading to a large reduction in repo financing. This repo run episode is reminiscent of a classic bank run, but now a market-wide run on secured funding. Why would repo lenders care about counterparty risk when the lending seems to be well over-collateralized in a crisis? How do repo lenders' concerns about counterparty risk lead to a marketwide dry-up of repo funding?

To study the cause and the consequence of repo lenders' concern for counterparty risk, we develop a model where banks engage in margin trading through the use of repurchase agreements (repo). When repo lenders are reluctant to risk the hassle of seizing collateral, the repo lending is inherently under-collateralized relative to lenders' recovery value in default. As a result, collateral serves as a hostage that incentivizes borrowers to repay. In stress times when some borrowing banks become poorly capitalized, lenders set a higher margin to provide borrowers with incentive to repay. However, the initial increase in the repo margin can actually reduce borrowers' incentive to repay. The increase in repo margin tightens banks' collateral constraint leading to a lower asset price. The lower asset price can make it more profitable for banks to take excess risk in margin trading, reducing borrowers' incentive to repay. Consequently, a small decrease in banks' net-worth can lead to a large decrease in asset price and repo funding, a market-wide repo run.

In our model, each bank owns some illiquid loans and cash on its asset side. These banks are interpreted as investment banks who have made substantial bet on real-estate investment or subprime mortgage assets.
on the asset side. Banks differ only in the quality of their illiquid loans. To focus on a crisis scenario as in 2007, we look at cases where some banks have suffered large losses from their illiquid investment.

Banks can purchase a risky financial asset inelastically supplied in a competitive market. Besides using their own cash, they can buy the asset on margin through collateralized lending. To be specific, they can purchase the asset and finance a fraction of the purchase by borrowing against the asset as collateral from a group of repo lenders. We interpret this margin trading as dealer banks financing their inventory assets through the tri-party repo market. The payoff risk of these inventory assets can be either fundamental risk or uncertainty of selling these assets to end-buyers.

Lenders’ objective is to maximize total lending subject to the constraint that the lending is risk-free. We think these lenders as cash investors in the tri-party repo markets, typically money market mutual funds (MMMF) who are looking for a safe and liquid place to park their cash. To capture the idea that lenders are reluctant to seize collateral in default, we assume that lenders value the collateral asset less than borrowers do. In real world, these cash investors value the collateral less due to the existence of transaction cost, belief difference, headline risk of repo default, and fire-sale loss when forced to liquidate in an illiquid market. To create a role for counterparty risk, we assume that lenders are uninformed of whether their counterparties’ loan quality is high or low.

When all banks’ net-worth are high, lenders set the amount of repo lending per unit of collateral equal to the asset’s worst-state payoff. In this case, the counterparty concern is irrelevant, and the amount of repo lending depends only on collateral risk. However, when some banks’ net-worth becomes low, lenders set the amount of repo lending to suppress poorly-capitalized banks’ incentive to take excess risk in margin trading. In this case, the counterparty concern matters, in the sense that a decrease in banks’ net-worth leads to a decrease in the amount of repo lending, or equivalently an increase in the repo margin or haircut.

To see why, note that these infinitely risk-averse lenders must make sure that borrowers always repay if they are to lend at an amount higher than their valuation of the collateral. In that case, the collateral serves purely as a hostage that incentivizes borrowers to repay. When net-worth of poorly-capitalized banks is low, these banks have incentive to engage in risk-taking, that is, spending all their cash to purchase the asset on margin to obtain the maximum leverage at the risk of becoming insolvent. As lenders are uninformed of
banks’ creditworthiness, lenders must set a high enough repo margin so that even those riskiest banks have no incentive to take excess risk.

More interestingly, a small decrease in banks’ net-worth can lead to a large increase in repo margin and a large decrease in the collateral asset price through an endogenous risk taking channel. Expecting a decrease in banks’ net-worth that increases their incentives to take excess risk, lenders initially increase the lending margin to reduce banks’ risk-taking incentives. However, the increase in lending margin depresses the collateral asset price, leading to an increase in banks’ risk-taking incentives. As a result, lenders have to further increase the repo margin all the way to a point where the collateral asset price is so low that asset purchase entails little downside risk and that counterparty concern becomes unimportant.

Formally, this endogenous risk taking channel leads to upward sloping demand for the collateral asset, generating equilibrium multiplicity. A small increase in fundamental risks, including counterparty risk and collateral risk, can lead to a large decrease in the collateral asset price and repo financing, when such change of parameter eliminates the possibility of the good equilibrium. With multiple equilibria, a large decline in asset price and repo financing can also be driven by self-fulfilling beliefs. Expecting a low asset price, lenders set a high repo margin to suppress banks’ strong risk-taking incentive. This tightens banks’ collateral constraint and results in a low asset demand, rationalizing the initial guess of a low asset price.

We interpret the shift from a good equilibrium to a bad one as a market-wide run on repo. The mechanism in our model resembles the market cash and repo run episode of the 2007-08 financial crisis. As the housing price started to fall, investment banks suffered loss from their real-estate investment and sub-prime mortgage exposure. As these major investment banks become poorly capitalized, their repo lenders started to worry more about counterparty risk due to an increase of their risk-taking incentive. This eventually led to a panic in the repo funding market, through both a large increase in haircut in the bilateral repo market and a massive withdrawal of repo funding from risky borrowers in the tri-party repo market. Consequently, asset price fell dramatically for all asset classes, including those that are not directly related to the initial housing shock.

The repo run mechanism in our paper differs from the existing literature that explains financial crisis in models with multiple equilibria. First of all, the mechanism in our paper is different from Brunnermeier and
Pedersen (2009), who also shows that a small shock can generate a margin spiral. While the mechanism in their paper works through lenders learning information about future fundamental volatility through asset price, our mechanism emphasizes lenders’ concern about counterparty risk, which depends on borrowers’ endogenous risk taking incentive. Second, our mechanism is different from models that generate multiple equilibria through endogenous collateral value, such as in Kiyotaki and Moore (1997) and Kuong (2015). Our model highlights multiple equilibria due to the effect of the endogenous collateral asset price at the debt-issuance date on borrowers’ risk taking incentive, keeping the collateral value fixed at the debt-repayment date. Third, our mechanism is also different from Diamond-Dybvig style bank run models\(^1\) that depend on strategic complementarily of multiple lenders of a single bank. The repo run in our model is a market-wide run driven by strategic concerns about counterparty risk from lenders of different borrowers.

We use the model to study the effectiveness of ex-post intervention policies that are related to the repo market. First, a liquidity backstop, such as the Primary Dealer Credit Facility (PDCF) that lends to primary dealers against risky collateral, can shift the system from the crisis equilibrium to the good equilibrium when repo run is driven by self-fulling beliefs. According to the model, the liquidity backstop works when the government announces to lend at a margin that is sufficiently lower than the prevailing margin in the crisis equilibrium. Interestingly, a necessary condition for a liquidity backstop to work is that the government is believed to have the ability to crowd out all private lending and effectively become the Lender of First Resort. However, once this condition is met, the government can shift the system out of a belief-drive repo run without lending a penny and remains the Lender of Last Resort.

Second, we compare the effectiveness of asset purchase and equity injection in shifting the financial system out of a fundamental-driven repo run. We assume that the government has limited resources and cannot suffer a loss from intervention policy. We find that because of the endogenous risk taking channel, equity injection in general is more effective than asset purchase in raising asset demand and thus shifting the system to the good equilibrium. Compared with asset purchase financed at market haircut, equity injection to all banks not only injects money for banks to purchase risky asset, but also relaxes banks collateral constraint as lenders set a lower repo haircut expecting a safer counterparty. As a result, equity injection to all banks is as effective as asset purchase financed at a haircut that corresponds to the largest possible amount of repo lending per collateral.

\(^1\)See Diamond and Dybvig (1983) for the original idea. Related papers include He and Xiong (2012), which considers a dynamic bank run, and Martin et al. (2014a) and Martin et al. (2014b), which extend the DD framework to study repo runs.
We also compare the effectiveness of equity injection to all banks and equity injection to risky banks. We find that it is ambiguous which policy is more effective in raising asset demand and shifting the system to a good equilibrium. The former policy makes risky banks safer and relaxes banks’ collateral constraint more, but the latter gives more money to safe banks who tend to purchase more assets without solvency concern. Equity injection to all banks is more effective when the repo margin in the crisis equilibrium is relatively low.

Third, we consider the effectiveness of an increase in lenders’ valuation of the collateral. We have in mind the Temporary Guarantee Program for MMMFs, which was established by U.S. treasury mainly to stop panics in the MMMF market during the financial crisis. Because the program makes MMMFs safer, these MMMFs would have less concern about fire-sale loss and headline risk of liquidating repo collateral when making repo lending in the tri-party repo market. As a result, such program can be effective in raising asset demand and shifting the financial system out of the crisis equilibrium.

Extending the model to allow banks to choose its ex-ante exposure to illiquid investments, we study the model’s implication for financial fragility in boom times. Interestingly, we find a "time-inconsistency" issue with respect to equilibrium multiplicity. A better expectation about future aggregate state leads to a higher investment in profitable illiquid loans. However, this can make the date-1 asset market in an unstable equilibrium after the economy is hit by a negative aggregate shock. This unstable equilibrium is fragile in the sense that a small negative perturbation can lead to market crash and repo run.

