# Repo Collateral and Counterparty Risks: Theory and Evidence


**Abstract**

We propose a dynamic search-based asset pricing model with collateral and counterparty risks to examine the role of these risks in the repo market and the secondary market for collateral. We show that collateral and counterparty risks increase expected loss in repo transactions, discourage trading activity, and reduce demand for collateral. Funding costs in the repo market and yield spreads of bond collateral increase with these risks and this effect magni.es in times of stress. We test these hypotheses using deal-level MBS repo data in N-MFP and N-Q .lings and aggregate data. Empirical evidence supports the predictions of the model.



JEL classi.cation: G01; G10; G12

Keywords: Collateral risk; counterparty risk; mortgage repo market; MBS yield spreads; search externalities

# 1 Introduction

The repurchase agreement (repo) market has emerged as the primary channel of financial market liquidity. Indeed, the repo market is a major source of short-term financing for government securities dealers, and both financial and nonfinancial institutions. As such, the repo market is pivotal for market liquidity and corporate financing, and variations in the performance of the repo market can have profound implications for financial stability and asset pricing. Understanding the function of the repo market and the behavior of repo spreads is of fundamental importance for ascertaining the determinants of borrowing costs and financing choices. It is also essential for assessing funding availability and presaging changes in financial conditions with potential consequences for macroeconomic outcomes.

This paper investigates the role of collateral and counterparty risks in the repo market. Collateral risk directly affects the terms of repo contracts, i.e., lending rates and margin decrease with collateral quality. High repo rates and margin in turn discourage borrowing and lower leverage and liquidity, which can significantly affect asset prices. Investigating the causes of financial crisis, Brunnermeier and Pedersen (2009), Gârleanu and Pedersen (2011), and Geanakoplos (2010) study the role of securities as collateral in financing, and the implications for liquidity and asset pricing. An important finding is that variations in collateral value and margin affect market liquidity and induces leverage cycle, leading to booms and busts (see also Geanakoplos (2010); Shen et al. (2014)). Counterparty risk is another key factor in the repo market as repo deals build on the trust in counterparties. Jarrow and Yu (2001) show that counterparty risk is vital for the pricing of defaultable securities. Taylor (2009), Krishnamurthy (2010), Singh and Aitken (2010), Gorton and Metrick (2012), and Liu and Wu (2017) suggest that counterparty risk is the driving force for repo runs in the subprime crisis. Collectively, past studies suggest that both collateral and counterparty risks are critical factors in the repo market, and any theoretical model must incorporate these factors in order to be able to satisfactorily explain the phenomena in this market and their relations to financial stability and macroeconomic performance. In this paper, we propose a dynamic asset pricing model with search frictions to examine the effects of collateral and counterparty risks on the funding cost in the repo market and collateral value in the asset market, and test the implications of this model using the repo and spot market data of mortgage-backed securities (MBS).

Repo financing is a collateralized loan in which the repo security serves the same function as collateral. Collateral is a form of protection for the cash lender's interest against the risk that the cash borrower may not be able to repay the principal and interest. Collateral quality is thus essential for ensuring the soundness of repo transactions. Low quality collateral has high default probability and price risk. To compensate for these risks, repo spreads and haircut (or margin) will have to adjust to give cash lenders a sufficient compensation and protection.

In addition to collateral risk, market participants face counterparty risk in repo transactions. A repo deal involves two parties, the repo buyer and seller, and two transactions, transferring a security in exchange for cash and repurchasing it at maturity. The repo buyer could be an investor interested in investing money to earn interest or some one who wants to borrow the security for the shortselling purpose. The repo buyer (cash lender or security borrower) may fail to deliver the security or the repo seller (security lender) may fail to buy it back at the maturity date. Even if the collateral is of good quality, one party can default for various reasons, resulting in a loss to its counterparty as the collateral may have lost value or become illiquid (e.g., due to fire sales). The counterparty's credit is hence a major concern in repo lending.[1] If one party defaults, another party may suffer losses and increase its own risk of default, which may further increase default risk of other counterparties through rehypothecation or other intricate financial relations. When multiple parties are involved in trading on the same security and collateral is rehypothecated, it can lead to a string of defaults and contagion (see Liu and Wu (2017)).

A number of studies have investigated the role of collateral quality in the repo market. Gorton and Ordoñez (2014) suggests that the subprime crisis is a collateral crisis. Their model shows that a sudden loss of confidence in response to an aggregate shock provides an incentive for the private sector to produce information about the quality of collateral. Lee (2015) analyzes the relationship between collateral circulation and financial stability, and find that while collateral circulation makes repos liquid and increases investment and economic efficiency, it increases the risk of fragility in the financial system. On the empirical

[1] The government regulatory agency has advised repo market participants that their primary concern in transactions should be the creditworthiness of the counterparty (see May 2013 annual report of the Financial Stability Oversight Council (FSOC) for the guidance on counterparty risk management practices).

front, Hu, Pan and Wang (2015) and Auh and Landoni (2016) provide empirical evidence on the effects of collateral quality in the repo market. Aggarwal et al. (2017) find that quality collateral is important for a normal function of repo markets, and a shortage of quality assets for collateral can cause market distortion.

Another strand of research examines the role of counterparty risk in the repo market (see, for example, Taylor (2009); Krishnamurthy (2010); Singh and Aitken (2010); Gorton and Metrick (2012); Liu and Wu (2017)). These studies show that counterparty risk has significant impacts on repo spreads, capital provision, asset prices and economic activity. Taylor (2009) suggests that the underlying cause of the subprime crisis is inherently a counterparty risk issue. Gorton and Metrick (2012) find evidence that counterparty risk is behind the heightened repo spreads during the subprime crisis. Liu and Wu (2017) develop a dynamic asset pricing model with counterparty risk and show that it affects Treasury repo spreads and on-/off-the-run spreads.

Existing theoretical models have investigated the issues of collateral risk and counterparty risk separately (e.g., Gorton and Ordoñez (2014), Lee (2015), Infante and Vardoulakis (2018) for collateral risk; and Jarrow and Yu, 2001, Liu and Wu (2017) for counterparty risk). At the same time, past empirical studies on the repo market have typically formed test hypotheses without a theoretical model, and thus lack a solid theoretical foundation (see, for example, Gorton and Metrick (2012); Hu et al. (2015); Auh and Landoni (2016)). This paper bridges these gaps in the extant literature. First, we develop a search-based dynamic asset pricing model that incorporates both collateral and counterparty risks in the repo market. Second, we provide empirical tests on the implications of this model using the data of mortgage repos and the underlying MBS collateral. Despite the importance of collateral and counterparty risks in the repo market, there is little empirical research on the joint effects of these risks. Our work expands the literature by uncovering evidence that collateral and counterparty risks are priced in both repo and mortgage-backed securities markets, and that the effects of these risks magnify during the financial crisis. Besides counterparty and collateral risks, we find that search frictions, liquidity, volatility, market uncertainty, relationship trading, and term structure factors are relevant for the pricing of repos and collateral. Importantly, the effects of collateral and counterparty risks remain highly significant even after controlling for these factors.

The issues of repo funding and collateralization have attracted considerable attention recently from academic researchers and policy makers. This paper is related to a number of studies on the repo market (see, for example, Bartolini et al. (2011); Gorton and Metrick (2012); Martin et al. (2014); Copeland et al. (2014); Krishnamurthy et al. (2014); Hu, Pan and Wang (2015); Auh and Landoni (2016); Han, and Nikolaou (2016); Liu (2016); Fuhrer et al. (2016); Begalle et al. (2016); Gorton et al. (2017); Matta and Perotti (2017); Du and Palia (2018); Infante and Vardoulakis (2018)). Auh and Landoni (2016) examine the effects of collateral quality on mortgage repo spreads and margin using a proprietary data set of bilateral repos. Our empirical analysis complements their study by using long-span triparty mortgage repo data and examining the role of both counterparty and collateral risks in the repo market. We find that activity in the repo market has a spillover effect on the pricing of mortgage-backed securities. More importantly, we build a pricing model to assess the role of collateral and counterparty risk factors in the repo market, which provides a theoretical foundation for our empirical tests. Moreover, as we consider both liquid (new) and illiquid (old) bonds as collateral in the theoretical model, our work is related to the studies on the yield spread of on- and off-the-runs and repo specialness (see, for example, Duffie (1996); Krishnamurthy (2002); Longstaff et al. (2005); Vayanos and Weill (2008); Graveline and McBrady (2011)). While these papers examine the effects of liquidity, shortselling activity, and the supply of and demand for collateral, we further account for the effects of counterparty and collateral risks on the spreads of new and old bonds.

Our empirical analysis is related to the research on mortgages and mortgage-backed securities (see, for example, Gabaix et al. (2007); Hanson (2014); Carlin et al. (2014); Hancock and Passmore (2014); Boyarchenko et al. (2015); Chernov et al. (2016); Kitsul and Ochoa (2016); Malkhozov et al. (2016)). Our work expands this literature by investigating the effects of counterparty and collateral risks on the fee of lending MBS and yield spreads in the mortgage repo market, and the pricing of new (liquid) versus old (illiquid) mortgage-backed securities. Gorton and Metrick (2012) provide evidence that counterparty risk in the repo market affects credit spreads of risky bonds in the spot market. Banerjee and Graveline (2014) and Liu and Wu (2017) find that the trading activity in the repo market can affect the pricing of the underlying collateral asset. Building on this line of research, we show that both counterparty and collateral risks in the repo market can affect the pricing of mortgage-backed securities in the secondary market.

The remainder of this paper is organized as follows. Section 2 provides the institutional background in the mortgage repo market. Section 3 presents a search-based model with collateral and counterparty risks. Following this, numerical solutions are provided to show the effects of collateral and counterparty risks, search intensity, volatility, market uncertainty risk aversion, and interest rates on the lending fee and the pricing of the underlying repo collateral. Section 4 discusses the data and Section 5 presents the empirical evidence based on time-series aggregate data and cross-sectional repo deal-level data. Finally, Section 6 summarizes major findings and concludes the paper.

## 2 The institutional background

Repurchase agreements (or repos) are used for financing and securities lending. Financial institutions, securities dealers, hedge funds and non-financial institutions may tap in the repo market to borrow money. On the other side of the market, institutional investors, such as pension funds, mutual funds, corporate treasurers, and state and local governments may turn to repos for short-term investment while retaining flexibility for rollover. Over the past several decades, the demand for repos has grown considerably as nonfinancial firms have accumulated a substantial amount of cash holding, and states and municipalities have expanded their uses of repos to invest their idle cash.

Aside from cash lending, repos are widely used for borrowing securities to cover short positions. Repos are used by financial institutions and hedge funds to create short-selling positions and manage their leverage exposure. Repos used for the short-selling purpose resemble securities lending and the interest given up by the buyer reflects the lending fee paid for security borrowing. In security lending business, high demand can arise for certain types of securities, for which repo buyers are willing to accept lower interest rates. These securities are said to be “on special”. The lending fee for such securities can be substantial when demand is excessively high. The hard-sought securities are typically newly issued securities or on-the-runs which are much more liquid than the old or off-the-run issues.

The repo market is a secured financing market where collateral is used to mitigate risk. Collateral is used for protecting the repo buyer’s interest against the risk that the seller may default. Although repo financing is similar to collateralized bank loans, it has distinct features. Unlike a secured bank loan in which collateral is used to secure the lending, repo collateral is sold and bought back at maturity which is typically short term. In a repo transaction, the title of the security (collateral) is transferred to the repo buyer free and clear, as opposed to just granting a security interest for the cash loan. Hence, the repo buyer is in effect the owner of the collateral asset and can sell the asset outright or pledge it to a third party. Under the US Bankruptcy Code, repo investors are protected by the safe-harbor provision which allows repos to be exempted from the automatic stay so that investors' claims will not end up in the bankruptcy court as a result of counterparty default. Despite this privilege, the collateral securing the repo may not provide full protection for the repo buyer as the value of collateral may change and fall short of the buyer's claim. How good the protection is for the repo buyer (cash lender) in part depends on the quality of collateral. High-quality collateral has low price risk and better protection for the cash lender. To limit the counterparty's exposure, a haircut or margin is applied, which depends on collateral quality and counterparty risk. Haircut is a way of overcollateralizing to protect the cash lender.

A variety of assets can be posted as collateral in the repo market. The list ranges from the safest asset, like Treasury securities, to highly risky structural products such as collateralized loan (CLO) or debt (CDO) obligations. Collateral risk is an important factor in repo transactions. Repo rates and/or haircuts tend to be higher for transactions secured by riskier collateral. Another major factor in repo transactions is the creditworthiness of repo counterparty. Counterparty risk is a concern because collateral may only provide partial protection for repo transactions. A default by a counterparty can still be costly despite the safe harbor provision granted to the cash lender. Apart from collateral risk itself, an exercise of collateral right entails operational and legal risks associated with administrative delays, market liquidity and volatility, and costs in replacing defaulted repos and in unwinding or replacing hedges for investment portfolios. The cash lender may not be able to claim the "consequential losses" due to suboptimal hedging or portfolio and security inventory management resulting from a counterparty default.

A substantial amount of repos uses mortgage-backed securities as collateral. Prior to the subprime crisis, there was a housing and credit boom. Many mortgages were securitized into bonds and used as collateral in the repo market. Between 1996 and 2007, nonagency or private residential mortgage-backed security issuance increased by 1,248 percent and commercial mortgage-backed securities (CMBS) increased by 1,691 percent (see Gorton and Ordoñez (2014)). The high growth was primarily fueled by the housing boom prior to the subprime crisis. A big chunk of mortgages was securitized into bonds by government agencies and government-sponsored enterprises like Fannie Mae and Freddie Mac. As housing prices started to decline, mortgage-backed securities based on shaky loans turn highly risky. The lenders in the repo market began to question the quality of MBS collateral and became reluctant to lend cash. Since the function of the repo market is fundamentally built on trust, the loss of confidence in repo counterparty has systemic consequences. The collapse of the housing market led the cash lenders to doubt not only the value of MBS collateral but also other collateral and securitizations, and became unwilling to roll over loans. When the repos were not renewed, the volume of MBS collateral shrank considerably. Over the period of 2007 and 2012, non-agency residential MBS collateral fell by 100 percent while CMBS fell by 91 percent.[2] The decline in the amount of collateral posted in the repo market was accelerated by the deleveraging of dealers and sharp decreases in both new bond issuance and collateral valuation.

During the subprime crisis, MBS yield spreads reached historical highs as mortgage default mounted. Yield spreads increased for the private-labeled MBS as well as agency-backed MBS. The MBS backed by US government agency or sponsored enterprises normally have limited credit risk because these securities are explicitly or implicitly guaranteed by the government. However, these securities are by no means riskfree (see Chernov et al. (2016); Kitsul and Ochoa (2016)). First, while the risk of default for the underlying mortgages may be borne by government agencies, this protection is not imminent for government-sponsored enterprises. Government support for the MBS backed by sponsored enterprises Fannie Mae and Freddie Mac is only implicit and may happen only when they are under severe stress. For example, before Fannie Mae and Freddie Mac were finally placed in federal conservatorships in September 2008, securities guaranteed by these enterprises already lost substantial value. Second, besides default risk, MBS value is subject to other risks such as prepayment, the

[2] See the statistics in US Mortgage-Related Issuance and Outstanding published by Securities Industry and Financial Market Association (SIFMA) and also Gorton and Ordoñez (2014).

timing of cash flows, and interest rate variability. Third, due to the interconnected structure of the repo market, a problem occurred in a segment of the repo market can quickly spill over to other segments. Thus, when cash lenders question the value of private-label MBS, it can adversely affect the value of other mortgage- or asset-backed securities.

Collateral rehypothecation is common in the repo market. The Credit Support Annex developed by the International Swaps and Derivatives Association (ISDA) defines the rights and rules for rehypothecation. The right of rehypothecation entitles a secured party to sell the posted collateral outright, lend the collateral in its securities lending business, or use the collateral to secure its own borrowings. Rehypothecation provides funding liquidity and lowers the cost of repo financing as the right of transfer makes the cash provider more willing to lend. Though rehypothecation enhances liquidity, it also increases counterparty risk. When a chain of trades are all supported by the same collateral, the protection for each party weakens. Rehypothecation can amplify market strains when participants become nervous about the possibility of counterparty default and reluctant to yield rehypothecation rights. Singh and Aitken (2010) document that the amount of assets available as collateral decreased by about $5 trillion as a result of reduced rehypothecation and collateral hoarding shortly after the collapse of Lehman Brothers.

Counterparty risk is a greater concern when the counterparties in the repo contract are involved also in other financial relations, i.e., through credit derivatives or other liabilities. In the financial market, many firms are interconnected by complex credit and business relations. Due to these complicated relations, the effect of counterparty risk can be significant when the probability of entering into financial distress by either party is high even if the collateral itself is relatively safe.

In this paper, we explore the effects of collateral quality and counterparty risks on security lending fee and the pricing of risky collateral in the secondary market. We first develop a dynamic asset pricing model with search frictions and collateral and counterparty risks, which accommodates the legal and institutional features of the repo market, to analyze the effects of these factors on repo trading activity, lending fee, and the value of collateral. We then take the model to the data in the MBS repo and spot markets to verify the implications of the theoretical model. A wide range of assets can be used as collateral in secured lending. Treasury obligations, agency securities, and mortgage-backed securities (MBS) are the three most popular collateral asset classes in repo funding. Repos using Treasury securities as collateral account for the largest share of the repo market, but there is also a very active market for the repos against the securities issued by government agencies and mortgage-backed securities. Repos collateralized by US Treasuries and agency securities have attracted much attention in empirical research partly due to their popularity as collateral of lending in the repo market (see, for example, Copeland et al. (2014); Krishnamurthy et al. (2014); Liu and Wu (2017)). In contrast, the issues on the repos with mortgage and other risky collateral have received much less attention and considerably underexplored.[3] The empirical analysis in this paper attempts to fill this gap.