**Literature review.** The paper belongs to the literature on collateralized debt and financial crisis. On one hand, the use of collateralized debt can increase debt capacity by alleviating financial frictions such as limited commitment (Hart and Moore (1994)), asymmetric information about borrowers (Stiglitz and Weiss (1981), Parlatore (2018)), and asymmetric information about the collateral (Dang et al. (2012) and Dang et al. (2013)). On the other hand, financial institutions’ reliance on collateralized debt creates financial fragility, because short-term collateralized debt makes bad shocks look more persistent (Acharya et al. (2011)), collateral asset can become information sensitive and lead to large contraction in debt financing (Dang et al. (2013), Gorton and Ordonez (2014), and Gorton and Ordonez (2016)), asset prices are more volatile when natural asset buyers use collateralized debt to trade on margin (Geanakoplos (2010) and Fostel and Geanakoplos (2014)), debt default triggers fire-sale externality when lenders have to liquidate the collateral (Infante (2013) and Kuong (2015)), debt default worsens lenders’ liquidity condition when they hold on to the collateral (Zhang (2014)), and strategic complementarity about runs (Martin et al. (2014a))
and Martin et al. (2014b)). The paper is in the latter camp that provides a new mechanism through which reliance on collateralized debt can make the financial system subject to repo runs.

Our paper is also related to the theoretical literature on funding constraint of financial institutions. In our paper, borrowers subject to a collateral constraint. However, the collateral constraint in our model depends on borrowers’ net-worth Benmelech and Bergman (2012) in bad times, because of lenders’ concern about counterparty risk. This makes the constraint more similar to an equity-like funding constraint as in He and Krishnamurthy (2013). Besides, our paper is also related to literature on risk shifting, such as Myers (1977), Acharya and Viswanathan (2011), and Diamond and Rajan (2011). In our paper, the risk shifting opportunity is endogenous as it depends on the market-determined collateral asset price.

Finally, our paper is related to the empirical literature on the repo market. On the bilateral repo market, evidence from Gorton and Metrick (2012a), Gorton and Metrick (2012b), and Gorton et al. (2018) show that repo haircut against risky collateral went up significantly during the financial crisis. On the tri-party repo market, evidence from Copeland et al. (2014) and Krishnamurthy et al. (2014) show that while haircut in tri-party market remains stable, lenders withdrew funding from repo against risky collateral and from repo with risky borrowers. The repo run mechanism of our model is consistent with these empirical evidence of the 2007-08 financial crisis.

In Section 2, we present the main model. In Section 3, we justify the key assumptions of the model and discuss the robustness of our results. In Section 4, we study the policy implication of the model. In Section 5, we extend the main model to study the model’s implication for financial fragility. In Section 6, we conclude the paper.

2 The Model

Consider a group of risk-neutral banks with unity measure. At date 1, each bank owns $l$ unit of cash and $\rho$ unit of illiquid loans. The illiquid loan has no resale value at date 1 and only pays off at date 2. Banks

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differ in the quality of their illiquid assets. To be specific, a measure \( \theta \) of banks have high quality illiquid assets that pay off \( X_H \) per unit, while the rest \( 1 - \theta \) banks have low quality illiquid asset that pay off \( X_L \) per unit. We assume that a bank’s type is its private information. Meanwhile, each bank has \( \eta \) unit of debt in place. Each unit of debt requires a repayment of 1 unit of cash at date 2. A bank’s objective is to maximize its expected payoff at date 2, subject to limited liability. We assume that a bank obtains a positive non-pledgeable charter value \( C \) whenever it stays solvent at date 2.  

At date 1, banks can purchase a financial asset in a competitive market. The total supply of the financial asset is \( A \). If held by a bank, the asset pays \( v_H \) in the good state with probability \( q \) and \( v_L \) in the bad state with probability \( 1 - q \) at date 2. Let \( \bar{v} = qv_H + (1 - q)v_L \) be the expected value of an asset. Besides purchasing the asset with its internal cash, a bank can purchase the asset with cash borrowed from a group of lenders. Because of borrowers’ limited commitment, lending takes the form of collateralized debt backed by the financial asset. In another word, banks can buy the financial asset on margin: they can purchase the asset and finance a fraction of the purchase by borrowing against it as collateral. The rest fraction that a bank cannot borrow against is usually known as the margin or haircut, which must be financed by the bank’s equity.

Lenders are deep-pocketed. Their outside option has zero net return, so they are willing to lend as long as they break even. For simplicity, we assume that lenders are infinitely risk-averse. As will be shown later, each lender quote a single risk-free collateralized debt contract, characterized by the amount of lending per collateral \( D \), that allow borrowers to borrow \( D \) unit of cash per unit of collateral. To pin down the equilibrium, we assume that a lender’s objective is to maximize its total lending. This assumption can be rationalized by the fact that safe claims carry a liquidity premium for large institutional lenders that are subject to redemption needs.

The key assumption is that a lender only value the collateral asset at \( v < v_L \) at date 2 in the bad state. There are many reasons why the lender expect to collect less from collateral assets than a borrower do. First of all, any intrinsic reason that makes the lender a lender can explain the valuation difference. Parlatore (2018) shows that a borrower values the collateral asset more than a lender does because the borrower can borrower against the asset in the future to raise money for future investment opportunity.

More importantly, the lender would typically have a lower valuation of the collateral asset when seizing it.

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3 Instead, we can assume that the banker bears a positive bankruptcy cost, or that the bank will suffer a run (by its existing creditors) that destroys the value of illiquid loan whenever the bank’s net-worth goes below zero. The key is to introduce a wedge so that these risk-neutral banks can perform some risk-averse behavior when close to default.
in a default for a few reasons. First, there may be headline risk that leads to a run on the lender. Second, the lender may have institutional restrictions in holding specific types of risky collaterals. As a result, they have to sell the collateral immediately in markets where liquidity is supposed to be low.\(^4\) Third, there is substantial hassle associated with seizing collateral in default, including transaction cost and litigation cost due to dispute of collateral evaluation. Lastly, even if there is a market for the seller to sell the collateral to a borrower, we would still expect a gap in valuation in stress times, because borrowers may not be willing to take additional position when their leverage constraint starts to bind.

Because lenders value the collateral less than borrowers do, borrowers can ex-post negotiate down the debt payment to \(u\) were they given full bargaining power. Expecting this, those infinitely risk-averse lenders will only lend \(u\) per unit of collateral. To increase their debt capacity, borrowers must have a credible device to commit not to renegotiate. Repurchase agreement, or repo, is such a commitment device.\(^5\) Because repo is exempt from automatic stay in bankruptcy, the collateral will be automatically transferred to the lender were repayment not made in full, which precludes any renegotiation prior to default. While such automatic transfer increases the collateral asset’s debt capacity, the fact that lenders ex-post are reluctant to risk the hassle of seizing collateral makes their ex-ante lending decision contingent on borrowers’ balance-sheet strength. Throughout this paper, we interpret the collateralized debt contract in the model as a repo contract that is exempt from automatic stay. To simplify, we assume that repo lenders have no recourse to borrowers' balance sheet, nor can they force borrowers into bankruptcy when borrowers default on repo.

**Interpretation 1: Dealer Banks and Tri-party Repo.** We interpret banks in the model as dealer banks who finance their inventory assets through the tri-party repo market in order make a profit by selling these assets to end-investors at a higher price. The dealer business can be risky because of fundamental risk of the inventory assets and uncertainty in end-investors’ asset demand. The illiquid loan in the model is interpreted as banks’ real-estate investment and subprime mortgage exposure on banks’ balance sheet, and the debt in place in the model as banks’ long-term debt and commercial paper. For the lender side, repo lenders in our model are interpreted as money market mutual funds (MMMF) who treats repo as a safe investment. Because of institutional restrictions, an MMMF may be forced to liquidate the collateral, even relatively safe one such as agency MBS, when its counterparty defaults, generating substantial fire-sale loss. Our assumption that lenders value the collateral less than borrowers captures this real-world friction.

\(^4\)One reason why market liquidity is low is because of the fire-sale channel in Shleifer and Vishny (1992). When one bank defaults, all other banks are very likely to be financially constrained and thus not willing to bid high for risky assets.

\(^5\)Alternatively, first-come-first-served demand deposit can be such a commitment device. See Diamond and Rajan (2001) for details.
Interpretation 2: Hedge Funds and Bilateral Repo. The model can also be interpreted as hedge funds conduct leveraged trading through the bilateral repo market. Due to limited arbitrage, a hedge fund implementing a trading strategy with high leverage can be risky even if the strategy is well-hedged. The situation that some banks’ net illiquid asset is negative in the model can be interpreted as a hedge fund’s previous trading loss or a redemption after bad performance. For the lender side, repo lenders in our model are now interpreted as prime brokers that lend to hedge funds through bilateral repo contracts. Although prime brokers can be experts in evaluating and trading collateral assets, they may still value these collateral assets less when their counterparty defaults, mainly because of their own funding problem in stress times.

Timeline of the model is the following. At date 1, a lender is matched with a bank. Each lender chooses to quote a zero-rate repo contract that allows the bank to borrow $D$ unit of cash per unit of collateral. There is full competition between lenders, so a bank can walk away from a lender to find another if he is not satisfied with the provided repo contract. Then, a bank chooses its asset purchase and repo issuance decision. The asset price is then determined in a competitive market. At date 2, all assets and all liabilities mature. Each bank pays off its debt subject to limited liability.

2.1 Banks’ Risk-taking Incentive

Define a bank’s net illiquid asset as its date-2 value of illiquid assets net of debt repayment, $x_i = \rho X_i - \eta$ for $i = H, L$. Then an $i$-type bank’s net-worth is $l + x_i$. We impose the following parameter restrictions on $x_H$ and $x_L$.

**Assumption 1**: $x_H > 0$, $x_L < 0$ and $x_L + l > 0$.

Under Assumption 1, the model captures those periods of market stress where some banks becomes thinly-capitalized due to a low value of their illiquid investment.

Let’s consider the problem of a bank with net illiquid asset $x$. We restrict the attention on banks that have a positive initial net-worth, i.e. those with $x > -l$. At date 1, the bank is randomly matched with a repo lender. The repo lender lends $D$ against one unit of financial asset as collateral. The bank chooses its asset
position $a$, cash holding $c$ and repo issuance $b$ to maximize its expected payoff at date 2,

$$\max_{a,b,c} q(x + a v_H + c - b + C) + (1 - q)(x + a v_L + c - b + C)^+$$

where $(y + C)^+ = y + C$ if $y \geq 0$ and $0$ otherwise. Intuitively, the bank’s charter value $C$ will be foregone in bankruptcy when the bank’s net-worth becomes negative. This is true when we assume that the charter value $C$ is not pledgeable and therefore a wedge, so a bank cannot borrow against it to avoid default.

The bank is subject to the budget constraint and the collateral constraint,

$$aP + c = l + b$$

$$b = aD$$

According to the bank’s budget constraint, the bank is allocating its internal cash and borrowed money between asset purchase and cash holding. According to its collateral constraint, the bank’s debt capacity is determined by the product of the amount of collateral the bank owns and the amount of lending per collateral.

Here we assume that the bank always borrows up to its collateral constraint, i.e. $b_i = a_i D$. If a bank’s collateral constraint is slack, it can always borrow up to the constraint and put the extra borrowed money as cash. This does not alter the bank’s budget constraint and expected payoff, because both cash and debt earn zero interest rate in the model. Therefore it is without loss of generality to assume so. More convincingly, the bank will strictly prefer to borrow up to the constraint if we assume that the bank earns an arbitrarily small interest rate on its cash holding.

As a result, the bank’s budget constraint can be rewritten as $a_i(P - D) + c_i = l$. This budget constraint can be interpreted as the bank uses its internal cash either to pay the margin $P - D$ of its levered asset position or to hold as cash. We can plug in the budget constraint and rewrite the bank’s problem as

$$\max_{a \in [0, \frac{l}{P - D}]} q(x + l + a(v_H - P) + C) + (1 - q)(x + l + a(v_L - P) + C)^+$$

Because the charter value creates a bankruptcy wedge, the bank’s optimal policy can exhibit risk-neutral,
risk-averse, or risk-seeking behavior, depending crucially on a bank’s net-worth. Proposition 1 summarizes the bank’s optimal policy as a function of its net illiquid asset $x$.

**Proposition 1.** When $P < \bar{v}$, a bank’s optimal asset position is

$$a^*(P, D, x) = \begin{cases} \frac{l}{P-D}, & x \in [-l, x_2(P, D)) \cup (x_1(P, D), +\infty) \\ \frac{l+x}{P-v}, & x \in [x_2(P, D), x_1(P, D)] \end{cases}$$

The two threshold values are given by $x_1(P, D) = \frac{D-\bar{v}L}{P-D}$ and $x_2(P, D) = x_1(P, D) - \frac{(1-q)C}{vH} - \frac{P-v}{vH-P}$.

When $P = \bar{v}$, banks with $x > x_2(P, D)$ are indifferent between any asset position within the range of $[0, a^*(P, D, x)]$. Banks with $x < x_2(P, D)$ still choose to invest $a^*(P, D, x) = \frac{l}{P-D}$.

When its net illiquid asset is larger than $x_1(P, D)$, the bank is well-capitalized because the bankruptcy wedge will never be triggered. To see this, first notice that the largest amount of asset the bank can purchase is $\frac{l}{P-D}$, while the largest amount of asset the bank can hold without being insolvent at repayment date is $\frac{l+x}{P-v}$. When $x > x_1(P, D)$, we have $\frac{l}{P-D} < \frac{l+x}{P-v}$, so the bank will always stay solvent for any amount of asset it chooses to hold. As a result, the bank acts as if it is risk-neutral: whenever the asset price is less than the expected value of the asset, the bank purchases $a^* = \frac{l}{P-D}$, the largest amount of asset it can buy through the use of repo financing. In this case the bank obtains the highest leverage and holds no cash at hand.

When its net illiquid asset is less than $x_1(P, D)$, the bank is poorly-capitalized because it can become insolvent at repayment date if it chooses to obtain the highest leverage. Thus the bank faces a choice between a safe strategy and a risky strategy. The safe strategy is to purchase $\frac{l+x}{P-v}$ unit of asset so that the bank stay solvent at repayment date, while the risky strategy is to purchase $\frac{l}{P-D}$ unit of asset so that the bank obtains the highest leverage but becomes insolvent when the asset pays low. The cost of risk-taking, i.e. choosing the risky strategy, is to lose the charter value in bad times, while the benefit is to obtain a larger asset position $\Delta = \frac{l}{P-D} - \frac{l+x}{P-v}$ that pays off more in good times. In another word, the risky strategy allows the bank to shift risk to creditors at the risk of costly bankruptcy.

When $x \in [x_2(P, D), x_1(P, D)]$, the benefit of risk taking cannot be justified by the cost. Therefore, the bank acts as if it is risk-averse: it chooses the safe strategy, limiting its asset position to $a^* = \frac{l+x}{P-v}$ and holding...
positive amount of cash, even when there is positive profit in purchasing the asset from a risk-neutral perspective. When $x < x_2(P, D)$, the benefit of risk taking outweighs the cost. Therefore, the bank acts as if it is risk-seeking: it chooses the risky strategy, purchasing $\frac{l}{P-D}$ amount of asset to obtain the highest leverage, even when there is no (or even a negative) profit in purchasing the asset from a risk-neutral perspective.

Given the bank’s optimal asset choice $a^* = a^*(P, D, x)$, the bank’s optimal cash holding and repo issuance are $c^* = l - a^*(P - D)$, and $b^* = a^*D$, and the equilibrium asset price is determined in a competitive market where the fixed asset supply equals the total asset demand that comes from both high-type and low-type banks.

\[ \theta a^*(P, D, x_H) + (1 - \theta)a^*(P, D, x_L) = A \]  

(2)

2.2 Collateral as Hostage

Now let’s consider the problem of a lender who is matched with a bank of unknown type. The lender’s objective is to maximizing its total lending. The lender is infinitely risk-averse, so it values a repo contract in terms of its worst-case scenario. We further restrict our attention to the set of contracts that have zero interest rate. We show in the Appendix that this is without loss of generality: when there is perfect competition between lenders, they indeed find it optimal to offer a single zero-rate contract that attracts both high-type and low-type banks in the equilibrium. The lender’s decision boils down to choosing the amount of lending per collateral $D$.

When the borrower repays at date 2, the lender always deliver the collateral because the lender values the collateral less than the borrower does. In real world, the lender may fail to deliver the collateral due to a few reasons such as liquidity shortage or settlement failure. In another word, there is a two-sided limited commitment problem in repo transactions: no only the borrower may fail to repay, but the lender may not deliver the collateral. In the model, we focus on the limited commitment problem of the borrower side only.

When the borrower fails to repay, the lender seizes the collateral. We assume that the lender cannot place the borrower in default. In real world, the innocent party in a repo default is entitled either to declare an event of default in respect of all transactions between the two parties or effect a close-out of the affected
transaction only. Neither treatment allows repo lenders to place the borrower in a full default. For simplicity, we further assume that the lender has no recourse to the borrower’s balance sheet. This assumption can be motivated by the hassle and uncertainty of valuing collateral and computing net position in a default. The model’s main result will be robust if we allow for limited recourse.

The repo lender chooses the amount of lending per unit of collateral to maximize its total lending subject to the constraint that the lending is risk-free, that is

$$\max_D \theta b^*(P, D, x_H) + (1 - \theta)b^*(P, D, x_L)$$

subject to

$$D \leq v_L$$

$$x_L \geq x_2(P, D) \quad \cup \quad D \leq u$$

Under the constraint that the lending is risk-free, it is easy to show that the maximizing total lending is equivalent to maximizing $D$, the amount of lending per unit of collateral. Because of the no-recourse assumption, a necessary but not sufficient condition for the borrower to always repay the repo is that the repurchase price of the repo must not be higher than the borrower’s valuation of the collateral in the bad state. This is the no-recourse constraint in (3).