# 3 A Search-based model with collateral and counterparty risks

We propose a search-based model that accounts for the effects of collateral quality, counterparty default risk and search frictions in the repo market on lending fee, and the pricing of collateral asset in the secondary market. This model is a generalization of Vayanos and Weill (2008) to consider collateral and counterparty risks. In this section, we focus on the main results of our model and highlight the key differences between our model and that of Vayanos and Weill (2008). Following this, we provide numerical solutions to demonstrate the effects of collateral and counterparty risks and other factors on the lending fee and the pricing of risky assets used as collateral. Technicalities and tedious equations in the model are placed in the appendix. Table 1 provides the definitions of variables and parameters in the model, and the parameter values used in numerical solutions.

## 3.1 The model

In our search-based model, there are two risk assets with identical cash flow and supply. Agents can hold long or short positions in either assets. These agents are infinitely lived and form a continuum with infinite mass. The two risky assets differ in liquidity but have an identical cumulative income process, $D_{it}$, $i = 1, 2$, as follows:

$$dD_{it} = \tau \left[1 - (1 - \chi) N_m\right] dt + \sigma_d dB_t^d \tag{1}$$

[3] Exceptions are Hu et al. (2016) and Auh and Landoni (2016).

where $N_m$ is an adapted, right-continuous pure jump process with $N_m(0) = 0$ and a jump intensity $\delta_m$, $\tau$ is the expected income (or dividend) and $1 - \chi$, where $0 < \chi < 1$, is the loss severity rate of default after a jump. The two assets, 1 and 2, pay the same income $\tau$ before the default and $\chi\tau$ after, and are in identical supply, $S$. The cumulative income process after the jump can be written as

$$dD_{it} = \chi\tau dt + \sigma_d dB_t^d. \tag{2}$$

The assets can be corporate bonds, mortgage-backed securities (MBS), or other defaultable securities which serve as repo collateral. For a corporate bond, $\chi$ is simply the loss rate upon default for that bond. In case of an MBS secured by a pool of mortgages, the default risk can be characterized by the probability of losing a certain percentage ($\chi$) of value in the pool (e.g., an MBS conduit). The pool loses some value when a mortgage in the portfolio defaults. The defaulted mortgage drops out of the pool with a recovery value. For simplicity, we assume that when a mortgage in the pool defaults, the recovery value from the defaulted mortgage is automatically reinvested in a similar MBS. Thus, any loss associated with a mortgage default can be represented by the loss of income in an MBS pool.

The two assets have the same quality, i.e., default risk and recovery rate, except that there is a difference in liquidity. Asset 1 is more liquid and is a collateral preferred by repo traders. This could be a newly issued bond or MBS (on the run) which is actively traded in the market and easier to locate by repo participants and shortsellers. Asset 2 is less liquid which could be an old bond or MBS issue held by buy-and-hold investors, who intend to hold it for a long term and therefore, are not interested in trading the asset. This asset is not the preferred collateral due to its lack of liquidity and a difficulty to locate counterparty.

To establish an agent's value function, which is derived from the utility flow for the agent, we consider two regimes: before and after the jump or the default of a bond.[4] The

[4] This model can be generalized to the case of $N$ regimes where $\tau = \{\tau_1, \tau_2, ..., \tau_N\}$ and $\sigma_d = \{\sigma_{d1}, \sigma_{d2}, ..., \sigma_{dN}\}$ are incremental dividend and volatility, respectively, and $B^d$ is a standard Brownian motion. We adopt the regime-switching approach in the model (Gray (1996)). A continuous-time, time-homogeneous Markov chain can be specified in terms of a $N \times N$ infinitesimal generator matrix

$$\Phi = \begin{pmatrix} \delta_{m11} & \delta_{m12} & ... & \delta_{m1N} \\ \delta_{m21} & \delta_{m22} & ... & \delta_{m2N} \\ ... & ... & ... & ... \\ \delta_{mN1} & \delta_{mN2} & ... & \delta_{mNN} \end{pmatrix}$$

time-homogeneous Markov chain is specified by a $2 \times 2$ infinitesimal generator matrix:

$$\Phi = \begin{pmatrix} -\delta_m & \delta_m \\ 0 & 0 \end{pmatrix}$$

where the off-diagonal term $\Phi$ represents the transition rates from the default to no-default states. The last row of zeros implies that the default state is absorbing, that is, when a default state occurs, one can no longer return to the no-default state.

The agent holds $q_{it}$ units of asset $i$, and the wealth process $W$ is given by

$$dW_t = \left[ rW_t - c_t + \sum_{i=1}^{2} \left( \tau \left[ 1 - (1-\chi) N_m \right] - rp_{i,t} \right) q_{it} \right] dt + \sigma_d \sum_{i=1}^{2} q_{it} dB_t^d + d\zeta_t \tag{3}$$

where $c_t$ is the agent's consumption process, $p_{i,t}$ is the price of asset $i$, and $\zeta_t$ is the endowment received by the agent. The agent's initial endowment comes from her portfolio excluding the asset. The cumulative endowment process is

$$d\zeta_t = mdt + \sigma_\zeta dB_t^\zeta - \sigma_N dN_t \tag{4}$$

where $m$ and $\sigma_\zeta$ are constants. $N_t$ is an adapted, right-continuous pure jump process with $N(0) = 0$. When $\zeta_t$ has a jump at time $t$, $dN_t = N_t - N_{t-} = 1$. The jump process has an intensity $\delta_b$. When $\zeta_t$ experiences a jump, the agent defaults with a loss $\sigma_N$ and exits the market. $B_t^\zeta$ is a Brownian motion and is correlated with $B_t^d$,

$$dB_t^\zeta = \rho_i dB_t^d + \sqrt{1 - \rho_i} dZ_t \tag{5}$$

where $Z_t$ is a standard Brownian motion independent of $B_t^d$, and $\rho_i$ is the instantaneous correlation between the asset dividend and endowment of agent $i$. The process $\rho_i$ can have a value of zero, or take two nonzero values: $\rho_i = \overline{\rho}$ for high-valuation agents and $\rho_i = \underline{\rho}$ for low-valuation agents.

There are two steps to determine an agent's utility before a default occurs. In the first step, we need to determine an agent's utility $W_{a,t}$ after the default of the asset (e.g., risky bond or mortgage). Once a default occurs, the income of an investment reduces to $\chi\tau$ and the agent optimizes her consumption, $\bar{c}$.

It takes two steps to determine an agent's utility before the asset (bond) defaults. First, an agent's utility $W_a$ after the asset default needs to be estimated. Agents optimize their consumptions, $\bar{c}$. Given the agent's utility function $J(\cdot, \cdot)$, the optimal condition for an agent with a valuation type of $\rho_i$ is given by the Hamilton-Jacobi-Bellman (HJB) equation. The agent takes the asset default probability into account in their investment decisions. The utility function after the asset default $J(W_{a,t}, \rho_i)$ is given by

$$
\begin{aligned}
0 = \sup_{\bar{c},\theta_o} & \left\{ -e^{-\gamma \bar{c}} + J_w \left(W_{a,t}, \rho_i\right) \left(rW_{a,t} - c_t + \chi\tau - rpq + m\right) \right. \\
& + \frac{1}{2} J_{ww} \left(W_{a,t}, \rho_i\right) \left(q^2 \sigma_d^2 + \sigma_\zeta^2 + 2\rho_i q \sigma_d \sigma_\zeta\right) - \beta J \left(W_{a,t}, \rho_i\right) \\
& \left. + \kappa \left(\rho_i, \rho_j\right) \left[J\left(W_{a,t}, \rho_j\right) - J\left(W_{a,t}, \rho_i\right)\right] + \delta_d [J(W_{a,t} - \sigma_N, \rho_i) - J\left(W_{a,t}, \rho_i\right)] \right\}.
\end{aligned} \tag{6}
$$

where $\gamma$ is the risk aversion coefficient, $\beta$ is an agent's time preference rate, and $\kappa\left(\rho_i, \rho_j\right)$ is the Poisson intensity with which the agent of type $\rho_i$ switches to type $\rho_j$. Since an agent can hold either asset, we drop the subscript of the asset that the agent holds. The term $J(W_{a,t}, \rho_i)$ is the agent's utility after a default. Conjecturing

$$
J\left(W, \rho_i\right) = -\frac{1}{r} e^{-r\gamma\left(W + V(\rho_i) - \frac{\gamma\sigma_\zeta^2}{2}\right) + \frac{r-\beta}{r}} \tag{7}
$$

where $V\left(\rho_i\right)$ is the value function of agent type $\rho_i$ and optimizing over $\bar{c}$, we have the first-order condition of the HJB equation:

$$
\bar{c} = r\left[w + V\left(\rho_i\right) - \frac{\gamma\sigma_\zeta^2}{2}\right] - \frac{r-\beta}{r\gamma}. \tag{8}
$$

Substituting (8) into (6), and using the linearization $e^x - 1 \approx x$, we have the value function after the assets default $V_a\left(\rho\right)$ as the solution of the following equation:

$$
0 = -rV_a\left(\rho\right) + \max_q \left\{\left(\zeta_D \tau + x_i\right) q + yq^2 - rpq\right\} + \kappa\left(\rho_i, \rho_j\right)\left[V_a\left(\rho_j\right) - V_a\left(\rho_i\right)\right] - \delta_b V_a\left(\rho_j\right). \tag{9}
$$

Given the utility function $J(W_{a,t}, \rho_i)$, after the asset defaults, the optimal condition for an agent with a valuation type of $\rho_i$ is set by the following HJB equation:

$$
\begin{aligned}
0 = \sup_{\bar{c},\theta_o} & \left\{ -e^{-\gamma \bar{c}} + J_w \left(W_{a,t}, \rho_i\right) \left(rW_{a,t} - c_t + \chi\tau - rpq + m\right) \right. \\
& + \frac{1}{2} J_{ww} \left(W_{a,t}, \rho_i\right) \left(q^2 \sigma_d^2 + \sigma_\zeta^2 + 2\rho_i q \sigma_d \sigma_\zeta\right) - \beta J \left(W_{a,t}, \rho_i\right) \\
& \left. + \kappa \left(\rho_i, \rho_j\right) \left[J\left(W_{a,t}, \rho_j\right) - J\left(W_{a,t}, \rho_i\right)\right] + \delta_d [J(W_{a,t} - \sigma_N, \rho_i) - J\left(W_{a,t}, \rho_i\right)] \right\}
\end{aligned} \tag{10}
$$

Before the asset defaults, the value utility $V_b\left(\rho\right)$ can be determined by taking into account the probability that the asset defaults. The agent's utility function $J(W_{b,t}, \rho_i)$ is given by the following HJB equation:

$$
\begin{aligned}
0 = \sup_{\bar{c},\theta_o} \{ & -e^{-\gamma\bar{c}} + J_w\left(W_{b,t},\rho_i\right)\left(rW_{b,t} - c_t + \tau - rpq + m\right) \\
& + \frac{1}{2} J_{ww}\left(W_{b,t},\rho_i\right)\left(q^2\sigma_d^2 + \sigma_\zeta^2 + 2\rho_i q\sigma_d\sigma_\zeta\right) - \beta J\left(W_{b,t},\rho_i\right) \\
& + \kappa\left(\rho_i,\rho_j\right)\left[J\left(W_{b,t},\rho_j\right) - J\left(W_{b,t},\rho_i\right)\right] + \delta_d[J(W_{b,t} - \sigma_N,\rho_i) - J\left(W_{b,t},\rho_i\right)] \\
& + \delta_m[J(W_{a,t},\rho_i) - J\left(W_{b,t},\rho_i\right)]\}
\end{aligned}
\tag{11}
$$

### 3.2 Agent types, utilities and equilibrium prices

Agents can establish a long or short positions in either asset and they derive a utility flow from holding a position. Agents consume a single good, and they can either hold a riskless asset or any of the two risky assets with identical income. Agents receive a random endowment which correlates with the cash flow from the asset. There are three types of agents with high, average and low valuation. The correlation between the endowment and the cash flow from the asset differs across agents: it is negative for high-valuation agents, zero for average-valuation agents, and positive for low-valuation agents. Agents can be high- or low-valuation agents for various reasons. For example, agents may have different expectations or asymmetric beliefs. A high-valuation agent may have a relatively optimistic belief and would like to take a speculative position or may have a desire to hedge a commitment to supplying collateral. Alternatively, she may wish to hold an asset whose cash flow is negatively correlated with her endowment income for the purpose of diversification. For this type of agent, a long position gives her a positive utility. On the other hand, a low-valuation agent may be relatively pessimistic and would like to take a short position or wish to hedge a commitment to accepting collateral. She may also wish to hedge a long position held in a different but correlated market. In any event, a short position gives this agent an extra utility.[5]

There are two markets: a spot market where agents buy and sell assets, and a repo market where short-sellers can borrow assets. In both markets, agents search for counterparty,

[5] See Duffie (1996) and Vayano and Weill (2008) for more detailed discussions for valuation types and different reasons for becoming an investor type. In this paper, we focus on the roles of shortselling and security lending. In a more general search-based model, the low-valuation type may include agents with low liquidity (a need for cash), high financing costs, hedging reasons to sell, a relative tax disadvantage, a lower personal use of the asset, or other reasons and the high-valuation type may include agents facing the opposite situations (see Duffie et al. (2005)).

and trade by meeting each other and bargaining over the price. There is a continuum of agents experiencing transitory needs to have a long or short position (see (A-1)-(A-8) in the appendix). Agents can long one share of either asset, short one share, or have no position at all. In the spot market, a high-valuation agent is initially a buyer $\bar{b}$. If she meets a seller of asset $i$ before reverting to average valuation, she bargains with the seller for the asset price $p_i$, $i \in \{1, 2\}$. If the bargaining turns out to be successful, the agent purchases the asset, and becomes a non-searcher $\overline{n}_i$. When a non-searcher reverts to average valuation, she becomes a seller $\overline{s}_i$ of the asset and looks for a buyer. When a buyer is found, she bargains with the buyer for the term, and if the bargaining turns out to be successful, she sells the asset and exits the spot market.

In the repo market, the agent who has bought asset $i$ can be a lender $\bar{l}_i$ who lends the asset to a borrower.[6] In this market, a low-valuation agent is initially a borrower $\underline{bo}$. If a borrower meets a lender of asset $i$ in the repo market, she bargains with the lender for a lending fee $w_i$. After successfully making a repo contract, she becomes a seller of type $\underline{s}_i$, and attempts to sell the asset borrowed. After selling the asset, she becomes a non-searcher of type $\underline{n}_i$. When she later wants to buy the asset in the spot market for delivery to the lender, she becomes a buyer of type $\underline{b}_i$. Upon finding a seller, she bargains for the term. If the bargaining is successful, she purchases and delivers the asset to the lender and closes the contract.

On the other hand, when a lender enters into a repo contract, she becomes a non-searcher. Depending on the type of the repo counterparty, $\underline{s}_i$, $\underline{n}_i$, or $\underline{b}_i$, she can be one of three types of non-searcher, $\overline{n}\underline{s}_i$, $\overline{n}\underline{n}_i$, or $\overline{n}\underline{b}_i$. Recall that a seller of type $\underline{s}_i$ still has the asset and attempts to sell it. If the lender terminates the contract, and the counterparty of type $\underline{s}_i$ returns the asset, the lender becomes a seller $\overline{s}_i$. If the lender terminates the contract but the borrower is either a non-searcher of type $\underline{n}_i$ or a buyer of type $\underline{b}_i$ who does not have the asset, the lender can seize the cash collateral posted by the borrower and exit the market.

This setup resembles that in Vayanos and Weill (2008) that assumes no counterparty and collateral risks in repo transactions. In their model, the security lender recovers the full asset value when terminating the contract and there is neither collateral nor counterparty default

[6] The borrower could be an agent who want to borrow the scurity to short sell. Alternatively, the borrower could be just an investor (e.g., money market fund) who takes in the collateral asset with no intention to short the security or to lend it for another shortseller.

risk.[7] Whenever a contract is terminated, both borrower and lender will be able to close their positions without any losses. Collateral and counterparty risks in repo transactions are ruled out.

Our model differs from Vayanos and Weill (2008) in that we account for both collateral and counterparty default risks in the repo market. In our model, the default probability and the loss severity rate are explicitly incorporated in a regime switching process. We assume that when a default occurs, agents receive a residual value of the asset. There are a number of reasons why the agent may recover only a fraction of the full value of the asset when a counterparty defaults. First, the security collateral may have lost value. Second, the cash collateral may be worth less than the security value because of a haircut, and the security lender therefore incurs a loss when the borrower defaults and fails to return the asset. Third, a loss may occur due to rehypothecation of the collateral when a counterparty defaults and the original owner cannot recover the asset. Fourth, counterparty risk can affect the agent's portfolio decisions. For example, concerns about counterparty default risk may impede the agent's decision to hedge her portfolios due to an unwillingness to borrow securities to short sell. This can lead to a significant portfolio loss in the market downturn. Lastly, a default by a transaction party imposes operational and legal risks on the safe or nondefaulting party, i.e., delay in liquidation, challenge by the defaulting party in the court, costs incurred in replacing the defaulted repos or in unwinding or replacing hedges. These incidents can incur nontrivial operational and legal costs to the nondefaulting party. In general, the recovery rate is expected to be less than one in the presence of counterparty risk. The recovery rate depends on collateral quality and both agent-specific and market conditions. The loss for the nondefaulting counterparty could be substantial if her claims were not collateralized or she became a general unsecured creditor as evidenced in the case of Lehman Brothers bankruptcy during the subprime crisis.

The potential asset default affects agents' utilities and their positions. For example, the lender will require a higher lending fee to compensate for the potential loss of counterparty default risk. An agent's value function have two regimes: before and after the default of a bond, and two steps are required to determine the agent's utility before a default occurs (see

[7] Their assumption ensures that upon termination of the contract with the borrower of type $\underline{n}_i$ or of type $\underline{b}_i$, the lender is equally well-off as a seller $\overline{s}_i$. See footnote 14 of Vayanos and Weill (2008).