As shown in the two constraints from (4), the repo lending is risk-free either when the borrower always repays or when the lending is fully secured from the lender’s perspective. To make sure that the borrower always repays, the contract has to induce the riskiest borrower, any bank with low type, not to take excess risks. This no-default constraint is given by $x_L \geq x_2(P, D)$, or equivalently $D \leq D^*(P) = \frac{C}{\frac{u - l}{v_H} + \frac{l}{v_H - P}}$. Meanwhile, the lending is fully secured from the lender’s perspective when the amount of lending per collateral is less than the lender’s valuation of the collateral, i.e. $D \leq u$. When this fully-secured constraint is satisfied, whether the borrower will repay the debt becomes irrelevant to lenders.

The two constraints correspond to two distinct roles that a collateral plays in a collateralized debt. For the no-default constraint, the collateral serves as a hostage that incentivizes the borrower to repay. For the fully-secured constraint, the collateral serves as a protection against the borrower’s default. To focus on
this case where the collateral serves as a hostage, we assume that the lender’s valuation of the collateral is sufficiently low by imposing the following parameter restriction.

**Assumption 2:** $u < \frac{lv}{l+L}.$

**Proposition 2.** Under Assumption 2, a lender sets the amount of lending per unit of collateral at $D = \min \{v, D^*(P)\}$, where $D^*(P) = P - \frac{l+x_{L}v}{P-v_{L}} \frac{l}{l+\frac{v_{H}-P}{v_{L}}+(1-q)C/q}. $

Proposition 2 summarizes a lender’s optimal lending decision. Intuitively, when the lender’s valuation of the collateral is sufficiently low, the lender is lending at an amount larger than its valuation of the collateral. Nevertheless, it still rationally expects a full repayment, because the borrower has incentive to always buy back the collateral at repayment date. The exact amount of lending is equal to the smaller of the collateral’s payoff in the bad state $v_{L}$ and the maximum amount of lending that satisfy the no-default constraint $D^*(P)$.

To study the property of the lender’s optimal policy, let’s first look at $D^*(P)$, the maximum amount of lending that satisfy the no-default constraint. We conduct a change of variable to instead look at $m(P) = P-D^*(P)$. Without considering the no-recourse constraint, $m(P)$ is the repo margin, which is defined as the dollar amount of the asset price that must be financed through the borrower’s equity. The graph will be similar for the repo haircut $h(P) \equiv 1 - \frac{D(P)}{P}$ is defined as the fraction of the asset price that must be financed through the borrower’s equity. Therefore we will use the word margin and haircut interchangeably.

$$m(P) = \frac{l}{P-v_{L}} + \frac{l}{v_{H}-P} \left(1-q\right)C/q$$

(6)

A decrease in asset price affects the repo margin through two channels. First, there is a fundamental risk channel. A decrease in asset price reduces the risk of purchasing the asset and thus makes the borrower’s balance sheet safer, because the loss in the bad state becomes smaller. Therefore, the lender worries less about the borrower’s default risk, leading to a decrease in repo margin. Second, there is a risk-taking incentive channel. A decrease in asset price increases banks’ incentive to take excess risk, because the gain in the good state becomes larger. Therefore, the lender worries more about the borrower’s default risk, leading to
a increase in repo margin.

As a result, the repo margin $m(P)$ is a non-monotonic function in asset price on $[v_L, v_H]$. When the asset price is low, the fundamental risk channel dominates, so a decrease in asset price leads to a decrease in repo margin. To see this, consider the extreme case where the asset price converges to $v_L$ from above. In this case, the repo margin converges to 0, because purchasing the asset becomes risk-free. When the asset price is high, the risk-taking incentive channel dominates, so a decrease in asset price lead to an increase in repo margin. To see this, consider the extreme case where the asset price converges to $v_H$ from below. In this case, the repo margin again converges to 0, because the benefit of risk taking becomes infinitely small.

To restrict our attention to the most interesting case, we further impose the following parameter restrictions.

**Assumption 3** $l + x_L < \frac{\theta C}{1 - q}$.

Assumption 3 is a sufficient condition for the repo margin to be a non-monotonic function in asset price on the range of possible market-clearing asset prices $[v_L, \bar{v}]$.

Figure 1 plots the lender’s optimal amount of lending per collateral as a function of asset price on $[v_L, \bar{v}]$. When the asset price is above a certain threshold, the no-recourse constraint binds. The amount of lending per collateral is simply $v_L$, the asset’s payoff in the bad state. In this case, the repo margin is equal to $P - v_L$, which is decreasing in the asset price.  

When the asset price is below the threshold, the amount of lending per collateral is determined by the no-default constraint. In this case, the amount of lending per collateral is $D^*(P)$, and the repo margin is $m(P)$ are both non-monotonic functions in asset price. When the asset price is high, a decrease in asset price increases the borrower’s incentive to take excess risk, raising the lender’s concern about the borrower’s default risk. As a result, a decrease in asset price leads to an increase in repo margin and a decrease in the amount of lending per collateral. When the asset price is low, a decrease in asset price reduces the borrower’s risk of purchasing the asset, reducing the lender’s concern about the borrower’s default risk. As a result,

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\[The \text{existence of this region depends on parameter values. For instance, the region is likely to exist when the charter value } C \text{ is large, because banks would have less incentive to take excess risk in that case.}\]
Figure 1: The figure plots the repo margin (solid black) and the amount of repo lending per collateral (dash-dot blue) as functions of the collateral asset price. Parameter values are $v_H = 1.03$, $v_L = 0.88$, $q = 0.8$, $\bar{v} = 1$, $l = 0.5$, $x_H = 0.1$, $x_L = -0.4$, $\theta = 0.8$, $u = 0.78$ and $C = 0.6$.

A decrease in asset price leads to a decrease in repo margin and an increase in the amount of lending per collateral.  

2.3 Belief-Driven Repo Run

An equilibrium is defined as an asset price $P$ such that (i) Given the collateral asset price $P$ and the amount of lending per collateral $D$, $a^*(P, D, x_i)$ maximizes the expected payoff of a bank with type $i = H, L$; (ii) Given the collateral asset price $P$, $D$ maximizes a lender’s total lending subject to the constraint that the lending is risk-free; (iii) The collateral asset price $P$ is determined by the market clearing condition in (2).

As a result, an equilibrium of the model can be characterized by a pair of $(P, D)$ that satisfies the following two equations. 

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7Note that the two functions in general have different tipping points, because the sum of the two is not a constant.
\[
D = \min \{v_L, D^*(P)\}
\]  
\[
\theta \frac{l}{P - D} + (1 - \theta) \frac{l + x_L}{P - v_L} = A
\]

where \( D^*(P) = P - \frac{l}{\theta L_L + (1 - \theta) H_H - P} \).

The first equation determines the amount of lending per collateral \( D \) as a function of asset price. This will be referred to as the collateral constraint equation, because \( D \) determines the tightness of a borrower’s collateral constraint. The second equation is the market clearing equation that determines asset price.

Figure 2: the figure plots the asset demand (in solid blue), the asset supply (in dash blue), and the amount of lending per collateral (in dash-dot red) as functions of the collateral asset price. The figure also pinpoints the three equilibria of the model.

Figure 2 plots the aggregate asset demand and supply as a function of the asset price on \([v_L, \bar{v}]\). As shown in the figure, the model can have multiple equilibria. To see this, consider the aggregate asset demand \( AD(P) = \theta \frac{l}{P - D} + (1 - \theta) \frac{l + x_L}{P - v_L} \), where \( D \) is given by the collateral constraint equation. Under Assumption 3, there exists two price thresholds, \( P_a \) and \( P_b \), such that the aggregate asset demand decreases in asset price either when \( P < P_a \) or \( P > P_b \) but increases in the asset price in the intermediate region \([P_a, P_b]\).
The upward sloping asset demand is a result of borrowers facing an endogenous collateral constraint that adjusts to their risk-taking incentive. When the asset price is in the intermediate region, the lender sets the repo margin so that poorly-capitalized banks have incentive to take limited risk and stay solvent at the repayment date. A decrease in asset price makes it more profitable for banks to take excess risk in margin trading. To restore banks’ incentive for prudent risk management, the lender increases the repo margin. This tightens the collateral constraint of all borrowing banks, leading to a reduction in aggregate asset demand.

Because of this upward sloping asset demand, the model can generate multiple equilibria, as shown in Figure 2. Typically the model has three equilibria, including two stable equilibria and an unstable one on the upward sloping part of the demand curve. Among the two stable equilibria, there is a good equilibrium that features high asset price and high repo financing, and a bad one that features low asset price and low repo financing.

Let’s comparing the repo financing, defined as the amount of lending per collateral, in the two stable equilibria. In the good equilibrium, the amount of lending is determined by the asset’s worst-state payoff, i.e. \( D = v_L \). In another word, the debt capacity of a collateral asset depends only on the collateral risk. However, in the bad equilibrium, the amount of lending is determined by \( D = D^*(P) \), which is much smaller than \( v_L \). More importantly, this amount depends not only on the asset’s worst-state payoff but also on the borrower’s risk-taking incentive. In another word, the debt capacity of a collateral asset depends on both collateral risk and counterparty risk.

In the tri-party repo market during normal times, while there is considerable variation in repo haircut across different collateral assets, there is little variation in repo haircut against the same collateral across different borrowers. This is consistent with the model’s good equilibrium where repo haircut is equal to \( 1 - \frac{v_L}{P} \), which depends only on collateral risk.\(^8\) During stress times, there is considerable variation in repo financing against the same collateral across different borrowers. Risky borrowers face a contraction in their repo financing, especially those against risky collateral assets. This is consistent with the model’s bad equilibrium where the amount of repo financing depends on both collateral risk and counterparty risk.