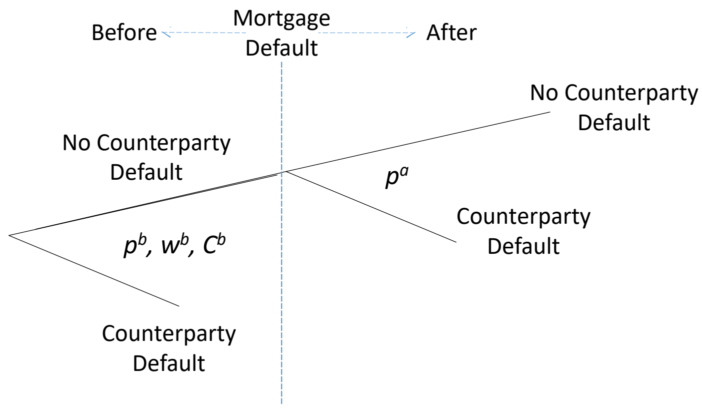


Figure 1. Collateral default risk and counterparty risk

Figure 1). In the first step, we determine an agent's utility after the asset default. Once a default occurs, the income of an investment reduces to a fraction of the income before the default. The agent adjusts her consumption and optimizes her utility based on the reduced income. The spot and repo markets reach a new equilibrium and a new asset price ($p^a$).

In the second step, we determine an agent's utility before the asset default by taking into account the probability of default, and the asset price after default. Consequently, the default probability and loss severity affect the agent's utility before the asset default, and in turn, affects the lending fee ($w^b$and the repo spread), cash collateral ($C^b$), and the asset price ($p^b$) before the default actually occurs. For example, if borrowers and lenders in the repo market anticipate that a bond may default, the lending fee will be determined by taking into account the probability of collateral default and the loss given default.

There is another complication in our model. After the asset default, there are two different groups of agents: the agents who entered the repo agreement before the asset default and the agents who did not sign a repo agreement contract before the asset default. We postulate that the agents who did not have a repo agreement contract before the default would determine the asset price $p^a$ after the default. For those agents who entered a repo agreement before the asset default, they either paid or received the lending fee and the cash value of the asset with a certain haircut based on the pre-default asset income, and the cash collateral tendered. Consequently, the agents who entered repo agreements before the asset default have different utilities from those who did not enter the repo agreements before the asset default. The expected income and the price changes after the asset default affect agents' utilities before the default. To adjust the utilities for those agents who entered a repo agreement before the asset default, iterations are needed. First, we estimate the asset price $p^a$ after the asset default using (A-9) - (A-18) in the appendix and estimate agents' utilities after the asset default. Then keeping $p^a$ the same as in the first step, we estimate the utilities of those agents who entered repo agreements before the asset default but stay in the market after the asset default using (A-19) - (A-30) in the appendix. This process is repeated until the after-default utilities of this group of agents converge.

Besides collateral default risk, a repo counterparty can default due to a negative endowment shock. A negative endowment shock can result in significant losses and cause an agent to default or fail to fulfill the obligation stipulated in the repo contract agreement. Our model accounts for this counterparty default risk. More specifically, an agent has a default probability, which is correlated with the value of assets in the agent's portfolio. To accommodate the effect of counterparty risk, besides high-, average-, and low-valuation types of agents, we introduce the default (bankruptcy) type of agents. A mortgage-backed security borrower in a repo transaction may default and terminate the contract, and the lender of this security may not be able to recover it. As an example, during the financial crisis, an investment bank such as Lehman may have possessed a bond posted by a client through a repo contract, or borrowed a bond by entering a repo contract directly but later went bankrupt. If this bond is not segregated legally from Lehman's general assets or is rehypothecated to obtain a loan from the third party, the original lender of this security may not be able to get it back as the bond may become part of the bankruptcy estate or seized by the third party. If a borrower goes bankrupt and terminates the contract, a counterparty default occurs. Similarly, a security lender (cash borrower) can default due to an unexpected endowment shock, then terminates the contract and exits the market. For example, a hedge fund who posts collateral for financing from a dealer bank may incur substantial losses in subprime mortgage investments, and then goes bankrupt and terminates the contract. In the general setting of our model, asset lenders and borrowers both have a chance to default. Besides this general setting, we consider the special cases that only one party can default or there is asymmetry in the importance of borrower and lender defaults.

To summarize, in Vayanos and Weill (2008) all short-sellers prefer to borrow the liquid asset. These short-sellers buy back the asset eventually to cover their position. Their trading activity increases the asset's liquidity and reduces search frictions. The owners of the liquid asset can lend it to short-sellers for a fee. If asset 1 is liquid while asset 2 is illiquid and the price of the liquid asset carries a specialness premium. Lenders are willing to pay a higher price for the liquid asset, and lend it to short sellers to earn the lending fee.

In contrast, in our generalized model with counterparty and collateral default risks, the situation becomes much more complicated. If one security is more liquid than the other, the shortselling activity will still concentrate on the liquid security. While the price of the liquid security may be higher than the illiquid one, resulting in a positive yield spread between new and old bonds, this liquidity effect will now interact with other risk factors in the model.

There are multiple sources of default risk in the model. First, the assets are defaultable. This risk affects agents' consumption and their utility functions which, in turn, affects agents' valuation of assets. Second, all agents' endowments are risky. A portfolio endowment shock can cause a substantial financial loss to an agent and trigger a default. Third, an agent's default affects her counterparty. For example, the security borrower's default leads to a failure to deliver the security she borrowed. If the security lender also borrowed the security from a third party, she could fail to deliver the security too. This risk associated with a repo counterparty affects the shortselling surplus, lending fee and the price of the collateral asset. Thus, in our model an agent in the repo market faces three types of default risk: the mortgage default risk, a possible default due to a negative shock on her own endowment, and a possible counterparty default.

In a repo market free of collateral default risk, short-sellers are always willing to pay more lending fee to borrow securities that they can sell at a higher price in the cash market. By contrast, in the repo market with default risk, the collateral is risky, and a counterparty can default. When counterparty default risk increases, the security lender demands a higher lending fee to compensate default risk. The increase in the lending fee discourages short-sellers to borrow and therefore, reduces the demand for collateral. On the other hand, if default risk of the security lender increases, his/her counterparty will be less willing to enter the repo contract to provide capital. This can lower the leverage ratio for the cash borrower (security lender) to buy more securities, which in turn dampens the demand for securities and exerts a downward pressure on prices. In the same way, when default risk of collateral increases, the demand for the collateral decreases as it becomes less secure. These ramifications result in more complicated effects on the lending fee and the pricing of repos and the underlying collateral. Therefore, the model with default risk (see (A-9) - (A-18) and (A-19) - (A-30) in the appendix) can generate different implications for the lending fee in the repo market and asset prices in the spot market. In our numerical analysis, we consider both cases of symmetric and asymmetric counterparty defaults. In the symmetric case, both security lender and borrower can default whereas in the asymmetric case, only the security lender or the security borrower can default. We show that the effects of counterparty and collateral risks on lending fee and collateral valuation can be quite different depending on which side of counterparty is more likely to default. We next turn to numerical analysis to assess the effects of counterparty and collateral defaults.

### 3.3 Numerical solutions

Default risk affects the lending fee in the repo market and the yield spread of bonds in the spot market. Besides collateral and counterparty default risks, factors such as agents' search intensity, risk aversion and interest rates are also important determinants of these variables. In this section, we examine the effects of these factors by numerical solutions. The parameters used in the numerical analysis are given in Panel B of Table 1. We solve the exact system of equations (A-9) - (A-18) and (A-19) - (A-30) in the appendix numerically and present the results in Figures 2 through 11. For illustrative purpose, we assume that the collateral asset in the model is an MBS. This imposition enables us to link our numerical analysis more closely to our later empirical analysis. Nevertheless, our model can be applied to any repos using risky bonds as collateral.

We first assess the effects of default risk on the lending fee and yield spread of the MBS used as the collateral in the repo market. We begin with the general case that lenders and borrowers can both default and then explore the special case of asymmetric defaults by different counterparties. In the case of asymmetric defaults, only one party may default, and the other party is relatively safe or has a "deep pocket" and consequently, will not default and instead only incurs a loss. Investigating these cases enables us to assess the effect of counterparty risk when counterparty default risk is asymmetric in importance.

Figure 2 shows the effect of collateral default risk on the lending fee and the yield spread of the MBS used for repo funding. When the probability of mortgage default increases, the yield spread goes up while the lending fee goes down. Collateral default risk has a direct impact on the value of MBS collateral. When mortgage default risk increases, the value of collateral decreases and the repo becomes riskier. Exchanging cash for MBS securities exposes the security borrower to higher risk. As a consequence of the increasing asymmetric risk between holding cash and holding securities, the security borrower (cash lender) will pay a lower lending fee, or require a higher repo rate to compensate for this risk in response to an increase in mortgage default risk. Higher MBS default risk reduces the demand for collateral in the repo market, which in turn further decreases the collateral value and raises the yield spread of MBS in the spot market.

The impact of mortgage default depends on the magnitude of loss given default. Figure 3 shows the effect of loss severity rates on the MBS yield spread and the lending fee. The yield spread increases and the lending fee decreases with loss severity. An increase in the loss rate of mortgage default has a direct positive impact on the yield spread in the MBS market. The loss severity rate increases the expected loss of possessing the MBS collateral. In anticipating higher expected loss of holding collateral, the security borrower (cash lender) will only be willing to pay a lower lending fee to the security lender. At the same time, the increase in the expected loss dampens the demand for collateral, which decreases the value and increases the yield spread of MBS.

As expected, the combined effect of default probability and the severity of loss given default is much stronger. Figure 4 plots the yield spread and lending fee against the default probability at two different levels of loss severity. Results show the lending fee curve shifts downward as the loss rate increases. A higher loss severity rate (20%) is associated with a lower lending fee given any level of mortgage default probability. The security borrower pays a lower lending fee when the potential loss is larger. The lending fee decreases with mortgage default probability at an increasing rate. In contrast, an increase in the loss severity rate shifts up the curve of yield spreads. Given a default probability, a higher loss severity rate is associated with lower demand for collateral and higher MBS yield spreads.

We next introduce counterparty default risk. Figure 5 shows the results when both counterparties (repo buyers and sellers) can default. The solid curves show the effects of mortgage default risk when the counterparty default probability is zero, and the dash curves show the effects of mortgage default risk when the counterparty default probability is 2%. When the probability of default for both parties increases, the lending fee decreases and the

MBS yield spread increases. Shortsellers focus on the liquid (new) MBS in their security borrowings and the liquid MBS continues to be preferred collateral in the repo market. When the overall counterparty risk increases, the security borrower with cash has the upper hand to force the lending fee to go down in response to an increase in the lender's default risk. Thus, although both borrowers and lenders may default, the lending fee is more sensitive to the latter's default risk. The negative effect of security lenders' default risk on the lending fee outweighs the positive effect of security borrowers' default risk, leading to a decrease in the lending fee when the default risk of both parties increases. Meanwhile, an increase in counterparty risk dampens the activity in the repo market and decreases the demand for collateral, leading to an increase in the yield spread of MBS.

The results in Figure 5 suggest a negative interaction effect of collateral and counterparty risks on the security lending fee. As the repo rate is negatively related to the lending fee, this impiles a positive interaction effect of these risks on the repo rate. Thus, counterparty risk can reinforce the effect of collateral risk.

When the financial market is in turmoil, the agents who hold risky securities generally face greater risk and are more likely to borrow cash. Whether or not they are able to lend their securities in exchange for cash affects their chance of survival. To examine this asymmetric effect, we consider a polarized case that the security lender faces default risk due to an endowment shock, whereas the cash lender does not have such a shock.

Figure 6 shows the effect of mortgage default probability conditional on the security lender's default risk. The solid curves show the effects of mortgage default risk when counterparty default probability is zero, and the dash curves show the effects when the security lender's default probability is 2%. When the lender's default probability increases, the yield spread is shifted upward and the lending fee is shifted downward. The security lender's default can be either before and after the MBS default. In case that the lender defaults before the mortgage default, the borrower can simply sell the security, if she still holds it, to close the position. If the borrower has sold the security, she can borrow it again or buy it back from the spot market. The market value of the MBS is in general greater than the cash collateral before the mortgage default due to a non-zero haircut. Conversely, if the lender defaults after the mortgage default, the borrower loses her cash collateral. She may sell the defaulted security at a lower price. In this case, she could not recover the cash collateral by returning the lender a cheaper MBS. After the mortgage default, the market value of the security is likely to be much lower than the cash collateral and the borrower takes a loss. The case involving mortgage default risk complicates the gains or losses of counterparties. Figure 6 shows that the mortgage default probability increases the yield spread and reduces the lending fee when only the lender can default.

Consider next the opposite case that only the security borrower defaults. Figure 7 shows the effect of the mortgage default probability conditional on the security borrower's default risk due to an endowment shock, assuming that the security lender does not have such shock. The solid curves show the effects of mortgage default risk when counterparty default probability is zero, and the dash curves show the effects of mortgage default risk when the borrower's default probability is 2%. When the security borrower's default risk increases, the lending fee increases. This is because the lender raises the lending fee in anticipating the higher counterparty default risk. In case that the security borrower defaults before the mortgage defaults, the lender can just use the cash collateral to purchase the security to close the position, and return to the repo market to lend again. Assuming that the spot market condition remains the same, the value of the MBS is likely to be higher than the cash collateral due to the haircut, and the lender takes a loss. In case that the borrower defaults after the mortgage default, the lender can simply take the cash or buy the MBS at a lower price. Compared to the lender's default risk effect in Figure 6, the security borrower default has much less impact on the yield spread as the purchase of the security lender to restock the collateral offsets the effect of the security borrower's default on the lending fee and the yield spread.

The analysis above focus on the effect of default risk on the yield spread of the liquid MBS used as the repo collateral. Like the default-free model (i.e., no collateral and counterparty risk), in our model shortsellers continue to prefer the liquid MBS because it is easier for them to locate the counterparty. However, the situation becomes more complicated in that the yield spread between the liquid and illiquid securities is no longer dependent on just the liquidity difference between the two securities but also on other factors in the model. We next explore the effect of default risk on the yield spread between liquid and liquid bonds. In this analysis, we focus on the general setting of the model where both borrower and lender can default.

Figure 8 shows the effect of mortgage default risk on the yield spread between liquid and illiquid mortgage-backed securities. Results show that the yields of both securities are an increasing function of MBS default risk, and thus the change of yield spread is relatively small. Because default risk impacts both liquid and illiquid securities, there remains a positive spread between the illiquid and liquid MBSs. The liquid MBS still trades at a higher price as shortsellers' trading activity enhances its liquidity, making its liquidity and bargaining discounts lower than those of illiquid MBS. This result is consistent with the finding in Duffie (1996) and Vayanos and Weill (2008) for a positive yield spread between the liquid and illiquid securities. In addition, our results show that the yield spread between the liquid and illiquid securities declines as the mortgage default risk increases.

Search frictions affect the bargaining and negotiation in the repo market. We next examine the effect of search intensity on repo activity and the equilibrium in the repo and spot markets. In the model, both repo and spot markets operate through agents' search. Agents are matched in pairs and they negotiate the terms of trade bilaterally. Higher search intensity by an agent can improve her terms of trade and affect asset prices. Given the critical role of search in the model, it is important to understand the effect of search intensity on lending fee and yield spreads. In this analysis, again we focus on the general setting of the model where both borrower and lender can default.

The effect of mortgage default probability is conditional on the level of search intensity. Figure 9 plots the yield spread against the default probability at two different levels of search intensity, $\lambda = \{1 \times 10^6, 2 \times 10^6\}$. Mortgage default risk increases MBS yield spreads, regardless of the level of search intensity. More importantly, the curve that relates the yield spread to mortgage default probability shifts upward when the level of search intensity drops. For a given default probability, the lower the search intensity (solid curve), the higher the MBS yield spread. Lower search intensity elevates search frictions, which has a negative impact on the demand for repo collateral, leading to a lower MBS price in the spot market. In addition, search intensity affects the relation of the lending fee to default risk. Given a mortgage default probability, when search intensity is low (solid curve), the lending fee is low due to a feedback effect of low demand for collateral.

Risk aversion is another factor that affects the markets. Figure 10 shows the effects of mortgage default probability on the yield spread and lending fee conditional on two different levels of cost for risk bearing. Holding other parameters constant, the cost of risk bearing reflects agents' risk aversion. Results show that a higher cost of risk bearing ($y = 0.6$) is associated with a higher yield spread and a lower lending fee given any level of the mortgage default risk. When default risk increases, as in the subprime crisis, investors become more risk averse and less willing to engage in repo transactions with a risky collateral. As a result, the MBS spread increases with risk aversion when the market is more uncertain. On the other hand, the lending fee decreases with risk aversion as the demand for risky collateral drops.

The yield spread and lending fee also depend on the level of interest rates. Figure 11 shows how the effects of interest rates and mortgage default probability interact. In general, the level of interest rates is correlated with economic conditions. Higher interest rates are typically associated with a good economy with lower default rates. Figure 11 shows that the effect of interest rate on the MBS yield spread is positive, that is, given a default probability, a higher interest rate lowers the yield spread. Figure 11 also shows that the effect of interest rate level on the leading fee is negative, that is, given a default probability, a higher interest rate decreases the lending fee.

The analysis above focus on the lending fee and the pricing of collateral. In the repo market, repo rates and lending fees are negatively correlated, other things being equal. As an example, when a collateral is on special, the lending fee is high and the repo rate is low. In general, higher lending fees are associated with lower repo rates. We test the implications of the model using the data of repo rates which are much easier to get than lending fees.

In summary, the generalized search-based model with collateral and counterparty risks generates a number of important implications for the lending fee, repo rates and the yield spread of the MBS securities, which can be validated using empirical data. Particularly, the model suggests that the repo and MBS yield spreads are affected by collateral default risk, counterparty risk, search intensity (or liquidity), specialness, risk aversion and term structure. In empirical investigation, we use real data to test these implications in different economic environments. We now turn to empirical tests.

# 4 Data

The data sample consists of both individual repo deals and aggregate indices of repos and mortgage-backed securities. We perform cross-sectional analysis using individual repo deal data which are collected from the filings of money market funds (MMFs) to the Securities and Exchange Commission (SEC). In addition, we conduct the time-series analysis using the aggregate data collected from the Federal Reserve Board, Bloomberg and other sources. Using this data set, we examine the temporal relation of repo spreads and MBS yield spreads with collateral and counterparty risks with controls for other risk factors. We provide a description for these data below.

## 4.1 Individual repo deal data

To examine the role of counterparty risk and collateral quality directly, we use the data of individual repo deals with different types of collateral and counterparties. The data of individual repo deals are collected from the top 20 MMF families' quarterly and monthly filings to SEC. The top 20 MMF families (include 96 MMFs) account for more than 80% of total triparty repos (see Krishnamurthy et al. (2014)). The SEC filings are the only source of publicly available data for repo transactions. Prior to 2010, MMFs are required to file form N-Q quarterly to disclosure the outstanding positions in their portfolios to the SEC. The filings contain the information of the MMF's ID, counterparty, repo rate, transaction dated date, repo due date, borrowing amount, and the value and type of collateral for each repo deal. We calculate the haircut rate and maturity for each repo deal based on the filing information. Since 2010, money market funds have been required to file form N-MFP monthly for their holdings. Although the sample period is shorter, form N-MFP filings contain more information about MMF investment holdings than form N-Q. The former includes more detailed descriptions for types of securities, coupons, maturity, and issuers, and monthly changes in MMF repo positions.

We parse the individual deal data on forms N-Q and N-MFP from EDGAR. This generates two data sets of repo transactions over the period from July 2004 to December 2015 (on N-Q) and from July 2010 to December 2016 (on N-MFP), respectively. We use these data sets to examine the role of collateral quality and counterparty risk in affecting repo spreads and haircut rates for each contract.

To analyze the effect of collateral quality, we separate repo transactions based on their collateral type. We first drop repo deals with multiple types of collateral to avoid the confounding effect. The N-Q form does not provide information for MBS issuers. For this data, we divide the repo deals into two groups with Treasury and MBS collateral, respectively, to study the effect of collateral quality on the repo terms. Treasuries are default free and presumably have the best quality. Comparing the repos with Treasury and MBS collateral reveals the effect of collateral quality. In contrast, form N-MFP filings include the information for MBS issuers. For this data, we categorize repos based on the description of MBS issuers. Repos are divided into three categories: mortgage-backed securities issued by Ginnie Mae, Fannie Mae or Freddie Mac, and private issuers, respectively. We use this grouping to further differentiate collateral quality and its effects on repo terms.

Table 2 summarizes the characteristics of repos with different types of collateral. Panels A and B reports summary statistics of repo deals in the N-Q data set that use Treasuries and MBS as collateral, respectively. Repo spreads are repo rates in excess of riskfree rates. The federal fund rate is used as the riskfree rate for the overnight repo and the rates of overnight index swaps (OIS) with different maturities are used as riskfree rates for repos with other maturities. In principle, repos with higher collateral risk should compensate their investors with a higher repo spread or have a higher haircut rate. As shown, repo spreads and haircut rates are higher for MBS repos (0.31% and 5.38%) than for Treasury repos (-0.06% and 1.91%). On-the-run Treasuries can be on special, resulting in repo rates lower than spot rates. On average, the repos with MBS collateral have longer maturity (71 days) than those with Treasury collateral (14 days) and also have slightly smaller size.

Panels C, D, and E provide summary statistics for the three categories of MBS collateral for the repos included in the N-MFP data set. Collateral issued by Ginnie Mae has the highest quality, since it is fully guaranteed by the U.S. government whereas private-label MBS collateral has the lowest quality. Repos collateralized with the private-label MBS have the highest average mortgage repo spread and haircut rate (0.45% and 0.06%), and those with the MBS issued by Ginnie Mae have the lowest repo spread and haircut (0.02% and 0.02%). Overall, these patterns are consistent with the finding of Auh and Landoni (2016) from the bilateral repo data of a hedge fund that repo deals with lower-quality collateral tend to have higher spreads, larger margin, smaller size, and longer maturity.

### 4.2 Time-series data

The main sources of our time-series aggregate data are Bloomberg, Federal Reserve Banks, Markit, and Yahoo Finance. Table 3 provides summary statistics for the variables used in empirical analysis. Panel A shows summary statistics of the data and Panel B reports the correlation among key explanatory variables. The sample period for the time-series data runs from September 2006 to December 2014.

The dependent variable in time-series regressions includes the agency's collateralized mortgage obligation (CMO) repo spreads at different maturities. The spread is the repo rate in excess of the risk-free rate with the same maturity. Mortgages are securitized into a CMO by maturity and risk. The agency CMO repo rate is the repo rate index collateralized by the CMOs issued by Ginnie Mae, Fannie Mae, and Freddie Mac. We collect the repo data from Bloomberg for six maturities: overnight, 1-, 2-, 3-week, and 1- and 3-month, respectively but in most analysis we omit 1-week and 1-month results for brevity. For the yield spread regression, we use the yields of agency MBS indices with maturities of less than 3 years, and 3, 3-5 and 5-7 years. These indices are constructed by Bank of America Merrill Lynch. We use the federal fund rate as the riskfree rate for overnight repos, and the maturity-matched overnight index swap (OIS) rates for other repos. For the MBS, we use constant maturity Treasury rates as riskfree rates to calculate yield spreads for different maturities.

Table 3 report summary statistics of time-series data. Panel A shows that mean repo spread increases monotonically with maturity. Repos of longer maturities have greater uncertainty and thus larger spreads. On average, the overnight repo spread is only 12 basis points whereas the one-month repo spread is 70 basis points.

We use delinquency rates on single-family residential mortgages as a proxy for default risk of mortgages in the MBS pool. Delinquency rates (seasonally adjusted) are retrieved from Federal Reserve Bank of St. Louis. The delinquent loans defined by FRED are those past due 30+ days collected from all commercial banks. High delinquency rates signal high probability of default for mortgages.

A commonly used counterparty default risk measure is the CDS spread (see Arora et al. (2012); Copeland et al. (2014)). We construct two CDS spread indexes. The first is the average five-year CDS spread of money market funds' counterparties in the triparty repo market. The CDS spread of MMF counterparty captures the direct counterparty default risk in repo transactions. We identify these counterparties from the MMF filings to the SEC and match them with the CDS data in the Markit database. The second measure is the average five-year CDS spread of primary dealers. The default risk of primary dealers is a good barometer for counterparty risk as primary dealers are major players in the repo market. Primary dealers are the main cash borrowers in the repo market and counterparties to their clients and money market funds (cash lenders). We identify primary dealers from the Federal Reserve Bank website and match them with the CDS data from Markit. Besides the CDS spreads, we use the LIBOR-OIS spread as another counterparty risk measure, which is the difference between the three-month LIBOR and OIS rates. Past studies have shown that this spread is a good proxy for marketwide counterparty risk (Taylor (2009); Gorton and Metrick (2012)). We take the log value of counterparty risk measures to mitigate the effect of outliers during the subprime crisis.

In addition to collateral risk and counterparty risk measures, we include several explanatory variables suggested by the literature (Collin-Dufresne et al. (2001); Carr and Wu (2006); Gorton and Metrick (2012)) to control for the risk of mortgage repos:

- The VIX index (from Yahoo Finance) to control for the effect of market uncertainty.
- The change in the illiquidity index to proxy the search friction. This index is taken from Hu et al. (2013), which is constructed by the deviation of daily Treasury prices from the estimated prices.
- The change in the ABX price index of BBB tranches to proxy the subprime mortgage risk. This index is constructed by Markit, which is a synthetic tradable index referencing a basket of 20 subprime mortgage-backed securities. The ABX price index captures the risk of the subprime market. The lower this index, the higher the risk of the securitized product.
- Term structure variables: changes in the ten-year Treasury rate, and the slope of Treasury yield curve which is the difference between ten-year and two-year Treasury rates.

Panel B of Table 3 shows correlations among independent variables. Counterparty risk measures are positively correlated. VIX has a fairly high correlation with counterparty risk measures, and also with delinquency rates. The slope of yield curve is also correlated with CDS spread measures. To mitigate the collinearity problem, we regress these variables against the counterparty risk measures and delinquency rates to obtain the residuals as control variables in our regression.

# 5 Empirical results

## 5.1 Collateral and counterparty risks and the cross section of repos

In this section, we examine whether collateral and counterparty risks are important factors for the funding cost in the repo market using the data of individual repo deals from the MMF's filings to the SEC. Using these data, we investigate the determinants of spreads in the cross section of mortgage repos. In the repo market, haircuts are commonly used to control for default risk. Therefore, we also examine the effects of counterparty and default risk on hair cuts. We first run the panel regressions of repo spreads and haircuts against collateral and counterparty risks and important characteristics of repo contracts to ascertain the effects of these variables in normal time and financial crisis. We then further controll for the effect of relationship lending on repo rates and haircuts.

### 5.1.1 Effects of collateral and counterparty risks

We run panel regressions of repo spreads and haircut rates using the repo deal data. A typical repo holding report filed by an MMF lists the notional amount, repo rate, initiation date, repurchase date, counterparty, type of collateral and the value of the collateral at the report date. The level of details about the underlying collateral varies substantially between funds. Some report fairly detailed categories, while others only report broad classes like "U.S. Treasury Bonds" and "Government Agency Obligations". Generally, the collateral portfolio consists of securities of similar type such as Treasury bonds or agency obligations of different maturities. However, in most cases, the report does not list the CUSIP identifier for collateral. This makes it difficult to pin down the specific MBS collateral used in a repurchase agreement and its quality (or credit rating). Instead, we group repos by the broad class to differentiate the quality of collateral. For the N-Q data, we introduce an MBS dummy variable, which is equal to one if the collateral of a repo is MBS and equal to zero if the collateral is Treasury. For the N-MFP data, MBS issuer information is available, and we introduce a finer credit risk indicator which takes value 1 if the collateral is the MBS issued by Ginnie Mae, 2 if it is issued by Fannie Mae or Freddie Mac, and 3 if it is issued by a private issuer.

Counterparty risk is measured by the spread of the five-year CDS of the MMF's counterparty in each repurchase agreement.[8] We match MMF counterparty's CDS from the Markit database with the SEC data. In addition, we control the effects of repurchase contract characteristics, such as maturity and borrowing amount (Size).

MMFs and their counterparties (e.g., dealer banks) maintain a strong long-term customer relationship. Hu et al. (2015) find that the fund families are the dominant factors in determining repo pricing. Each fund family adopts different pricing schemes, such as counterparty sensitive, counterparty and collateral sensitive, and uniform pricing. To control for the cross-sectional heterogeneity between MMFs and counterparties, we account for the lenders x borrowers fixed effect in panel regressions. We pair each MMF (cash lender) with their counterparties (cash borrowers) to control for fixed effects in panel regressions.[9]

Table 4 shows the results of panel regressions using the N-Q data from 2004 to 2015. Panel A reports the results for repo spread regressions. Columns 1-6 include the lenders x borrowers fixed effects in each repo deal, and columns 4-6 add a crisis dummy variable to capture the effect in the subprime crisis. Panel B reports the results for haircut rate regressions with a similar specification. All regressions account for the MMF clustering effect.[10]

Of particular interest are the effects of collateral quality and counterparty risks. The coefficient of the MBS dummy variable captures the effect of the collateral quality difference

[8] In the present case, we use the default risk measure of MMF counterparty (cash borrowers) as the primary measure of counterparty risk as in the Triparty repo market, MMF default risk is a lesser concern.

[9] Considering this fixed effect significantly increases the goodness-of-fit in regressions, compared to just controlling for the lender (MMF) fixed effect.

[10] We use the cluster-adjusted standard error clustered by each MMF. The cluster-adjusted standard error accounts for within-cluster correlations and heteroscedasticity. In our data, each fund family includes a number of funds. The funds within each family follow the same policy to price repo and to set haircut rates. Thus, there are correlations among MMFs of the same family and to provide a robust standard error, we use the MMF clustered standard error in in our panel regression to calucate t values.

between MBS and Treasury repos. In repo spread regression, this coefficient is significant at the one percent level for all specifications (columns 1 to 6), indicating that collateral default risk has a positive effect on repo spreads. The coefficient of counterparty risk is also highly significant, suggesting that counterparty risk is positively priced in the repo market. Consistent with the prediction of our theoretical model, higher default risk of security lenders (cash borrower) leads to lower lending fees or higher repo spreads. The results suggest that counterparty risk and collateral quality are important determinants of repo spreads.

The effects of collateral quality and counterparty risk reinforce each other in repo transactions. When introducing the interaction variable (see column 2), MBS dummy x counterparty CDS spread, we find its coefficient is significantly positive. Thus, there is an interaction effect of counterparty and collateral risks. The repos with the collateral of lower quality carry a higher risk premium to compensate their investors for bearing counterparty risk. There is a significant positive relation between repo spreads and maturity, implying the existence of a maturity premium. This is perhaps not surprising as long-maturity repos have higher uncertainty. On the other hand, size has no significant effect on repo spreads. When adding the haircut rate in column 3, we find that it has a positive coefficient. This could be due to the fact that when repo spreads are high, the market is more uncertain and so haircuts are also high. Auh and Landoni (2016) also reports a similar positive relation between repo spreads and haircut rates. They suggest that the substitution between haircut and repo spreads is apparent only when the fundamental collateral risk is invariant. When collateral risk varies with the market condition, repo spreads and haircut rates tend to be positively correlated. Our result is consistent with this view.

For the haircut regression (Panel B), the coefficient of counterparty CDS spreads is positive and significant at the one percent level, suggesting that counterparty risk plays a role in setting the haircut rate. Haircuts are higher for mortgage repos than for Treasury repos, as revealed by the positive coefficient of MBS dummy. The results show that a repo with lower collateral quality has a higher haircut rate. Higher haircuts imply higher effective cost of funding. on the other hand, maturity and size of mortgage repos have no significant effect on haircuts.

The right side of Panels A and B in Table 4 reports the results when the dummy variable of financial crisis is included. Repo spreads significantly increase during the crisis period. The effects of collateral and counterparty risk variables remain significant even after controlling for the crisis effect. On the other hand, the haircut rate has no significant change during the crisis period.

Table 5 shows results of repo spread and haircut rate regressions using the N-MFP data set from 2010 to 2016. Since the filing period of form N-MFP starts only from 2010, we do not include the crisis dummy variable for this sample. The N-MFP data give more detail for the classes of MBS collateral, which enables us to introduce a finer collateral credit quality indicator to further differentiate the effects of different MBSs. In columns (1) and (2), we use the MBS dummy as a collateral quality variable, which has value one for the private-label MBS. In columns (3) and (4), we use an alternative collateral quality indicator, which equals 1 for the MBS issued by Ginnie Mae, 2 by Fannie Mae or Freddie Mac, and 3 by private issuers. Results in columns (1) and (2) show that private-label MBS collateral has a distinctly positive effect on repo spreads. When further differentiating different MBSs (columns (3) and (4)), we find that repo spreads are the highest for private-label MBS collateral, followed by those issued by Fannie Mae or Freddie Mac, and then by Ginnie Mae. Results show that although MBSs issued by Fannie Mae and Freddie Mac are guaranteed by the U.S. government, investors perceive their quality differently from the MBS of Ginnie Mae which is wholly government owned. The counterparty risk variable is significant across all regressions. The results for the haircut regression show a similar effect of collateral quality for different MBSs. Clearly, collateral quality and counterparty risk are important for determining repo rates and haircuts.

In summary, the results strongly support the prediction of the model that high collateral and counterparty risks lead to high funding cost in the mortgage repo market. Using the transaction data of individual repo deals from the triparty repo market, we find evidence that both collateral and counterparty risks are priced in the mortgage repo market. Moreover, the funding cost in the mortgage repo market jumps during the financial crisis when market uncertainty and risk aversion heighten.

### 5.1.2 Controlling for the effect of relationship trading

The literature suggests that frictions exist in both banking and non-banking lendings. These frictions lead to relationship formation and create a channel that risk taking can result in spillover effects. Traditional banks maintain relationships with clients to mitigate frictions due to asymmetric information. In the non-banking sector, particularly MMFs, the primary cash lenders in the triparty repo market, also face strong performance-flow relationships pressure. Chernenko and Sunderam (2014) find that during the European crisis period, MMFs with a high Eurozone bank exposure withdraw their lending to the counterparties with a stronger relationship less frequently. He (2017) use the bilaterally-connected holding to measure the strength of relationship lending and find that the cross-holding relationship makes a difference in lending during the European crisis, but does not change the riskiness of securities, measured by spreads. Han and Nikolaou (2016) find that both MMFs and dealers form trading relationships with multiple dealers and they tend to allocate greater volumes to some preferred counterparties.

A question of interest is whether there is a role for relationship trading in the triparty repo market where transactions are often secured by reasonably good quality collateral that effectively mitigates the concern about asymmetric information on counterparty credit risk (Mills and Reed (2008)); Infante (2015); Hu et al. (2015)). In addition, participants in this market are sophisticated financial institutions. Thus, the cost of locating a given trade partner and setting up the related contractual infrastructure should be relatively small. However, Han and Nikolaou (2016) find that the relationship trading in triparty repo markets matter; the strength of relationship affects the likelihood of a repo deal, the repo spread, and buffer shocks to liquidity. They suggest that the seemingly contradictory results in previous triparty repo studies may be due to the relationship trading. For example, Hu et al. (2015) find that dealers' creditworthiness does not affect the terms of repo trades, but Copeland et al. (2014) find that dealer's identity does matter. One possible reason that dealers' identity matters is that it reflects the relationship trading with MMFs.

An important issue is whether the effects of collateral and counterparty risks are robust to the lending relationship. To investigate this issue, we include the proxy variables of relationship lending in the panel regression by controlling the long-term relationship between each pair of MMFs and dealer (or the lenders x borrowers fixed effect). We examine whether a stronger relationship between lenders and borrowers affects repo spreads and haircut rates and whether the economic and statistical significance of collateral and counterparty risks are robust to controlling for the effect of relationship lending.