\(^8\)While repo haircut is very stable in the time series during normal times, the model predicts that haircut varies with asset price. There are three ways to reconcile it. First, for safe collateral, there isn’t much variable in asset price. Second, because of risk-neutral measure, the variation in \( P \) comes largely from change in stochastic discount factor that also drives variation in \( v_L \). Third, the constant repo haircut is just a convenient way to keep track as an industry convention.
The two stable equilibria are self-fulfilling, in the sense that which equilibrium arises depends on lenders’ expectation of the collateral asset price. Expecting a high asset price, lenders expect their borrowers to have low incentive for risk taking. Therefore, they are willing to lend a large amount against the asset as collateral. This results in a higher asset demand, rationalizing the initial guess of the high asset price. On the contrary, expecting a low asset price, lenders expect the borrowers to have high incentive for risk taking. Therefore, they are willing to lend only a small amount of money against the asset as collateral. This results in a lower asset demand, rationalizing the initial guess of the low asset price.

We interpret the change from the good equilibrium to the bad one, due to an expectation shock, as a belief-driven repo run. The belief-driven repo run features a large decrease in asset price together with a market-wide reduction in repo financing, which is consistent with evidence during the 2007-08 financial crisis. In our model, one borrower borrows from only one lender, so there is no strategic concern between multiple lenders of a single borrower such as in the traditional Diamond-Dybvig bank run model. However, the equilibrium multiplicity is driven by strategic complementarity among lenders of different borrowers. To be specific, a lender tends to lend less when other lenders lend less, because such market-wide reduction in repo financing pushes down the asset price and thus increases the lender’s concern about counterparty risk.

2.4 Fundamental-driven Repo Run

Because of equilibrium multiplicity, a small shock on the value of collateral assets or the creditworthiness of banks can lead to a large change in asset price and repo financing. In this Section, we study such fundamental-driven repo run by examining the model’s comparative statics with respect to a few parameters that model either collateral risk or counterparty risk. Without loss of generality, we assume that the economy always coordinates to the good equilibrium when the model generates model equilibria.

**Collateral risk:** consider the following two mean-preserving spreads of the asset’s payoff at date 2. (i) Let the asset’s payoffs be \( \tilde{v}_H = v_H + \frac{(1-q)\delta}{q} \) in the good state and \( \tilde{v}_L = v_L - \delta \) in the bad state. (ii) Let the probability of good state be \( \tilde{q} = q - \frac{(1-q)\delta}{v_H - v_L + \delta} \) and the payoff in bad state be \( \tilde{v}_L = v_L - \delta \). An increase in \( \delta \) in both cases can be interpreted as an increase in collateral risk, and the comparative statics results are qualitatively the same. However, the interpretation of the two differs: the former is interpreted as an increase in the asset’s exposure to an aggregate shock, while the latter is interpreted as an increase in the asset’s tail risk.
Theoretically, an increase in collateral risk reduces the aggregate asset demand for two reasons. First, because of no recourse constraint, the amount of lending per collateral is decreasing in collateral risk. Second, because the asset is riskier, low-type banks’ risk-taking incentive increases. This is caused by the increase in the asset’s payoff in the good state in case (i) and the increase in the probability of good state in case (ii). To incentivize the banks not to take excess risk, lenders reduce the amount of lending per collateral, or equivalently increase the repo margin. This leads to a decrease in good-type banks’ asset demand, because their collateral constraints are tightened.

Figure 3 plots the equilibrium asset price and repo financing as functions of collateral risk $\delta$. When the collateral risk is small, the asset price and the amount of lending per collateral are independent of $\delta$. In this region, there is enough cash in the market so that the asset price is equal to the expected value of the collateral. As the collateral risk increases, the asset price starts to decrease as a result of cash-in-the-market pricing. However the amount of lending per collateral does not fall. Because the borrower’s risk-taking incentive is relatively weak at the given market price, lenders are still willing to lend at the asset’s worst-state payoff.

However, when the collateral risk increases above a threshold value $\delta^*$, both the asset price and the amount
of lending per collateral decrease discontinuously. This discontinuity is also shown in Figure 4: a small increase in collateral risk eliminates the possibility of the good equilibrium, resulting in a shift from the good to the bad equilibrium. Here is the intuition. At the threshold, an increase in collateral risk first reduces the aggregate asset demand, leading to a small decrease in asset price. However, the decrease in asset price increases lenders’ concern about counterparty risk due to an increase in borrowers’ risk-taking incentive. Consequently, lenders raise the repo margin. This tightens borrowers’ collateral constraint, resulting in a further decrease in the aggregate asset demand. As a result, the initial shock creates a margin spiral that leads to large falls in both asset price and repo financing. Above the threshold, a further increase in collateral risk continuous to reduce the asset price and repo financing.

![Figure 4](image-url)

Figure 4: this figure plots the discontinuous change in equilibrium asset price by increasing the collateral risk from $\delta = 0.06$ to $\delta = 0.0068$.

In the cross-section, this first comparative statics result provides two reasons why relatively safer assets have a higher debt capacity when served as collateral. To be clear, here we are comparing two assets that are both exposed to the same aggregate shock (keeping $q$ fixed) but differ in their exposure to the shock. First, because safe assets maintain a high value in bad times, asset owners have higher incentive to buy back the asset when it is used as collateral. Second, because the expected gain and loss of purchasing a safer asset is smaller, asset buyers have less incentive to engage in risk taking through buying the asset on margin. Diff-
ferent from the common view that a safer collateral better protects the lender in default, these two reasons highlights the hostage role of collateral in a collateralized debt.

The second comparative statics result predicts that assets with larger tail risk have a smaller debt capacity when served as collateral. Similar to the above argument, there are two reasons why this is so in the model. First, asset buyers who collateralize out the asset in a repo transaction have lower incentive to buy back assets with larger tail risk when the tail risk materializes. Second, these asset buyers have more incentive to engage in risk taking through buying the asset on margin.

Interestingly, we can show that the financial system is also subject to such fundamental-driven repo run when considering an increase in $q$ or $v_H$ only. While an increase in $q$ or $v_H$ increases the expected value of the asset, it also increases banks’ risk-taking incentive as it becomes more profitable to bet on the upside event. As a result, a small increase in $q$ or $v_H$ can also lead to a large reduction in asset price and repo financing.

**Counterparty risk**: consider a decrease in low-type banks’ net illiquid asset value from $x_L$ to $x_L - \sigma$. This reduces the net-worth of poorly-capitalized banks, leading to an increase in banks’ risk-taking incentive. Therefore, we interpret an increase in $\sigma$ as an increase in borrowers’ counterparty risk.

Similarly, an increase in counterparty risk reduces the aggregate asset demand for two reasons. First, when the net-worth of low-type banks decreases, they must reduce their asset demand in order to stay solvent at repayment date. Second, the lower net-worth increases low-type banks’ risk-taking incentive. To incentivize these borrowers not to take excess risk, lenders reduce the amount of lending per collateral, or equivalently increase the repo margin. This leads to a tightening of the collateral constraint of all borrowers, reducing good-type banks’ demand for the asset.

Figure 5 plots the equilibrium asset price and repo financing as functions of $\delta$. We find that when the net-worth of poorly-capitalized banks decrease below a threshold value $\delta^*$, both the asset price and the amount of lending per collateral decrease discontinuously.

At the threshold, a small increase in collateral risk eliminates the possibility of the good equilibrium, result-
Figure 5: this graph plots the equilibrium asset price and repo lending as functions of counterparty risk $\sigma$. Here we consider $x_L = -0.3 - \sigma$ where $\delta \in [0, 2]$.

At the threshold, an increase in counterparty risk first reduces the aggregate asset demand, leading to a small decrease in asset price. However, the initial decrease in asset price increases borrowers’ risk-taking incentive, leading to a tightening of borrowers’ collateral constraint and thus a further decrease in the aggregate asset demand. Consequently, the initial small shock generates a margin spiral that leads to a large decrease in asset price and repo financing.

We interpret the decrease in banks’ net illiquid asset value as a negative shock on the bank’s balance sheet. In our model, a small shock that reduces banks’ net-worth can have a large effect on the price and the debt capacity of assets not directly exposed to the initial shock. This is consistent with evidence during the 2007 financial crisis. As the housing price started to fall, investment banks suffered loss from their real-estate investment and sub-prime mortgage exposure. As these major investment banks become poorly capitalized, their repo lenders started to worry more about counterparty risk due to an increase of their risk-taking incentive. This eventually led to a panic in the funding market, where we saw a large increase in haircut in the bilateral repo market and a massive withdrawal of repo funding from risky borrowers in the tri-party repo market. Consequently, asset price fell dramatically for nearly all asset classes, including those that are not directly related to the initial housing shock.
3 Discussions

In this Section, we justify the key assumptions of the model, and discuss the robustness of our main results with respect to a few simplifying assumptions.