We measure the strength of the lending relationship between a fund family and a dealer by the concentration of a fund-family's total lending to a dealer or the concentration of a dealer's total borrowing from the fund family. We use two relationship lending measures based on the concentration of trading amount and collateral value that are commonly used in the literature (see, for example, Ashcraft and Duffie (2007); Afonso et al. (2014); Chernenko and Sunderam (2014); Han and Nikolaou (2016)). These measures are calculated from the perspectives of both MMF (RS_Fund) and dealer (RS_Dealer) respectively, using the data three months prior to the repo transaction. Specifically, the fund-dealer and the dealer-fund lending relationships are measured as follows:

$$RS\_Fund_{f,d,t} = \frac{\sum_{s=t-1}^{t-c} X_{f,d,s}}{\sum_{s=t-1}^{t-c} \sum_{d=1}^{N_d} X_{f,d,s}}$$

$$RS\_Dealer_{f,d,t} = \frac{\sum_{s=t-1}^{t-c} X_{f,d,s}}{\sum_{s=t-1}^{t-c} \sum_{f=1}^{N_f} X_{f,d,s}}$$

where $X_{f,d,t}$ denotes either the dollar volume of repos or collateral value posted by cash borrowers between a fund family $f$ and a dealer $d$ in the past three month ($c = 90$) before a repo transaction.

From the MMF's point of view, the strength of its relationship with dealer ($d$) is the dollar volume or collateral value of repos that the fund family trade with the dealer over the past three months divided by the total amount of repos to all dealers. The higher this ratio, the higher the concentration (reliance) of the MMF's repo trading to a specific dealer, or the stronger the trading relationship. The strength of a dealer's relationship with an MMF family is interpreted similarly. The stronger trading relationship from the dealer's point of view implies the higher reliance to a specific MMF.

Table 6 shows the results of panel regressions that incorporate the effect of relationship trading using the N-Q data from 2005 to 2015. Panel A reports the estimates for repo spread regressions, and Panel B reports the estimates for haircut rate regressions. All regressions account for lenders x borrowers fixed effects and the MMF clustering effect. We report standardized coefficient estimates to facilitate consistent comparison for the effects of counterparty risk, collateral risk and relationship lending.

There are two major findings. First, collateral risk and counterparty risk continue to be highly significant both statistically and economically even after controlling the effect of relationship lending. The standardized coefficients of these two risk measures are 0.39 (0.21) and 0.27 (0.16) in repo spread (haircut rate) regression, respectively when we use the borrowing amount in defining the relationship trading and include all variables in the regression (see column 2). As shown, these two variables exert the greatest effects on repo spreads and haircuts. Second, the lending relationship affects the terms of repos during the crisis period. In the regression, we include two crisis dummy variables and their interactions with relationship trading. Besides the subprime crisis dummy, we include a European crisis dummy (1 if the sample period is from 2011/6/1 to 2012/6/1). We find that a greater lending relationship of MMFs with a dealer leads to less bargaining power for the repo spread and haircut rate. This result is consistent with Han and Nikolaou's (2016) finding. When a fund family relies more heavily on a specific dealer to lend the money, it will be more inclined to accept a lower repo rate or a lower haircut rate during the crisis period when counterparty risk is high (i.e., the coefficient of crisis x RS_Fund is negative). In contrast, when a dealer relies more on a specific fund family to borrow the money, it will be asked to pay higher funding cost, in terms of higher repo rates and higher haircuts (i.e., the coefficient of European crisis x RS_Dealer is positive), during the crisis when counterparty risk is high.

Collectively, the results continue to suggest that collateral and counterparty risks lead to high funding cost in the mortgage repo market. Both variables have significant effects on repo spreads and haircut rates, and these effects are robust to controlling for the effect of relationship lending.

### 5.2 Time-series regressions

The analysis above uses individual repo deal data to examine whether the collateral quality and counterparty risk affect MBS repo spreads and haircuts. In this section, we reinforce these findings with time-series regressions of aggregate data. The time-series analysis allows us to explore the long-term behavior of repo spreads and examine its temporal relation with counterparty and collateral risks in a more systematic way. The time-series data are more suitable for testing some of the theoretical implications associated with changing market conditions and investment environments. In addition, the time-series analysis uses the aggregate data that include the repos in both triparty and bilateral markets, which broaden the coverage of our sample. Furthermore, an important implication of the theoretical model is that repo trading activity affects the yield spread of the MBS used as collateral in the repo. This spillover effect from the repo to spot market is easier to capture using the unbroken time-series data of mortgage-backed securities spreads. For the yield spread regression, we use the data of agency MBS indices constructed by Bank of America Merrill Lynch. All time-series data are in daily frequency.

We use delinquency rates on single-family residential mortgages as the collateral risk measure in time-series regressions. To capture marketwide counterparty risk effect, we use three counterparty risk measures: MMF counterparty and primary dealer CDS spreads, and LIBOR-OIS spreads. Other important factors in the regression include market volatility (VIX), liquidity frictions (represented by the illiquidity index), market risk (ABX prices associated with subprime mortgages) and term structure variables. The model suggests that volatility, illiquidity and market risk have positive effects on repo spreads. Interest rates are correlated with economic conditions, and the slope of yield curve reflects the expectation of future short rates. We use these variables to control the term structure effects.

Table 7 reports the results of time-series regressions. For brevity, we only report the results for overnight, 2-week, 1-month and 3-month repos and our results are robust to other maturities (e.g., 1-week and 2-month). The results strongly support the theoretical prediction that collateral and counterparty risks are positively related to mortgage repo spreads. These findings reinforce the cross-sectional analysis and suggest that collateral and counterparty risks are important factors of funding cost in collateral lending.

The coefficient of illiquidity is significantly positive, indicating that the repo rate is high when liquidity is low (or search friction is high). The variable of market volatility, VIX, is significant with the expected sign for longer-maturity repos, suggesting that market uncertainty (or risk aversion) is more important for the pricing of longer-maturity mortgage repos. Term structural variables also affect repo spreads. In line with the model prediction, changes in interest rates have a positive effect on repo spreads.[11] Overall, the results are consistent with the predictions of our theoretical model that search frictions, risk aversion and interest rates play important roles in affecting repo spreads.

We also run regressions using the housing price index and current yields as alternative

[11] Repo spreads and interest rates are often positively correlated in the money market. Our finding of a positive relation between repo spreads and changes in interest rates is consistent with the evidence documented by Gorton and Metrick (2012).

measures of collateral risk.[12] Results (omitted for brevity) show robustness of our results to these collateral risk proxies. Changes in the housing price index have a negative effect on repo spreads whereas changes in current coupon rates have a positive effect, both are significant at the one percent level.

### 5.2.1 MBS spread regressions

The search-based model also predicts that the activity in the repo market affects the pricing of the collateral in the spot market. It suggests that collateral and counterparty risks have a positive effect on the MBS yield spread. We next examine the role of collateral and counterparty risks in affecting MBS yield spreads by controlling for the effects of market uncertainty, illiquidity, subprime risk, and term structure variables.

The MBS spread variable is the yield of MBS index in excess of the risk-free rate with the same maturity. We use the change in the delinquency rate on single-family residential mortgages ($\Delta$Delinquency rate on residential) as the primary collateral risk measure but our results are robust to alternative measures such as the FHFA housing price index. The collateral risk measure reflects the health of the real estate mortgage market. The higher the delinquency rate, the riskier the MBS. Therefore, we expect a higher MBS spread with respect to a higher delinquency rate.

Table 8 reports the results of MBS yield spread regressions. We use the MBS with maturities less than 3 years, 3 years, 3-5 and 5-7 years. The coefficient of delinquency rates is positive and highly significant, indicating that an increase in the delinquency rates of residential mortgages leads to higher MBS yield spreads. In addition, consistent with the theoretical prediction, the coefficients of counterparty risk measures are significantly positive across the board. Results strongly support the prediction of the model that collateral and counterparty default risks in the repo market have important effects on the pricing of MBS in the spot market. This finding is robust to maturities of the MBS collateral and different

[12] Housing price is a good proxy for mortgage default risk. High housing price is associated with low default risk. We use the FHFA housing price index as a measure of aggregate housing price. In addition, we use the current coupon yield index as a proxy for default risk of mortgages. Carlin et al. (2014) use this measure to control for mortgage risk and Hancock and Passmore (2014) use it to evaluate the performance of agency MBS after Fed's large-scale asset purchases (LSAPs). The Bloomberg System provides the current coupon yield index with different maturities issued by Ginnie Mae, Fannie Mae, and Freddie Mac. We calculate the average current coupon yields for maturity above 15 years as an alternative collateral risk measure.

controls.

### 5.2.2 The effects of collateral and counterparty risks in times of stress

The results above show that collateral and counterparty risks have significant effects on repo spreads and MBS yield spreads. As investors are more risk averse during the financial crisis, the effect of collateral and counterparty risks should be more pronounced in times of stress. We next investigate this possibility.

Table 9 reports the results of regressions that include the crisis dummy interacted with collateral and counterparty risk measures. The crisis interaction dummy variable has value one for the period from July 2007 to January 2009 where the end of this period is set to the time that the Fed starts purchasing MBS in January 2009. The Fed purchased $1.25 trillion of agency MBS and this activity stabilized the mortgage market (see Boyarchenko et al. (2015); Chernov et al. (2016)). We run the panel regressions for repo spreads and MBS yield spreads by pooling the data for all maturities.

Table 9 shows that the coefficients of the interaction variable are positive and significant, suggesting that collateral and counterparty risks become much more important in times of stress. During the subprime crisis, counterparty default risk becomes a more serious concern. The sudden collapse of Bear Stearns and Lehman Brothers changes the perception of investors. Higher risk aversion makes investors less willing to lend to a problematic counterparty or lend on risky collateral. The higher risk-aversion significantly increases the counterparty and collateral risk premiums in the short-term financing market as repo investors require a higher compensation for bearing the repo risk. Similarly, the effects of collateral and counterparty risks on MBS spreads increase significantly during the financial crisis. The positive coefficients of repo counterparty risk variables suggest that counterparty risk in the repo market has a spillover effect on MBS spreads.

The results indicate that the effects of collateral and counterparty risks on repo spreads and MBS yield spreads magnify during the financial crisis. There is strong evidence that the effects of collateral and counterparty risks become magnify in times of stress, which can be attributed to the increase in risk aversion and market uncertainty during the financial crisis.

### 5.3 Structural Regression-Path Analysis

The preceding analysis shows the importance of collateral and counterparty risks in the pricing of repos and MBSs. As the model predicts that the activity in the repo market has a spillover effect on the mortgage market, this can induce a feedback effect on the yield spread of MBS in the secondary market. In this section, we conduct the path analysis to assess the direct and indirect effects of collateral and counterparty default risks. Path analysis uses a structural equation model to examine how a source affects the outcome directly or indirectly through the mediating variables.

Specifically, we perform a path analysis using following structural equation model (see Baron and Kenny (1986); Pevzner et al. (2015); Hilary et al. (2016)):

$$YRP = a \cdot Coll + b \cdot CP + \delta \cdot Controls + \varepsilon_1 \tag{12}$$

$$YMBS = c \cdot YRP + a' \cdot Coll + b' \cdot CP + \delta' \cdot Controls + \varepsilon_2 \tag{13}$$

The coefficients $a'$ and $b'$ represent the direct effect of collateral risk ($Coll$) and counterparty risk ($CP$) on the MBS yield spread ($YMBS$). The coefficients of $a \cdot c$ and $b \cdot c$ represent the indirect (spillover) effect of collateral and counterparty risks from the repo market to the spot market through the variation in repo spreads ($YRP$). The significance of the indirect effect is evaluated using the Sobel (1982) test statistics. In both repo spread and yield spread regressions, we use the same control variables as in previous time-series regressions.

Table 10 reports the results of the path analysis that shows how collateral and counterparty risks affect MBS yield spreads using four mediating paths: overnight, 2-week, 1-month, and 3-month repo spreads. For brevity, we only report the results based on the yield spread ($YMBS$) of the 3-year MBS index (M1A0) but our results are robust to the use of the MBS indexes with other maturities. $CP$ is the MMF counterparty's CDS spreads and $Coll$ is the collateral risk measure using the delinquency rate of residential mortgage payment.

The indirect effects of collateral and counterparty risks are highly significant when we use repos with maturities of 2 weeks and longer as mediators. The results suggest that counterparty risk and collateral risk in repo market have significant indirect effects on the MBS yield spread in the spot market. At the same time, the counterparty risk in the repo market has a significant direct effect on MBS yield spreads in the spot market. The direct effects of counterparty risk and collateral risk remain significant in the MBS yield spread regression even after controlling for the feedback effect from the repo market. Results suggest that the effects of collateral and counterparty risks on the MBS yield spread have both a direct component and an indirect channel through the repo lending market. The spillover effect from the repo market to the spot market contains the direct effect of repo counterparty risk on MBS yield spreads and the feedback effect of the repo spread change due to counterparty and collateral risks in the repo market. The evidence of path analysis lends support for the model's prediction that there is a spillover effect from the repo to MBS market.

# 6 Conclusion

In this paper, we propose a search-based model with collateral and counterparty risks to explain the lending fee and repo spreads in the mortgage repo market and yield spreads of mortgage-backed securities in the secondary market. This model accounts for the effects of collateral and counterparty risks beyond the usual effects of search frictions, liquidity, market uncertainty and term structure variables. We show that collateral and counterparty risks increase expected loss of counterparties in repo transactions and discourage repo trading activity and uses of mortgage-backed securities as collateral. As a consequence, they increase the repo spreads in the mortgage repo market and yield spreads in the mortgage-backed securities market. The effects magnify during the subprime crisis when default risk heightens and investors become more risk averse.

Empirical evidence strongly supports the predictions of the search-based model with collateral and counterparty risks. Collateral and counterparty risks have significantly positive effects on repo spreads and MBS yield spreads and these effects magnify in times of stress. The effects of collateral and counterparty risks are robust to different controls for the effects of illiquidity, market uncertainty and term structure variables. The results suggest that collateral and counterparty risks play an important role in determining mortgage repo spreads and prices of mortgage-backed securities used as repo collateral.

# Appendix: Utility flow and prices

Introducing the probabilities of counterparty and collateral defaults changes the inflow-outflow equations in the search-based model that determine the measures of agents $\mu_i$:

$$\text{Buyers } \bar{b} \quad \overline{F} = \overline{\kappa}\mu_{\bar{b}} + \sum_{i=1}^{2} \lambda \mu_{si}\mu_{\bar{b}} + \delta_{\bar{b}}\mu_{\bar{b}} \tag{A-1}$$

$$\text{Lenders } \bar{l}_i \quad \lambda \mu_{\bar{b}}\mu_{si} + f_i = \overline{\kappa}\mu_{\bar{l}i} + \nu_i \mu_{\underline{bo}}\mu_{\bar{l}i} + \delta_{\bar{l}i}\mu_{\bar{l}i} \tag{A-2}$$

$$\text{Nonsearchers } \overline{n}_i \quad \nu_i \mu_{\bar{l}i}\mu_{\underline{bo}} = f_i + \overline{\kappa}\mu_{\overline{n}i} + \delta_{\overline{n}i}\mu_{\overline{n}i} \tag{A-3}$$

$$Sellers \ \bar{s}_i \quad \overline{\kappa}\mu_{\bar{l}i} + \overline{\kappa}\mu_{\underline{s}i} = \lambda \mu_{bi}\mu_{\bar{s}i} + \delta_{\bar{s}i}\mu_{\bar{s}i} \tag{A-4}$$

$$\text{Borrowers } \underline{bo} \quad \underline{F} + \sum_{i=1}^{2} \overline{\kappa}\left(\mu_{\underline{s}i} + \mu_{\underline{n}i}\right) = \underline{\kappa}\mu_{\underline{bo}} + \sum_{i=1}^{2} \nu_i \mu_{\bar{l}i}\mu_{\underline{bo}} + \delta_{\underline{bo}}\mu_{\underline{bo}} \tag{A-5}$$

$$\text{Sellers } \underline{s}_i \quad \nu_i \mu_{\bar{l}i}\mu_{\underline{bo}} = \overline{\kappa}\mu_{\underline{s}i} + \underline{\kappa}\mu_{\underline{s}i} + \lambda \mu_{bi}\mu_{\underline{s}i} + \delta_{\underline{s}i}\mu_{\underline{s}i} \tag{A-6}$$

$$\text{Nonsearchers } \underline{n}_i \quad \lambda \mu_{bi}\mu_{\underline{s}i} = \overline{\kappa}\mu_{\underline{n}i} + \underline{\kappa}\mu_{\underline{n}i} + \delta_{\underline{n}i}\mu_{\underline{n}i} \tag{A-7}$$

$$\text{Buyers } \underline{b}_i \quad \underline{\kappa}\mu_{\underline{n}i} = \overline{\kappa}\mu_{\underline{b}i} + \lambda \mu_{si}\mu_{\underline{b}i} + \delta_{\underline{b}i}\mu_{\underline{b}i} \tag{A-8}$$

where $\bar{b}_i$ is an agent who seeks to buy an asset (MBS) $i$, $\bar{l}_i$ a lender of asset $i$, $\overline{n}_i$ an agent who has lent asset $i$, $\bar{s}_i$ a seller who seeks to sell an asset, $\underline{bo}$ an agent who seeks to borrow an asset, $\underline{s}_i$ a borrower of asset $i$ who seeks to sell it, $\underline{n}_i$ a borrower of asset $i$ who has sold it, and $\underline{b}_i$ the agent who has sold asset $i$ and seeks to buy it back for delivery to the lender.