Asymmetric information and counterparty risk. Our main results are driven by two key assumptions of the model. First is the assumption that lenders are uninformed of their counterparty’s creditworthiness. Under this assumption, lenders provide only a single type of repo contract that attracts both well-capitalized and poorly-capitalized banks. If borrowers’ types are common knowledge, lenders can set a higher amount of lending for well-capitalized banks who are assumed to have zero default risk. Then the aggregate demand function becomes

\[ \theta \frac{1}{P-v_L} + (1-\theta) \frac{l+x_L}{P-v_L}. \]

This demand function is always downward sloping in asset price, because a change in asset price does change the collateral constraint of well-capitalized banks.

We think this asymmetric information assumption a reasonable one, since it attempts to capture the fact that repo lenders have less knowledge of borrowers’ balance sheet strength than borrowers themselves do. According to our model, lenders’ concern about counterparty risk can affect repo financing and asset price in a discontinuous manner when borrowers are expected to be poorly capitalized.

Different valuation of collateral. Another key assumption is that lenders value the collateral less than borrowers do. This is the key assumption that give rise to the hostage role of collateral. Because of this assumption, the collateral plays a hostage role when lenders are lending at an amount larger than their valuation of the collateral. In that case, lenders choose the maximum amount of lending that provides borrowers incentive to refrain from risk taking and always buy back the collateral. If lenders and borrowers have the same valuation over the asset in the bad state, i.e. \( u = v_L \), the debt capacity of an asset will be \( D = v_L \), which is independent of borrowers’ risk taking incentive. In another word, lenders care little about counterparty risk because the collateral fully insures lenders against borrowers’ default.

As a result, our theory applies more to collateralized debt backed by collateral assets that are traded in illiquid secondary markets with limited buyers, but less to those backed by collateral assets that can be
easily traded without a large price impact. One proxy for a collateral asset’s secondary market illiquidity, as in Begalle et al. (2016) is the expected time to liquidate a certain amount of the asset without large price impact. Therefore, the repo run intuition in this paper applies more to those collateral assets that take longer time to liquidate.

Infinite risk-aversion. The model’s main results are robust when we assume that lenders are highly, but less than infinitely, risk-averse. When lenders are infinitely risk-averse, the repo rate is fixed at zero, and only the amount of lending per collateral adjusts so as to provide borrowers with incentive to buy back the collateral. When lenders are less than infinitely risk-averse, the repo rate also becomes endogenous. When lenders are enough risk-averse, a decrease in asset price leads to an increase in both the repo rate and the repo margin. The increase in repo rate compensates lenders for higher default risk due to an increase in borrowers’ risk-taking incentives, while the increase in repo margin partially offsets the increase of borrowers’ risk-taking incentives. Similar to the main model, the increase in repo margin further depresses asset price, leading to multiple equilibria similar to the main results shown above. Somewhat differently, the bad equilibrium will now be associated with a higher repo rate and a larger repo margin. This is consistently with evidence in the tri-party repo market during the 2007 crisis. (Krishnamurthy et al. (2014))

One-borrower-one-lender assumption. In the model, we assume that one borrower borrows only from one lender. While the single lender fully internalizes the effect of its lending decision on the borrower’s portfolio choice, the model still generates multiple equilibria because of the strategic complementary between lenders of different borrowers. We think this assumption captures well the borrowing of hedge funds in the bilateral repo market, as most hedge funds have only one prime broker and they borrow through a bilateral repo normally from their prime broker (Eren (2015)).

The equilibrium multiplicity in our model remains when we assume that a borrower has to borrow from multiple lenders. However, the strategic complementary between multiple lenders of the same borrower introduces additional layer of fragility: it makes the bad equilibrium unstable against a trembling hand. In the bad equilibrium, all lenders of a single bank lend the right amount so that the bank is indifferent between limiting their asset position to stay solvent and risk taking. Expecting a small group of lenders to deviate by lending a little more than this right amount, all lenders expect the borrower to take excess risk and become insolvent in the bad state. As a result, they reduce their lending to their valuation of the collateral. This alternative specification is more relevant to the tri-party repo market where large dealer banks borrow
from multiple cash investors as a result of large funding need and liquidity risk diversification. As shown in Krishnamurthy et al. (2014), MMMFs stopped accepting private-label ABS as collateral in the tri-party repo market during the Lehman crisis. This can be explained by the strategic uncertainty among lenders of the same borrowers and by the fact that the lenders’ valuation of those risky collateral was very low during the crisis.

4 Policy Implication

This section considers the model’s implication about ex-post government interventions during a financial crisis. Think of the borrowers in the model as dealer banks that are financing their inventory in the tri-party repo market. The model captures a scenario where some dealer banks suffer loss from their illiquid investment and become poorly capitalized. To compare the effect of different intervention programs, we focus on studying their effect on the aggregate asset demand. For one thing, a higher aggregate asset demand implies a higher possibility of the existence of the good equilibrium. For the other thing, such evaluation is relevant because one of the government’s major policy objectives with respect to ex-post intervention is to stop the price of assets from falling far below their fundamental value. To the extent that falling asset prices in a market turmoil can depress real economy activity and lead to lower welfare, the government will lean towards intervention policies that are more effective in raising asset price, all else being equal.

**Liquidity backstop.** Let’s first consider programs where central banks provide funding liquidity to dealer banks. We have in mind the Primary Dealer Credit Facility (PDCF), which was established in March of 2008 to provide a source of liquidity, in the form of collateralized funding, to primary dealers when such funding was not available elsewhere. In the model, we consider the economy to be at the bad stable equilibrium as a result of belief-driven repo run. We ask the question that how the central bank can move the equilibrium to the good stable one through providing repo lending to borrowers.

In Figure 6, the economy is in the bad stable equilibrium $E_A$ where the collateral asset price and repo financing are significantly lower than those in the good stable equilibrium $E_C$. The central bank can directly lend to borrowers against the asset as collateral. In another word, the central bank acts as a big player that competes with repo lenders. If the central bank is lending at the current market level $D = 0.7875$, it does not help the economy at all. Indeed, the problem of the bad equilibrium is not a lack of liquidity per se, but
a lack of borrowers’ incentive to stay safe as a result of the low asset price.

It turns out that if the government can shift the equilibrium to the good one by promising to lend freely at $D = 0.8480 + \delta$ per unit of collateral, where $0.8480$ is the amount of lending per collateral in the unstable equilibrium $E_B$ and $\delta$ is an infinitely small positive amount. When the central bank promises to lend at $D_B = 0.8480$ to all borrowers, borrowers expect the asset price to increase to the unstable equilibrium level $P_B = 0.9772$. If the central bank promises to lend a little bit more than that, borrowers expect a small increase in asset price. This increase in asset price reduces borrowers’ risk-taking incentive, relieving lenders’ concern about counterparty risk. As a result, lenders set a smaller repo haircut, leading to an increase in asset demand. Eventually the economy moves to the good equilibrium where the asset price is $P_C = 1$, and private lenders are lending $D_C = 0.88$ per collateral, an amount larger than central bank’s liquidity provision.

After the PDCF was put in use on 2008, there is suggestive evidence that PDCF was lending to primary dealers against risky collateral assets at a haircut larger than current market haircut, but lower than the haircut in normal times (Ball (2018)). Our model provides one reason why such choice of repo haircut can work in terms of shifting the financial system out of a crisis.
To shift to the good equilibrium, the central bank must have the ability to lend to all borrowers at an amount larger than the current market level. However, once the private sector expects that, the equilibrium shifts to the good one where lenders provide more financing than the central bank. As a result, the central bank does not need to lend a penny. To put it in another way, the government can make the economy immune to belief-driven repo run by promising to lend freely at an amount lower than the market level in the good equilibrium but higher than that in the bad equilibrium.

However, if the central bank does not have the ability or credibility to lend to all borrowers at an amount larger than the current market level, it cannot shift the economy to the good equilibrium. More problematically, the central bank can be making risky repo lending. The failure to raise asset price makes borrowers’ risk-taking incentives remain high. Then if the central bank is making insufficient lending at an amount larger than the current market level $D = 0.7875$, poorly-capitalized borrowers will obtain high leverage through lending from the central bank and become insolvent in the bad state.

In sum, the liquidity program works when the central bank has the ability to become the lender of first resort, but once it has worked, the central bank is in fact the lender of the last resort. This intuition is reminiscent of the effect of deposit insurance. According to our model, a liquidity backstop, or an expectation of it, can be effective in shifting the system out of crisis after a belief-driven repo run.

**Equity injection and asset purchase.** Let’s now compare and contrast the effect of equity injection and asset purchase. Specifically, consider that a government can spend $m$ amount of cash freely either to purchase the financial asset directly or to purchase equity claims of borrowers. To keep it simple, we assume that the government cannot suffer a loss in conducting intervention policies.

For asset purchase, we consider the following to two scenarios: (i) the government purchases the asset and collateralizes it out at the market haircut or (ii) the government purchase the asset and collateralizing it out at the lowest haircut that corresponds to $D = v_L$ amount of lending per unit of collateral. Figure 7 shows the effect of these two policies.