For simplicity, we set the default probability for individuals $\delta_i$ equal to a constant $\delta_b$ for all agents of type $i$ in the flow-value equations (A-9) - (A-18).[13] This assumption can be relaxed to obtain a general but more complicated result. Besides the agent's own default risk, she faces an additional (contagious) default risk when her counterparty defaults.[14]

The inflow-outflow equations equate the inflow into a type of agent to the outflow out of that type of agent. For instance, in (A-1), the inflow into buyers (type $\bar{b}$) is set equal to the outflow out of buyers in equilibrium. $\overline{F}$ is the inflow into type $\bar{b}$ as new buyers enter the

[13] To reduce the number of unknown parameters, we assume $\delta_{\underline{s}i} = \delta_{\underline{n}i} = \delta_{\underline{b}i} = \delta_b$. Because $\mu_{\overline{n}\underline{s}i} + \mu_{\overline{n}\underline{n}i} + \mu_{\overline{n}\underline{b}i} = \mu_{\overline{n}i}$, we have $\delta_{\underline{s}i}\mu_{\overline{n}\underline{s}i} + \delta_{\underline{n}i}\mu_{\overline{n}\underline{n}i} + \delta_{\underline{b}i}\mu_{\overline{n}\underline{b}i} = \delta_b\mu_{\overline{n}i}$.

[14] The conditional default probability is also assumed to be a constant for individual i. This assumption can be relaxed in a more general case.

market. $\overline{\kappa}$ is the Poisson intensity at which high-valuation agents revert to average valuation and are no longer buyers ($\underline{\kappa}$ is the Poisson intensity at which low-valuation agents revert to average valuation). $\lambda$ is the intensity at which a buyer finds a seller in the spot market and is a parameter measuring the efficiency of search. $\lambda\mu_{si}\mu_{\overline{b}}$ represents the outflow of buyers after they purchase the asset. After the buyers purchase the asset, they become nonsearchers $\overline{n}_i$. $\delta_{\overline{b}}$ is the default probability of buyers and $\delta_{\overline{b}}\mu_{\overline{b}}$ is the outflow of buyers when they default. Upon default, the buyer exits the market. There are additional parameters in other inflow-outflow equations, for example, $f_i$ is the inflow from type $\overline{n}_i$ to $\bar{l}_i$, $\nu_i$ is the intensity at which an agent finds a counterparty in the repo market, and $\underline{F}$ is the inflow into type $\underline{bo}$ when short-sellers enter the repo market (see definitions in Table 1).

In the above equations, agents' default risk has two implications. First, the defaulted agents exit the market, which changes the inflow and the outflow of the agents in equilibrium. Second, if the defaulted agents have the repo contracts, their counterparties may incur losses. For example, we have (A-3) for non-searcher type $\overline{n}_i$ where $\delta_{\overline{n}i}$ is the probability that type $\overline{n}_i$ agent will default. $\overline{n}\underline{n}_i$ is a lender whose counterparty $\underline{n}_i$ has sold the asset $i$, and $\overline{n}\underline{b}_i$ is a lender whose counterparty $\underline{b}_i$ seeks to buy asset $i$ to deliver. If a lender whose type is $\overline{n}\underline{n}_i$ or $\overline{n}\underline{b}_i$ defaults on the contract, her counterparty, the agent of type $\underline{n}_i$ or $\underline{b}_i$, may not be able to recover their cash and incur losses. Similarly, agent type $\overline{n}_i$ has counterparties of agent types $\underline{s}_i$, $\underline{n}_i$, or $\underline{b}_i$. If either counterparty type $\underline{s}_i$ or $\underline{n}_i$ or $\underline{b}_i$ defaults, the agent of type $\overline{n}_i$, may not be able to recover the asset lent at the beginning of the contract and may suffer losses. Thus, counterparty default risk affects agents' utilities in equilibrium.

An agent $i$ optimizes her utility in equilibrium. After the asset default, the income decreases to $\chi\tau$ and we have the following flow-value equations to establish the equilibrium MBS price $p_i^a$ and lending fee $w_i^a$:

$$rV_{\overline{b}}^a = -\overline{\kappa}V_{\overline{b}}^a + \sum_{i=1}^{2} \lambda\mu_{si}\left(V_{\overline{l}i}^a - p_i^a - V_{\overline{b}}^a\right) + \delta_{\overline{b}}\left(V_d - V_{\overline{b}}^a\right) \tag{A-9}$$

$$rV_{\overline{l}i}^a = \chi\tau + \overline{x} - y + \overline{\kappa}(V_{\overline{s}i}^a - V_{\overline{l}i}^a) + \nu_i\mu_{\underline{bo}}\left(V_{\overline{n}\underline{s}i}^a - V_{\overline{l}i}^a\right) + \delta_{\overline{l}i}\left(V_d - V_{\overline{l}i}^a\right) \tag{A-10}$$

$$\begin{aligned} rV_{\overline{n}\underline{s}i}^a \quad = \quad & \chi\tau + \overline{x} - y + w_i^a + \overline{\kappa}(V_{\overline{s}i}^a - V_{\overline{n}\underline{s}i}^a) + \underline{\kappa}(V_{\overline{l}i}^a - V_{\overline{n}\underline{s}i}^a) \\ & + \lambda\mu_{bi}(V_{\overline{n}\underline{n}i}^a - V_{\overline{n}\underline{s}i}^a) + \delta_{\overline{n}\underline{s}i}\left(V_d - V_{\overline{n}\underline{s}i}^a\right) + \xi I_{i,1}\delta_{\underline{s}i}(V_{\overline{l}i}^a - p_i^a + \eta C_i^a - V_{\overline{n}\underline{s}i}^a) \end{aligned} \tag{A-11}$$

$$
\begin{aligned}
rV^a_{\overline{n}\underline{n}i} &= \chi\tau + \overline{x} - y + w^a_i + \overline{\kappa}(C^a_i - V^a_{\overline{n}\underline{n}i}) + \underline{\kappa}(V^a_{\overline{n}\underline{b}i} - V^a_{\overline{n}\underline{n}i}) \\
&\quad + \delta_{\overline{n}\underline{n}i}\left(V_d - V^a_{\overline{n}\underline{n}i}\right) + \xi I_{i,1}\delta_{\underline{n}i}(V^a_{\overline{l}i} - p^a_i + \eta C^a_i - V^a_{\overline{n}\underline{n}i}) \qquad \text{(A-12)}
\end{aligned}
$$

$$
\begin{aligned}
rV^a_{\overline{n}\underline{b}i} &= \chi\tau + \overline{x} - y + w^a_i + \overline{\kappa}(C^a_i - V^a_{\overline{n}\underline{b}i}) + \lambda\mu_{si}(V^a_{\overline{l}i} - V^a_{\overline{n}\underline{b}i}) \\
&\quad + \delta_{\overline{n}\underline{b}i}\left(V_d - V^a_{\overline{n}\underline{b}i}\right) + \xi I_{i,1}\delta_{\underline{b}i}\left(V^a_{\overline{l}i} - p^a_i + \eta C^a_i - V^a_{\overline{n}\underline{b}i}\right) \qquad \text{(A-13)}
\end{aligned}
$$

$$
rV^a_{\overline{s}i} = \chi\tau - y + \lambda\mu_{bi}\left(p^a_i - V^a_{\overline{s}i}\right) + \delta_{\overline{s}i}\left(V_d - V^a_{\overline{s}i}\right) \qquad \text{(A-14)}
$$

$$
rV^a_{\underline{bo}} = -\underline{\kappa}V^a_{\underline{bo}} + \sum_{i=1}^{2}\nu_i\mu_{\overline{l}i}\left(V^a_{\underline{s}i} - V^a_{\underline{bo}}\right) + \delta_{\underline{bo}}\left(V_d - V^a_{\underline{bo}}\right) \qquad \text{(A-15)}
$$

$$
\begin{aligned}
rV^a_{\underline{s}i} &= -w^a_i + \overline{\kappa}(V^a_{\underline{bo}} - V^a_{\underline{s}i}) \qquad \text{(A-16)} \\
&\quad -\underline{\kappa}V^a_{\underline{s}i} + \lambda\mu_{bi}\left(V^a_{\underline{n}i} + p^a_i - V^a_{\underline{s}i}\right) + \delta_{\underline{s}i}\left(V_d - V^a_{\underline{s}i}\right) + \varphi I_{i,1}\delta_{\overline{n}\underline{s}i}\left(V^a_{\underline{bo}} + p^a_i - \eta C^a_i - V^a_{\underline{s}i}\right)
\end{aligned}
$$

$$
\begin{aligned}
rV^a_{\underline{n}i} &= -\chi\tau + \underline{x} - y - w^a_i + \overline{\kappa}\left(V^a_{\underline{bo}} - C^a_i - V^a_{\underline{n}i}\right) \qquad \text{(A-17)} \\
&\quad + \underline{\kappa}\left(V^a_{\underline{b}i} - V^a_{\underline{n}i}\right) + \delta_{\underline{n}i}\left(V_d - V^a_{\underline{n}i}\right) + \varphi I_{i,1}\delta_{\overline{n}\underline{n}i}\left(V^a_{\underline{bo}} - \eta C^a_i - V^a_{\underline{n}i}\right)
\end{aligned}
$$

$$
\begin{aligned}
rV^a_{\underline{b}i} &= -\chi\tau - y - w^a_i + \overline{\kappa}\left(-C^a_i - V^a_{\underline{b}i}\right) \qquad \text{(A-18)} \\
&\quad + \lambda\mu_{si}\left(-p^a_i - V^a_{\underline{b}i}\right) + \delta_{\underline{b}i}\left(V_d - V^a_{\underline{b}i}\right) + \varphi I_{i,1}\delta_{\overline{n}\underline{b}i}\left(-\eta C^a_i - V^a_{\underline{b}i}\right)
\end{aligned}
$$

where the superscripts $a$ denotes "after" the default, $r$ is the risk-free rate, $V_i$ is the utility of agent $i$, i.e., $V_{\underline{n}i}$ ($V_{\underline{b}i}$) is the utility of a low-valuation nonsearcher (buyer), $V_d$ is the utility if an agent defaults, $I_{i,1}$ is an identity function (Kronecker delta):

$$
I_{i,1} = \begin{cases} 0 & \text{if } i \neq 1 \\ 1 & \text{if } i = 1 \end{cases},
$$

and $\delta_{\underline{n}i}$ in (A-17) is the default probability of agent type $\underline{n}_i$. Other parameters in the system of equations are: $p_i$ the price of asset $i$, $\tau$ the expected dividend, $y$ cost of risk bearing, $w_i$ a fee paid by the borrower to the lender of asset $i$, and $\overline{x}(\underline{x})$ is hedging benefit for high (low) valuation agents.

Before the asset default, the investment income is $\tau$. However, the asset has a default probability $\delta_m$, and agents take the default probability, loss upon default, and their utilities after the default into account in their evaluation before the default occurs. The equilibrium asset price $p^b_i$ and lending fee $w^b_i$ are the solutions of the following flow-value equations:

$$rV^b_{\bar{b}} = -\overline{\kappa}V^b_{\bar{b}} + \sum_{i=1}^{2} \lambda\mu_{si}\left(V^b_{\bar{l}i} - p^b_i - V^b_{\bar{b}}\right) + \delta_{\bar{b}}\left(V_d - V^b_{\bar{b}}\right) + \delta_m\left(V^a_{\bar{b}} - V^b_{\bar{b}}\right) \quad \text{(A-19)}$$

$$rV^b_{\bar{l}i} = \tau + \overline{x} - y + \overline{\kappa}(V^b_{\bar{s}i} - V^b_{\bar{l}i}) + \nu_i\mu_{\underline{bo}}\left(V^b_{\overline{n}\underline{s}i} - V^b_{\bar{l}i}\right) \quad \text{(A-20)}$$

$$+\delta_{\bar{l}i}\left(V_d - V^b_{\bar{l}i}\right) + \delta_m\left(V^a_{\bar{l}i} - V^b_{\bar{l}i}\right) \quad \text{(A-21)}$$

$$rV^b_{\overline{n}\underline{s}i} = \tau + \overline{x} - y + w^b_i + \overline{\kappa}(V^b_{\bar{s}i} - V^b_{\overline{n}\underline{s}i}) + \underline{\kappa}(V^b_{\bar{l}i} - V^b_{\overline{n}\underline{s}i}) + \lambda\mu_{bi}(V^b_{\overline{n}\underline{n}i} - V^b_{\overline{n}\underline{s}i}) \quad \text{(A-22)}$$

$$+\delta_{\overline{n}\underline{s}i}\left(V_d - V^b_{\overline{n}\underline{s}i}\right) + \xi I_{i,1}\delta_{\underline{s}i}(V^a_{\bar{l}i} - p^a_i + \eta C^b_i - V^b_{\overline{n}\underline{s}i}) + \delta_m\left(V^a_{\overline{n}\underline{s}i} - V^b_{\overline{n}\underline{s}i}\right) \quad \text{(A-23)}$$

$$rV^b_{\overline{n}\underline{n}i} = \tau + \overline{x} - y + w^b_i + \overline{\kappa}(C^b_i - V^b_{\overline{n}\underline{n}i}) + \underline{\kappa}(V^b_{\overline{n}\underline{b}i} - V^b_{\overline{n}\underline{n}i})$$

$$+\delta_{\overline{n}\underline{n}i}\left(V_d - V^b_{\overline{n}\underline{n}i}\right) + \xi I_{i,1}\delta_{\underline{n}i}(V^a_{\bar{l}i} - p^a_i + \eta C^b_i - V^b_{\overline{n}\underline{n}i}) + \delta_m\left(V^a_{\overline{n}\underline{s}i} - V^b_{\overline{n}\underline{s}i}\right) \quad \text{(A-24)}$$

$$rV^b_{\overline{n}\underline{b}i} = \tau + \overline{x} - y + w^b_i + \overline{\kappa}(C^b_i - V^b_{\overline{n}\underline{b}i}) + \lambda\mu_{si}(V^b_{\bar{l}i} - V^b_{\overline{n}\underline{b}i})$$

$$+\delta_{\overline{n}\underline{b}i}\left(V_d - V^b_{\overline{n}\underline{b}i}\right) + \xi I_{i,1}\delta_{\underline{b}i}\left(V^a_{\bar{l}i} - p^a_i + \eta C^b_i - V^b_{\overline{n}\underline{b}i}\right) + \delta_m\left(V^a_{\overline{n}\underline{b}i} - V^b_{\overline{n}\underline{b}i}\right) \quad \text{(A-25)}$$

$$rV^b_{\bar{s}i} = \tau - y + \lambda\mu_{bi}\left(p^b_i - V^b_{\bar{s}i}\right) + \delta_{\bar{s}i}\left(V_d - V^b_{\bar{s}i}\right) + \delta_m\left(V^a_{\bar{s}i} - V^b_{\bar{s}i}\right) \quad \text{(A-26)}$$

$$rV^b_{\underline{bo}} = -\underline{\kappa}V^b_{\underline{bo}} + \sum_{i=1}^{2} \nu_i\mu_{\bar{l}i}\left(V^b_{\underline{s}i} - V^b_{\underline{bo}}\right) + \delta_{\underline{bo}}\left(V_d - V^b_{\underline{bo}}\right) + \delta_m\left(V^a_{\underline{bo}} - V^b_{\underline{bo}}\right) \quad \text{(A-27)}$$

$$rV^b_{\underline{s}i} = -w^b_i + \overline{\kappa}(V^b_{\underline{bo}} - V^b_{\underline{s}i}) - \underline{\kappa}V^b_{\underline{s}i} + \lambda\mu_{bi}\left(V^b_{\underline{n}i} + p^b_i - V^b_{\underline{s}i}\right)$$

$$+\delta_{\underline{s}i}\left(V_d - V^b_{\underline{s}i}\right) + \varphi I_{i,1}\delta_{\overline{n}\underline{s}i}\left(V^a_{\underline{bo}} + p^a_i - \eta C^b_i - V^b_{\underline{s}i}\right) + \delta_m\left(V^a_{\underline{s}i} - V^b_{\underline{s}i}\right) \quad \text{(A-28)}$$

$$rV^b_{\underline{n}i} = -\tau + \underline{x} - y - w^b_i + \overline{\kappa}\left(V^b_{\underline{bo}} - C^b_i - V^b_{\underline{n}i}\right) + \underline{\kappa}\left(V^b_{\underline{b}i} - V^b_{\underline{n}i}\right)$$

$$+\delta_{\underline{n}i}\left(V_d - V^b_{\underline{n}i}\right) + \varphi I_{i,1}\delta_{\overline{n}\underline{n}i}\left(V^a_{\underline{bo}} - \eta C^b_i - V^b_{\underline{n}i}\right) + \delta_m\left(V^a_{\underline{s}i} - V^b_{\underline{n}i}\right) \quad \text{(A-29)}$$

$$rV^b_{\underline{b}i} = -\tau - y - w^b_i + \overline{\kappa}\left(-C^b_i - V^b_{\underline{b}i}\right) + \lambda\mu_{si}\left(-p^b_i - V^b_{\underline{b}i}\right)$$

$$+\delta_{\underline{b}i}\left(V_d - V^b_{\underline{b}i}\right) + \varphi I_{i,1}\delta_{\overline{n}\underline{b}i}\left(-\eta C^b_i - V^b_{\underline{b}i}\right) + \delta_m\left(V^a_{\underline{b}i} - V^b_{\underline{b}i}\right) \quad \text{(A-30)}$$

where the superscript $b$ denotes "before" the default.[15]

[15] This model can be generalized to the case of $N$ regimes where $\tau = \{\tau_1, \tau_2, ..., \tau_N\}$ and $\sigma_d = \{\sigma_{d1}, \sigma_{d2}, ..., \sigma_{dN}\}$ are incremental dividend and volatility, respectively, and $B^d$ is a standard Brownian motion. We adopt the regime-switching approach in the model (Gray (1996)). A continuous-time, time-homogeneous Markov chain can be specified in terms of a $N \times N$ infinitesimal generator matrix

$$\Phi = \begin{pmatrix} \delta_{m11} & \delta_{m12} & ... & \delta_{m1N} \\ \delta_{m21} & \delta_{m22} & ... & \delta_{m2N} \\ ... & ... & ... & ... \\ \delta_{mN1} & \delta_{mN2} & ... & \delta_{mNN} \end{pmatrix}$$

A departure from previous repo market studies is that the current model accounts for the impacts of both collateral and counterparty default risks on an agent's utility and asset pricing. For example, in Vayanos and Weill (2008), $C_i$ represents the cash collateral which is equal to the full value of the asset. In the event of contract termination, the lender is assumed to be able to recover the full value of the asset. A security lender terminates the contract with probability $\overline{\kappa}$ when she reverts to average valuation. When agent type $\overline{n}\underline{n}_i$ ($\overline{n}\underline{b}_i$) reverts to average valuation and terminates the contract, the security lender either recovers the asset or receives the full cash value of the asset. If the security lender recovers the asset, then she becomes a seller. Alternatively, if the security borrower cannot deliver the asset, the lender receives the full cash value of the asset and purchases the asset from the spot market. In either case, agent type $\overline{n}\underline{n}_i$ ($\overline{n}\underline{b}_i$) becomes a seller with the value function of $V_{\overline{s}i}$.[16] That is, in the Vayanos-Weill model, $C_i$ is equal to $V_{\overline{s}i}$ and there is no default loss in the event of contract termination.

In contrast, we introduce the asset (collateral) default in the present model. After the default event occurs, the income from the asset decreases by $(1-\chi)\,\tau$ and the price of the asset reduces from $p_i^b$ to $p_i^a$. For example, after an asset defaults, the short-seller $\underline{b}_i$ can buy back the asset at lower price $p_i^a$ and deliver it to the lender $\overline{n}\underline{b}_i$. On the other hand, the asset lender $\overline{n}\underline{b}_i$ would get the collateral back at a value lower than that at the time they lent it out. The expected income and price changes after the default affect agents' valuation on the asset in the spot market. In addition, these changes affect the utilities of lenders and borrowers on the repo market before the asset default.

Moreover, we introduce counterparty default risk. In this setting, when agent type $\underline{s}_i$ ($\underline{n}_i$ or $\underline{b}_i$) defaults, her counterparty $\overline{n}\underline{s}_i$ ($\overline{n}\underline{n}_i$ or $\overline{n}\underline{b}_i$) is affected. We add the term $\eta$ where $\eta < 1$ in (A-11) ((A-12) or (A-13)) to represent the recovery rate of repo when the counterparty defaults, or 1-$\eta$ is an agent's loss due to a counterparty default. We posit that upon the security borrower default, agent type $\overline{n}\underline{s}_i$ ($\overline{n}\underline{n}_i$ or $\overline{n}\underline{b}_i$) recovers only a fraction $\eta$ of the full cash value of the before-default security, $C_i$.[17] Because her counterparty has defaulted, she is no longer a security lender. She buys back the security at the market price and becomes a lender again. On the other hand, when the security lender $\overline{n}\underline{s}_i$ ($\overline{n}\underline{n}_i$ or $\overline{n}\underline{b}_i$) defaults,

[16] See (C26) on page 16 of the online appendix of Vayanos and Weill (2008).

[17] The loss rate (1 - $\eta$) includes the haircut in the repo contract.

the borrower $\underline{s}_i$ ($\underline{n}_i$ or $\underline{b}_i$) loses his cash but keeps the security he borrowed. Because of his counterparty defaults, he is no longer a borrower. He sells the security and becomes a borrower again (see (A-16), (A-17), and (A-18)). Thus, interactions between buyers and sellers are not only dependent on search intensity but also affected by default risk.

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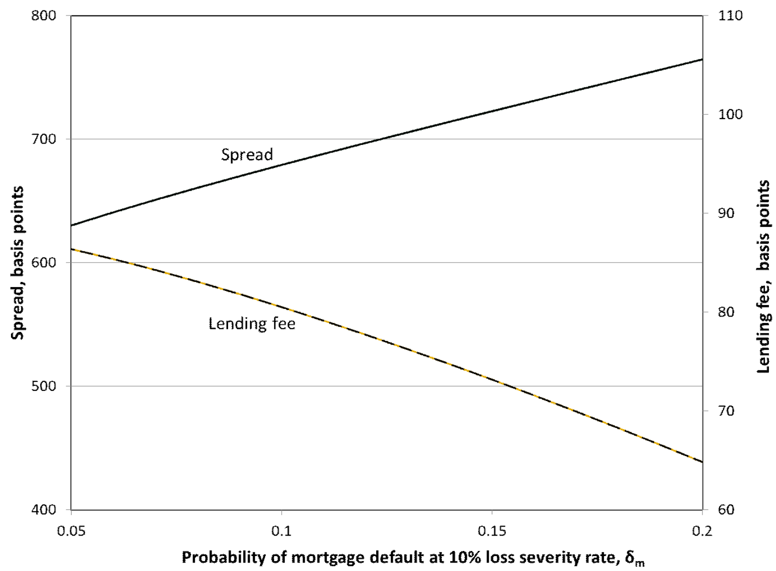


Figure 2. The effect of mortgage default probability on the yield spread and the lending fee. The quality is measured by the probability of losing 10% mortgage payments (1-$\chi = 0.1$).

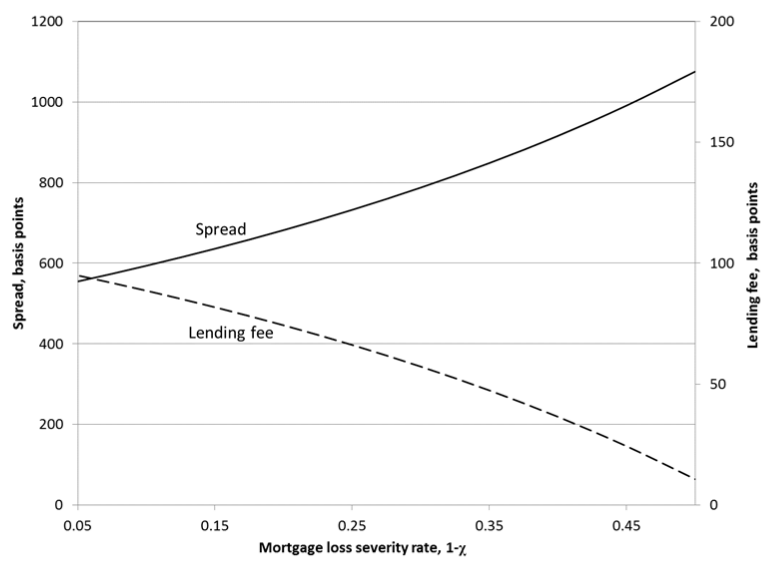


Figure 3. The effect of mortgage default loss rate on the yield spread and the lending fee. The collateral quality is measured by the loss rate of mortgage payments, assuming the mortgage default probability of the loss severity rate is 10% ($\delta_m = 0.1$).

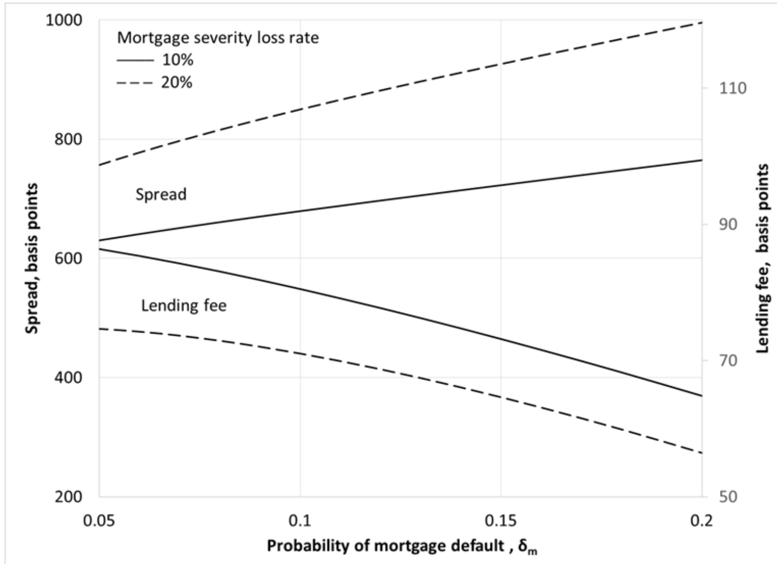


Figure 4. The impact of mortgage loss rate on the effect of collateral default probability on the yield spread and the lending fee.

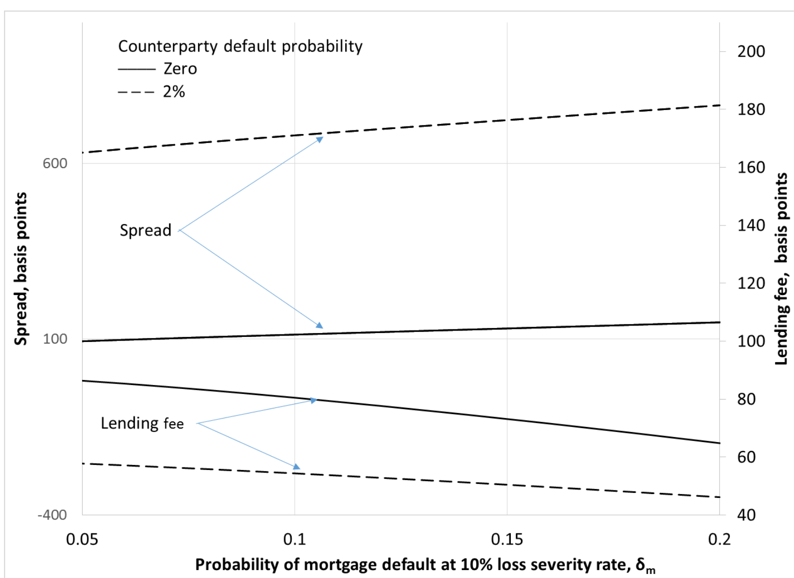


Figure 5. The impact of counterparty default risk on the yield spread and the lending fee. The collateral quality is measured by the probability of losing 10% mortgage payments (1-$\chi = 0.1$).

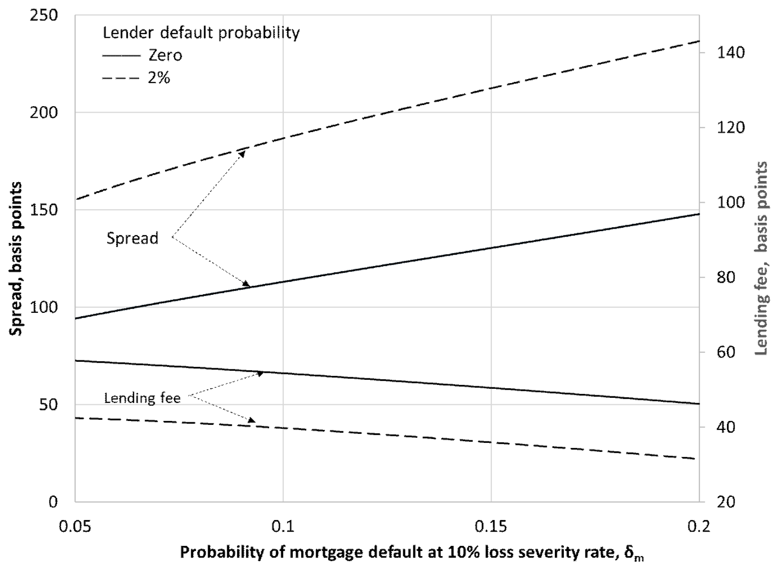


Figure 6. The effect of lender default risk and mortgage quality on the yield spread and the lending fee. The quality is measured by the mortgage default probability at 10% loss severity rate ($1\text{-}\chi = 0.1$).

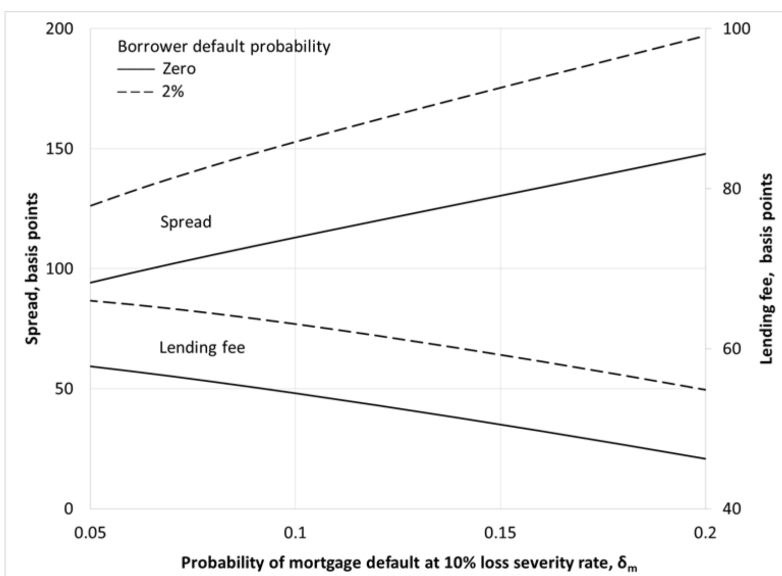


Figure 7. The effect of borrower default risk and mortgage quality on the yield spread and the lending fee. The quality is measured by the mortgage default probability at 10% loss severity rate ($1\text{-}\chi = 0.1$).

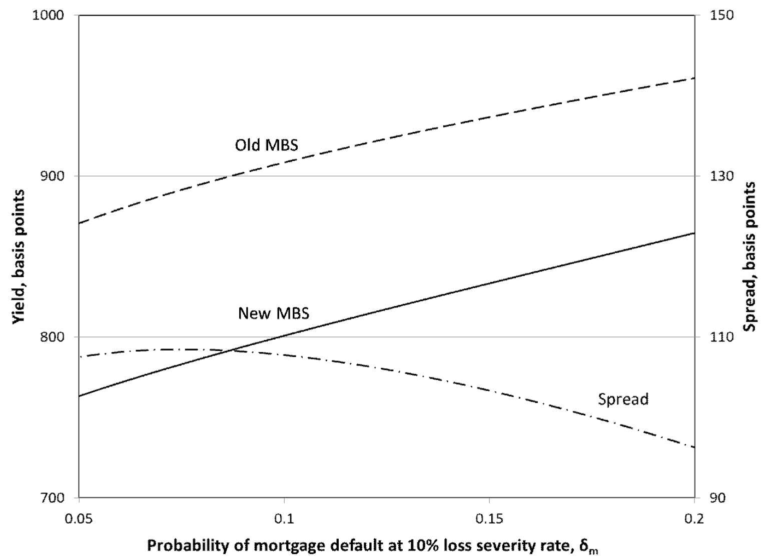


Figure 8. The yield of new versus old mortgage-backd securities.

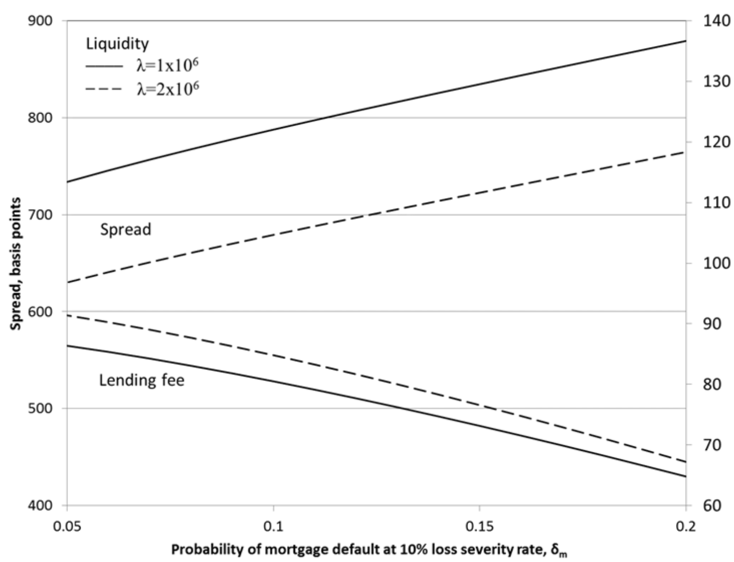


Figure 9. The impact of search intensity and mortgage quality on the yield spread and lending fee. The quality is measured by the mortgage default probability assuming the loss severity rate is 10% (1-$\chi = 0.1$).

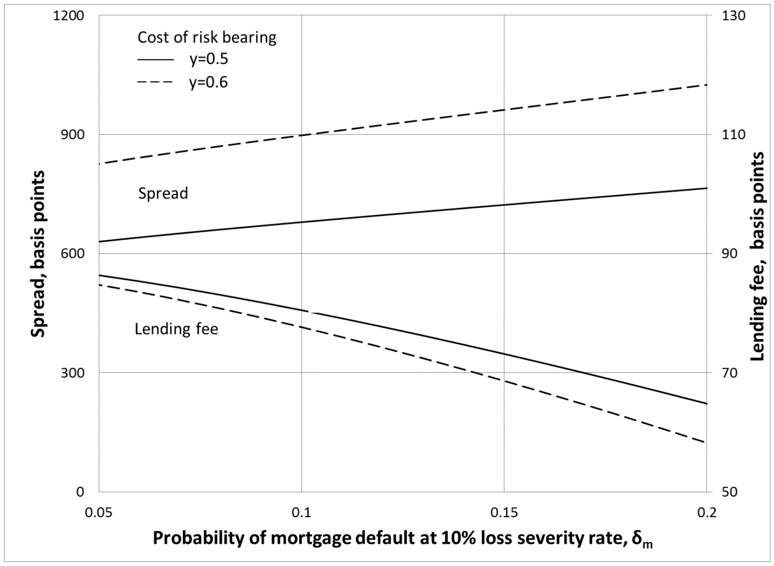


Figure 10. The effect of the cost of risk bearing and mortgage quality on the yield spread and lending fee. The quality is measured by the mortgage default probability of losing 10% mortgage payments (1-$\chi = 0.1$).