Not surprisingly, in both scenarios, the asset demand becomes higher. The increase in asset demand is
Figure 7: this figure shows the asset demand curve when there is no intervention (solid black), when there is directly asset purchase financed at the market haircut (dash blue) and when there is directly asset purchase financed at the lowest haircut (dash-dot green). The total spending of asset purchase is fixed at $m = 0.05$.

larger when the government can collateralize the asset at the lowest haircut to obtain a more leverage position. Note that asset purchase does not change the amount of repo lending per collateral as a function of the collateral asset price. This is because borrowers’ creditworthiness is unchanged, keeping the asset price fixed.

For equity injection, consider the following to two scenarios: (i) the government equally purchases equity claims of all banks or (ii) the government purchases equity claims of those poorly-capitalized banks only. To make it a fair comparison, we assume that while the government can identify weak banks, they inject equity to those banks secretly without introducing information about banks’ creditworthiness to the public. The alternative case will be discussed later. Figure 8 shows the effect of these two policies.

In the first case where the government purchases equity claims of all banks, both the asset demand curve and the collateral constraint curve shift upwards. Intuitively, injecting capital into banks increase asset demand through two channels. First, there is a direct purchase channel: injecting equity gives all banks more cash to buy assets at the market haircut. Second, there is the endogenous collateral constraint channel: injecting equity reduces the market haircut and relax banks’ collateral constraint. The latter is so because risky banks become safer after equity injection, so lenders worry less about counterparty risk.
Interestingly, we find that the government injecting equity to all banks is more effective in raising asset demand than directly purchasing the asset on margin at the market haircut, and is equivalently effective as directly purchasing the asset on margin at the lowest haircut. The former is so because the effect of the government purchasing asset at the market haircut is as strong as the direct purchase channel of equity injection, but equity injection has an additional effect through relaxing banks’ collateral constraint. In fact, the effect of this additional collateral constraint channel is so large so that injecting equity has the same effect as using the same amount of cash to purchase the asset on margin with the highest amount of repo financing.

We also find that the effect of injecting equity to all banks does is the same whether the government force banks to use the injected cash to pay down their debt or not. Forcing all banks to pay down debt makes banks safer, increasing the effect of the collateral constraint channel. However, it also reduces the amount of cash banks hold, decreasing the effect of the direct purchase channel. As a result, these two perfectly cancel out each other, leaving the total effect unchanged.

Let’s now consider the second case where the government purchases equity claims of risky banks only. Comparing to an undifferentiated equity injection, an equity injection to only risky banks make these banks better
capitalized. As a result, the asset demand should increase more through the collateral constraint channel. However, because risky banks have incentive to hoard cash for solvency concerns, the asset demand should increase less through the directly purchase channel. In sum, it is ambiguous which policy works better. Qualitatively, we find that injecting equity to all banks is more effective in raising asset demand as long as the repo margin is not very high in a repo run.

In this section we consider the potential informational value of equity injection. When equity injection to banks are carried out through the government designs an equity purchase price to screen off safe banks, the government’s intention to attract risky banks generates an interesting strategic consideration. First of all, our model predicts that for such a policy to work, the equity purchase price must give risky banks a subsidy relative to the risky bank’s equity price after the policy works. This is because banks actually make more profit when asset price is low. When the equity purchase price is between risky banks’ equity price after the policy works and their current equity price, a risky bank would accept (reject) the equity purchase offer if expecting all others to accept (reject) the offer. When the equity purchase price is above risky banks’ current equity price, while all risky banks take the equity offer, the policy risks providing too much subsidy to screen off safe banks. In that case, equity injection is the least effective: all banks accept a big subsidy through taking the equity offer, yet asset price and repo financing remain low at the crisis equilibrium.

**Debt guarantee** After the Reserve Primary Fund broke the buck after Lehman defaulted, the U.S. treasury introduced the Temporary Guarantee Program for money market funds to arrest a run on prime money market mutual funds (MMMFs). Note that these prime MMMFs are those who invest heavily in the tri-party repo market as lenders. Therefore we argue that a side effect of this debt guarantee is that it restores these MMMFs’ incentive to lend against risky collateral. In the model, we interpret it as an increase in $u$, which is the lender’s valuation of the collateral.

In our model, an increase in $u$ has no effect on the equilibrium when $u$ is below a threshold value given in Assumption 2. However, when $u$ increases above that threshold, lenders sometimes lend at their valuation of the collateral despite high counterparty risk. This is shown in Figure 9, where we show asset demand and repo financing as functions of asset price when setting $u = 0.82$ instead of $u = .78$ as in Figure 2. This increases the amount of repo financing when the asset price in the intermediate region, lending to an increase in borrowers’ asset demand. Moreover, the demand curve becomes less upward-sloping, making the system more stable against belief-driven or fundamental-driven repo runs.
Toxic asset relief. In 2009, U.S. Treasury and FDIC created the Legacy Loan Program, a public-private investment program that taps TARP money to purchase troubled and illiquid loans and other assets from insured banks and thrifts. Here we use our model to think about the effect of removing toxic assets from risky banks’ balance sheet.

Taking the model at face value, we find that removing bad illiquid assets from banks’ balance sheet have no effect on the price of other financial assets. This is because we assume that bad illiquid assets are known to be bad for sure at date 0 with no future payoff uncertainty. When these bad assets can be worse in the future, removing bad illiquid assets from banks’ balance sheet can increase the price of other financial assets. To see this, consider the extension of the main model where the payoff of poorly capitalized banks’ illiquid asset becomes risky. Because lenders care about borrowers’ solvency in the worst-state scenario, the repo margin concerns the worst-state value of banks’ illiquid asset. Removing these bad illiquid assets from banks makes lenders worry less about counterparty risk. As a result, lenders are willing to lend more to banks against other financial assets as collateral, leading to a increase in the price of these financial assets.

Therefore, removing illiquid assets from risky banks is more effective when these removed assets are more toxic, in the sense that they entail larger downside risk in the future. The government should remove from risky banks those illiquid assets that can lose a lot of value in the future, but not those that have lost a lot of value before but have little downside risk in the future.
5 Endogenous Risk Exposure and Financial Fragility

We have shown that a small increase in collateral risk or counterparty risk can lead to a large decrease in asset price and repo financing in times when some borrowers are assumed exogenously to be poorly capitalized. This section extends the main model to study banks’ endogenous exposure to balance sheet shocks by introducing banks’ ex-ante investment decision between making illiquid investment and holding cash.

The model is extended to a three-date environment where banks at date 0 first choose to invest between illiquid loan and cash. At date 0, each bank owns 1 unit of cash and has $\eta$ unit of debt that requires a total repayment of $\eta$ unit of cash at date 2. The bank can choose to purchase $\rho^i \in [0, 1]$ unit of illiquid asset. Each unit of illiquid asset costs 1 unit of cash at date. The illiquid asset pays off only at date 2 and has no liquidation value at date 1. The payoff of banks’ illiquid assets is subject to both an aggregate shock and an idiosyncratic shock that will realize at date 1. When the aggregate state is good, which happens with probability $\alpha$, all banks’ illiquid asset pays $X_H$ for sure. When the aggregate state is bad, which happens with probability $1 - \alpha$, banks’ asset payoffs become heterogeneous. Specifically, each bank’s illiquid assets pay $X_H$ with probability $\theta(\rho^i)$ and $X_L$ with probability $1 - \theta(\rho^i)$. This idiosyncratic shock is independent across banks. The probability of success $\theta(\rho^i)$ is a decreasing function of $\rho^i$, the amount of illiquid asset purchase.

At date 1, both the aggregate shock and the idiosyncratic shocks realize. The model onwards becomes almost the same as the main model. Each bank owns $l^i = 1 - \rho^i$ unit of cash and $x^i = \rho^i \tilde{X} - \eta$ unit of net illiquid asset, where $\tilde{X}$ is equal to $X_H$ or $X_L$, depending on both the aggregate shock and an idiosyncratic shock.

We assume that a bank obtains a positive charter value $C$ whenever it stays solvent at date 2. Banks can purchase a financial asset in a competitive market. The total supply of the financial asset is $A$. If held by a bank, the asset pays $v_H$ with probability $q$ and $v_L$ with probability $1 - q$ at date 2. Same as before, each bank can purchase the asset with cash borrowed from a group of lenders. Lenders are uninformed of borrowers’ idiosyncratic shock, and offer a single type of risk-free repo contract to maximize its total lending. At date 2, all assets matures and banks repay creditors subject to limited liability.
To simplify our analysis, we focus on symmetric equilibrium where banks make the same investment choice at date 0. The equilibrium can be defined the asset prices \( P_j \) in the two aggregate state \( j = g, b \) such that (i) each lender at date 1 in state \( i \) chooses the amount of lending per collateral \( D_j \) to maximize its total (risk-free) lending, taking the asset price \( P_j \) as given; (ii) each bank at date 1 in state \( i \) makes asset purchase and debt issuance decision to maximize their expected payoff at date 2, taking the asset price \( P_j \) and the amount of lending per collateral \( D_j \) as given; (iii) the asset market clears at date 1 in both states; and (iv) each bank at date 0 chooses \( \rho \), the amount of investment in the illiquid asset to maximize their expected payoff at date 2, taking future asset price and repo financing as given.

In the good aggregate state at date 1, banks are homogenous in their cash and illiquid asset position. To incentivize borrowers not to take excess risk, lenders set the amount of lending per collateral \( D_g \) at the minimum of \( v_L \) and \( D^*_g(P_g) = P_g - \frac{1 - \rho}{\eta H - \rho \eta} \frac{1 - \rho}{\eta H - \rho \eta} + \frac{\rho X_H - \eta}{\eta H - \rho \eta} \). To focus on the case where no-recourse constraint binds for banks with illiquid asset of high value, we impose parameter restrictions to make sure that (i) the net illiquid asset value of banks with high quality illiquid assets is positive in equilibrium, and that (2) there is enough cash in the market absorb all assets at the asset’s expected value. As a result, the asset price in the good aggregate state is \( P_g = \bar{v} \), and the amount of lending per collateral is \( D_g = v_L \).

In the bad aggregate state at date 2, banks are heterogenous exactly as the case in the main model. To incentivize borrowers not to take excess risk, lenders set the amount of lending per collateral \( D_b \) at the minimum of \( v_L \) and \( D^*_b(P_b) = P_b - \frac{1 - \rho}{\eta H - \rho \eta} \frac{1 - \rho}{\eta H - \rho \eta} + \frac{\rho X_L - \eta}{\eta H - \rho \eta} \). The market clearing condition in this case is \( \theta(\rho) \frac{1 - \rho}{P_b - D_g} + (1 - \theta(\rho)) \frac{1 - \rho \rho X_L - \eta}{P_b - v_L} = A. \)

Therefore, we can compute banks expected payoff at date 1 in different states. A bank’s expected payoff in the good aggregate state is \( U_g(\rho) = 1 - \rho + \rho X_H - \eta + C. \) In the bad aggregate state, a bank’s expected payoff in the good idiosyncratic state is \( U_{bg}(\rho) = \frac{\bar{v} - D_b}{P_b - D_b} (1 - \rho) + \rho X_H - \eta + C, \) and its expected payoff in the bad idiosyncratic state is \( U_{bb}(\rho) = \frac{\bar{v} - D_b}{P_b - v_L} (1 - \rho + \rho X_L - \eta) + C. \) At date 0, a bank chooses \( \rho \) to \( \max_{\rho \in [0,1]} \{ Q(\rho; P_b, D_b) \} = \{ \alpha U_g + (1 - \alpha)(\theta(\rho)U_{bg}(\rho) + (1 - \theta(\rho))U_{bb}(\rho)) \}. \) A necessary condition for an interior solution is that the first order condition has to be zero.

To sum up, in a symmetric equilibrium of the model, \( P_g = \bar{v} \) and \( D_g = v_L \) in the good state. In the good aggregate state, the collateral asset price is equal to the expected value of the asset, and the amount of
lending only depends on the worst-case payoff of the collateral. \((P_b, D_b, \rho)\), the asset price in the bad state, the amount of lending per collateral in the bad state, and the initial choice of illiquid asset purchase, have to satisfy the three equations below,

\[
D_b = \min \{v_L, D^*(P_b)\} \quad \text{(CCb)}
\]

\[
\theta(\rho) \frac{1 - \rho}{P_g - D_g} + (1 - \theta(\rho)) \frac{1 - \rho + \rho X_L - \eta}{P_g - v_L} = A \quad \text{(MCb)}
\]

\[
\rho = \arg\max_{\rho \in [0,1]} \{Q(\rho; P_b, D_b)\} \quad \text{(IAC)}
\]

The first and the second equation is the collateral constraint and the market clearing condition in the bad aggregate state. The third equation is a necessary condition of the optimality of illiquid asset investment decision. We show in the Appendix that this becomes a sufficient condition under mild restrictions on the shape of the function \(\theta(\rho)\) and the charter value \(C\).

Plugging the collateral constraint equation into the market clearing condition, we obtain a system of two equations and two unknowns \((P_b, \rho)\). The two equations are plotted in Figure 10.

![Figure 10](image-url)

Figure 10: this figure shows the market clearing condition (solid blue) and the optimality condition (dash red) as relations between asset price and initial investment decision. \(\alpha = 0.65\), \(A = 2.5\), and \(\theta = 0.6 - 0.1\rho\).
The optimality condition of illiquid asset investment decision shows a positive relation between \((P_b, \rho)\). This is because an increase in \(P_b\) reduces the profit of investing in the financial asset at date 1, pushing banks to invest more in the illiquid asset at date 0 until returns are equalized. The market clearing condition in the bad aggregate state has two turning points, because of the endogenous response of repo margin as in Section 2. When the asset price is either very high or very low, a decrease in asset price either has no effect or decreases the margin of repo lending. In either case, it leads to an increase in asset demand, pushing banks to invest more in the illiquid asset at date 0 until the market clearing condition is re-balanced. When the asset price is in the intermediate level, a decrease in asset price decreases asset demand as lenders raise repo margin to suppress borrowers’ risk-taking incentive. Therefore, the market clearing condition is rebalanced through an decrease in illiquid asset investment.

As shown in the figure, this model has a unique equilibrium. While we cannot prove the uniqueness of the equilibrium, here is the intuition why introducing the illiquid asset investment decision reduces the equilibrium multiplicity of the main model. Recall that the equilibrium multiplicity in the main model is because a decrease in asset price can lead to a tighter collateral constraint, reducing the aggregate asset demand. In this extended model, a decrease in asset price has an additional effect on asset demand through the initial choice of illiquid assets. Expecting a lower asset price at date 1, banks at date 0 expect a higher return of holding cash, and thus reducing their purchase of the illiquid asset. This increases the amount of cash in the banking sector at date 1, which leads to an increase in asset demand. This additional effect makes the demand curve less upward sloping, and thus reduces the extent of equilibrium multiplicity.

However, the uniqueness of equilibrium, if exists, is "time-inconsistent" in the following sense. Assume the economy has a unique equilibrium of \((\rho, P_g, D_g, P_b, D_g)\) at date 0. However, once the investment decision has been made at date 0, the economy is still subject to equilibrium multiplicity at date 1 in the bad aggregate state. More interestingly, the unique equilibrium at date 0 may be stable or unstable after hit by a negative aggregate shock at date 1, depending on which part of the demand curve the economy resides. Figure 9 illustrates this point by studying the effect of an increase in \(\alpha\), the probability that the good aggregate state occurs at date 1.

In the upper figure of Figure 11, when \(\alpha = \alpha_0\), the date 0 equilibrium is in the first region where asset price in the bad aggregate state is very high. As a result, while there are multiple equilibria at date 1 in the bad aggregate state, the original equilibrium is one of the two stable equilibria, which means that the original equilibrium is stable against small perturbations. However, when we increase \(\alpha\) to \(\alpha_1 > \alpha_0\), the date
Figure 11: this left panel shows the market clearing condition (solid blue) and the optimality condition when \( \alpha = 0.65 \) (dash red), and the optimality condition when \( \alpha = 0.67 \) (dash-dot green). The right panel shows the date 1 asset demand and supply in these two cases.

0 equilibrium enters in the second region where asset price in the bad aggregate state is in the intermediate level. As a result, when hit by a negative aggregate shock, the original equilibrium now becomes the unstable equilibrium that resides in the upper sloping part of the demand curve. This equilibrium is unstable because a small perturbation that decreases (increase) the asset price by a little can drive the economy all the way to the bad (good) stable equilibrium.

The model characterize fragility in the financial market in boom times. A decrease in aggregate downside risk (think of it as the housing boom before 2007) incentivizes banks to invest heavily on illiquid assets that are highly exposed to the aggregate risk. When the economy keeps in the good state, everything works out perfectly: those illiquid assets pay high, assets that are not heavily exposed to the aggregate risk are priced high, and the repo haircut is low. However, when the economy is hit by a negative aggregate shock, some banks suffer large loss on their illiquid asset positions. Due to the overhang of these poorly-capitalized banks as borrowers in the repo market, the financial market becomes inherently fragile. A small perturbation can lead to a large increase in repo haircut and a large fall in the price of assets in all asset classes.

The financial fragility, i.e. equilibrium instability in boom times, provides a rationale for financial regulation. Financial regulations that force financial institutions to expose less to the aggregate shock in good times can make the financial system less fragile in bad times when the economy is hit by negative aggregate shocks. Interestingly, while financial regulation in good times makes the financial system more robust against bad shocks, there is still a role for government intervention during a financial crisis that is caused by equilibrium.
multiplicity.

6 Conclusion

This paper shows that when repo collateral serves as a hostage that incentive borrowers to repay, the repo margin responds to counterparty risk in times when banks suffer loss on their balance sheet. The concern about counterparty risk, or more specifically the concern about borrowers’ risk-taking incentive, can make the asset market and the repo market unstable, as a small increase in fundamental risks, or a self-fulfilling belief shock, can shift the financial system to a crisis equilibrium with significantly lower asset price and repo financing. We show that in such a market crash and repo run, the effectiveness of ex-post intervention policies depends on the reason for the run as well as the design of those policies.

For future research, there are two interesting directions to go. First is to think more about policy evaluation. The paper studies the effectiveness of ex-post interventions in terms of their ability to raise asset demand. It is interesting and necessary to conduct a more normative policy analysis by introducing a welfare criteria into the model. Second is to think more about repo rollover. While this static model captures the run risk of repo, it misses the rollover loss episode of repo that can only be studied in a dynamic model. Therefore, it is important to study the model’s implication when repo is subject to rollover risk.
References