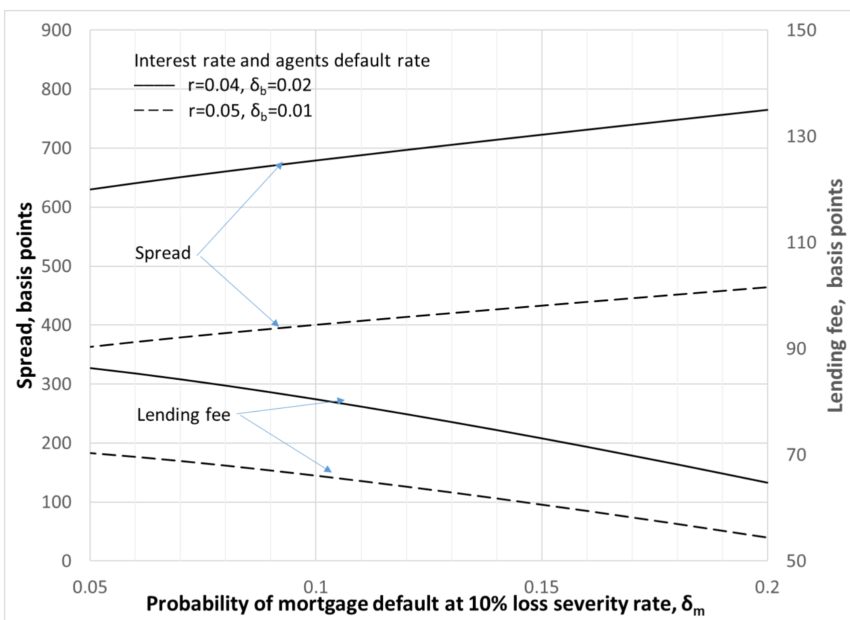


Figure 11. The impact of interest rates and mortgage quality on the yield spread and lending fee. The quality is measured by the mortgage default probability of losing 10% mortgage payments (1-$\chi = 0.1$).

Table 1. Panel A: Parameter definitions

| Variable | Definition |
|---|---|
| $\bar{b}_i$ | An agent seeks to buy an asset $i$ |
| $\underline{b}_i$ | Has sold asset $i$; seeks to buy it back and deliver to lender |
| $\underline{bo}$ | An agent who seeks to borrow an asset |
| $c$ | Consumption |
| $C_i$ | The full cash value of an asset $i$ |
| $f_i$ | Inflow from type $\overline{n}_i$ to $\bar{l}_i$ |
| $\overline{F}$ | Inflow into type $\underline{b}$ because new buyers enter the market |
| $\underline{F}$ | Outflow out of type $\underline{bo}$ because some borrowers exit from the market |
| $g_i$ | $\lambda\mu_i \to g_i$ when search frictions go to zero |
| $I$ | Number of assets |
| $\bar{l}_i$ | Lender of asset $i$ |
| $m_i$ | $\mu_i \to m_i$ when search frictions go to zero |
| $\overline{n}\underline{b}_i$ | Nonsearcher; repo counterparty $\underline{b}_i$ |
| $\overline{n}_i$ | An agent who has lent asset $i$ |
| $\underline{n}_i$ | Has borrowed and then sold asset $i$ |
| $\overline{n}\underline{n}_i$ | Nonsearcher; repo counterparty $\underline{n}_i$ |
| $\overline{n}\underline{s}_i$ | Nonsearcher; repo counterparty $\underline{s}_i$ |
| $p_i$ | Price of asset $i$ |
| $q_i$ | An agent's investment in asset $i$ |
| $r$ | Risk-free interest rate |
| $\overline{s}_i$ | Upon reverting to average valuation, a lender $\bar{l}_i$ becomes a seller |
| $\underline{s}_i$ | Has borrowed asset $i$; seeks to sell it |
| $S$ | Asset supply |
| $W_t$ | Wealth process |
| $v$ | A constant; $v_i = v$ if low valuation agents borrow asset $i$ |
| $v_i$ | Intensity at which an agent finds a counterparty in the repo market |
| $V_i^a$ | Utility of agent $i$ after ABS default |
| $V_i^b$ | Utility of agent $i$ before ABS default |
| $w_i$ | A fee paid by the borrower to the lender of asset $i$ |
| $\overline{x}$ | Hedging benefit for high-valuation agents |
| $\underline{x}$ | Hedging benefit for low-valuation agents |
| $y$ | Cost of risk bearing |
| $\beta$ | An agent's time preference rate |
| $\gamma$ | Risk aversion coefficient |
| $\delta_d$ | An agent default probability |
| $\delta_m$ | MBS default probability |
| $\zeta$ | Cumulative endowment process |
| $\eta$ | Recovery rate of repo if a counterparty defaults |
| $\theta$ | A fraction surplus that a lender receives from the borrower |
| $\overline{\kappa}$ | Poisson intensity with which high-valuation agents revert to average valuation |
| $\underline{\kappa}$ | Poisson intensity with which low-valuation agents revert to average valuation |
| $\lambda$ | Intensity at which an agent finds a counterparty in the bond market |

Panel A (continued): Parameter definitions

| Variable | Definition |
|---|---|
| $\mu_i$ | The measure of agent type $i$ |
| $\mu_{bi}$ | The measure of buyers of asset $i$: $\mu_{bi} = \mu_{\overline{b}i} + \mu_{\underline{b}i}$ |
| $\mu_{si}$ | The measure of sellers of asset $i$: $\mu_{si} = \mu_{\overline{s}i} + \mu_{\underline{s}i}$ |
| $\xi$ | Probability that lenders take loss conditional on their counterparty default |
| $\varphi$ | Probability that borrowers take loss conditional on their counterparty default |
| $\tau$ | Expected dividend |
| $\overline{\rho}_i$ | Correlation between the asset dividend and endowment for high-valuation agent $i$ |
| $\underline{\rho}_i$ | Correlation between the asset dividend and endowment for low-valuation agent $i$ |
| $\sigma_d$ | The standard deviation of the cumulative income process |
| $\sigma_N$ | the loss rate associated with an agent's endowment jump |
| $\sigma_\zeta$ | The standard deviation of the endowment process |
| $\phi$ | A fraction surplus that buyer receives in an efficient trade |
| $\chi$ | $1-\chi$ is the loss severity rate of the MBS income associated with default |
| $\Sigma_i$ | Surplus in a repo transaction of asset $i$ |

Panel B: Parameter values used in numerical solutions

| Variable | Value |
|---|---|
| $\overline{F}$ | 2.7 |
| $\underline{F}$ | 13.6 |
| $\overline{\kappa}$ | 2 |
| $\underline{\kappa}$ | 40 |
| $\lambda$ | $10^6$ |
| $\nu_1$ | $7.5\times10^4$ |
| $\nu_2$ | 0 |
| $r$ | 0.04 |
| $\tau$ | 1 |
| $\overline{x}$ | 0.4 |
| $\underline{x}$ | 1.6 |
| $y$ | 0.5 |
| $\eta$ | 0.5 |
| $S$ | 0.05 |
| $I$ | 20 |

**Table 2. Summary statistics of individual repo deals**

This table provides summary statistics for the variables associated with the individual repo deal data which are collected from the N-Q and N-MFP forms filed by the money market funds. The sample period is from July 2004 to December 2015 for the N-Q data and from July 2010 to December 2016 for the N-MFP data. Panels A and B report the statistics for Treasury and MBS repos, respectively, from form N-Q. Panels C, D and E report the statistics for the repo whose collateral is the MBS issued by Ginnie Mae, Fannie Mae or Freddie Mac, and private issuers, respectively, from form N-MFP. The repo spread is the repo rate minus the federal fund rate. The haircut rate is the ratio of the difference between the borrowing amount and collateral value to the collateral value, the maturity (in days) is the difference between the dated date of the repo contract and its due date, the size is the log of borrowing amount (in dollars). All reported spreads and returns are in percentage terms.

**Panel A. Treasury repos**

| Variable | Mean | Median | Maximum | Minimum | Std | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Repo rate | 0.787 | 0.130 | 5.430 | 0.000 | 1.519 | 2.095 | 2.846 |
| Repo spread | -0.057 | -0.010 | 0.840 | -1.420 | 0.240 | -3.541 | 17.824 |
| Haircut rate | 1.914 | 1.961 | 13.064 | 0.000 | 0.811 | 3.718 | 47.811 |
| Maturity | 14.302 | 3.000 | 398.000 | 0.000 | 39.447 | 5.713 | 40.827 |
| Size | 18.874 | 19.185 | 22.110 | 12.539 | 1.898 | -1.006 | 1.328 |
| No. observations | 4,893 | | | | | | |

**Panel B. MBS repos**

| Variable | Mean | Median | Maximum | Minimum | Std | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Repo rate | 1.531 | 0.620 | 5.750 | 0.050 | 1.887 | 1.272 | -0.149 |
| Repo spread | 0.308 | 0.260 | 0.850 | 0.000 | 0.259 | 0.473 | -1.033 |
| Haircut rate | 5.382 | 4.762 | 13.064 | 0.000 | 3.601 | 0.859 | -0.197 |
| Maturity | 70.719 | 41.500 | 365.000 | 1.000 | 85.888 | 1.732 | 3.085 |
| Size | 18.072 | 18.315 | 21.771 | 12.543 | 1.630 | -0.463 | -0.193 |
| No. observations | 2,428 | | | | | | |

**Panel C. Repos with Ginnie Mae MBS collateral**

| Variable | Mean | Median | Maximum | Minimum | Std | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Repo rate | 0.101 | 0.090 | 1.400 | 0.000 | 0.081 | 5.055 | 46.217 |
| Repo spread | 0.016 | 0.010 | 0.650 | -0.060 | 0.065 | 5.053 | 40.424 |
| Haircut rate | 0.022 | 0.020 | 0.075 | 0.020 | 0.004 | 4.831 | 43.452 |
| Maturity | 3.354 | 2.000 | 82.000 | 1.000 | 6.780 | 8.970 | 90.320 |
| Size | 18.389 | 18.603 | 22.117 | 8.588 | 1.168 | -0.574 | 2.817 |
| No. observations | 39,451 | | | | | | |

**Panel D. Repos with Fannie Mae or Freddie Mac MBS collateral**

| Variable | Mean | Median | Maximum | Minimum | Std | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Repo rate | 0.148 | 0.120 | 1.400 | 0.000 | 0.100 | 3.223 | 21.852 |
| Repo spread | 0.060 | 0.030 | 0.650 | -0.060 | 0.084 | 2.632 | 11.893 |
| Haircut rate | 0.025 | 0.026 | 0.075 | 0.020 | 0.006 | 1.728 | 11.376 |
| Maturity | 4.972 | 3.000 | 82.000 | 1.000 | 8.258 | 7.170 | 58.724 |
| Size | 17.992 | 18.082 | 22.117 | 8.588 | 1.412 | -0.600 | 1.008 |
| No. observations | 51,803 | | | | | | |

**Panel E. Repos with private-label MBS collateral**

| Variable | Mean | Median | Maximum | Minimum | Std | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Repo rate | 0.566 | 0.540 | 1.400 | 0.020 | 0.234 | 0.094 | -0.261 |
| Repo spread | 0.451 | 0.460 | 0.650 | -0.050 | 0.184 | -0.676 | -0.219 |
| Haircut rate | 0.060 | 0.074 | 0.075 | 0.020 | 0.021 | -1.091 | -0.512 |
| Maturity | 29.198 | 7.000 | 82.000 | 1.000 | 31.636 | 0.752 | -1.151 |
| Size | 16.637 | 16.524 | 20.565 | 8.798 | 1.374 | 0.074 | 0.531 |
| No. observations | 2,664 | | | | | | |

**Table 3. Summary statistics of time-series data**

This table provides summary statistics for the variables used in our time series regression. Panel A reports the descriptive statistics of time-series data over the sample period from 2006/9/21 to 2014/12/31. Panel B reports the correlation matrix of independent variables. The CMO repo spreads are the agency CMO repo rate minus the corresponding risk free rate within the same maturity. The agency CMO repo index is the index consisting of Fannie Mae, Freddie Mac, and Ginnie Mae's CMO repos computed by Bloomberg. The data include overnight, 2-week, 1-month and 3-month repos. The federal fund rate is used as the riskfree rate for the overnight repo and the rates of overnight index swaps (OIS) with different maturities are used as riskfree rates for repos with 2-week to 3-month maturities. The MBS spread is the yield of MBS index in excess of the riskfree rate within the same maturity. We use the yields of agency MBS/CMO indices constructed by Bank of America Merrill Lynch with maturity less than 3 years, and 3, 3-5 and 5-7 years. The riskfree rates are constant maturity Treasury rates with corresponding maturities. The collateral risk measure (Coll) we used is ΔDelinquency rate on residential mortgages, which is the change of the delinquency rate on single-family residential mortgages. There are three counterparty risk measures. The MMF counterparty CDS spread (CP1) is the log of average CDS spread of money market funds' counterparties with repo transactions. The primary dealer CDS spread (CP2) is the log of average CDS spread of primary dealers. The LIBOR-OIS (CP3) is the log of the spread between the three-month LIBOR and OIS rates. Other control variables include the log of VIX index to proxy uncertainty, the change of illiquidity index by Hu et al. (2013) to proxy illiquidity, the change of ABX index with BBB tranches to proxy subprime-related risk, the 10-year Treasury rate and the slope which is the difference between 10-year and 2-year Treasury rates. All spreads and returns are measured in percentage.

**Panel A. Descriptive statistics**

| Variable | | Mean | Median | Min | Max | Std | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| Agency CMO repo spreads | Overnight | 0.012 | 0.015 | -0.578 | 0.608 | 0.125 | -1.371 | 13.705 |
| | 2 Week | 0.027 | 0.029 | -0.505 | 0.563 | 0.115 | -0.700 | 13.378 |
| | 1 Month | 0.039 | 0.031 | -0.577 | 0.639 | 0.137 | 0.090 | 11.906 |
| | 3 Month | 0.070 | 0.049 | -0.663 | 0.761 | 0.137 | 2.341 | 14.656 |
| Agency MBS/CMO spreads | 0-3 Year | 1.348 | 1.170 | 0.410 | 4.880 | 0.657 | 1.999 | 5.266 |
| | 3 Year | 1.148 | 1.097 | -0.198 | 3.710 | 0.711 | 0.731 | 3.937 |
| | 3-5 Year | 1.556 | 1.420 | 0.570 | 5.750 | 0.638 | 1.748 | 5.339 |
| | 5-7 Year | 1.425 | 1.340 | 0.560 | 4.220 | 0.516 | 0.899 | 0.865 |
| Collateral risk measure | Coll | 0.140 | 0.100 | -0.660 | 1.380 | 0.553 | 0.454 | 2.212 |
| Counterparty risk measures | CP1 | -4.553 | -4.449 | -6.711 | -3.304 | 0.702 | -1.156 | 4.245 |
| | CP2 | -4.559 | -4.455 | -6.711 | -3.198 | 0.760 | -1.210 | 4.271 |
| | CP3 | -1.468 | -1.820 | -2.820 | 1.293 | 0.841 | 0.837 | 2.911 |
| Control variables | VIX | 2.979 | 2.918 | 2.292 | 4.393 | 0.397 | 0.799 | 3.465 |
| | ΔIlliquidity Index | 0.000 | -0.002 | -1.791 | 1.787 | 0.278 | 0.057 | 10.064 |
| | ΔABX-BBB | -0.014 | 0.000 | -0.741 | 0.741 | 0.265 | -0.161 | 6.173 |
| | Ten-year treasury | 3.076 | 2.949 | 1.388 | 5.295 | 0.943 | 0.283 | 2.140 |
| | ΔTen-year treasury | -0.001 | -0.004 | -0.473 | 0.266 | 0.653 | -0.184 | 5.708 |
| | Slope | 1.769 | 1.877 | -0.193 | 2.910 | 0.814 | -0.963 | 3.168 |

**Panel B. Correlation matrix**

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. ΔDelinquency rate on residential (Coll) | 1.00 | | | | | | | | | |
| 2. MMF counterparty CDS spreads (CP1) | 0.21 | 1.00 | | | | | | | | |
| 3. Primary dealer CDS spreads (CP2) | 0.20 | 0.99 | 1.00 | | | | | | | |
| 4. LIBOR-OIS (CP3) | 0.57 | 0.57 | 0.57 | 1.00 | | | | | | |
| 5. VIX | 0.62 | 0.62 | 0.64 | 0.72 | 1.00 | | | | | |
| 6. ΔIlliquidity index | -0.04 | -0.02 | -0.01 | 0.02 | 0.01 | 1.00 | | | | |
| 7. ΔABX-BBB | -0.05 | 0.06 | 0.06 | -0.04 | -0.02 | -0.02 | 1.00 | | | |
| 8. Ten-year Treasury rate | 0.46 | -0.63 | -0.64 | -0.05 | -0.03 | 0.03 | -0.11 | 1.00 | | |
| 9. ΔTen-year Treasury rate | -0.02 | -0.01 | -0.01 | -0.05 | -0.08 | -0.1 | 0.06 | 0.02 | 1.00 | |
| 10. Slope of term structure | -0.03 | 0.62 | 0.63 | 0.02 | 0.26 | -0.01 | 0.10 | -0.41 | 0.02 | 1.00 |

**Table 4. Panel regressions using the N-Q dataset**

This table reports the results of panel regressions. The data are from SEC's quarterly form N-Q, and the sample period is from July 2004 to December 2015. Panel A reports the results of repo spread regressions (log of one plus repo spread) and Panel B reports the results of haircut rate regression (log of one plus haircut rate). We include MBS Dummy (which is 1 if the collateral is MBS or 0 if the collateral is Treasury), counterparty CDS spreads (log), maturity (log of maturity), size (log of borrowing amount), and haircut rates (or repo spreads) as explanatory variables. The MMF x counterparty fixed effects is used in (1)-(6), the crisis dummy (which is 1 if the sample period is from 2007/7/1 to 2009/1/4) is included in (4)-(6), and all standard errors are adjusted by the MMF's clustering effect. The coefficient estimates, t-statistics (in parentheses), and the R-squared are reported. "*","**",and "***" indicate significance at the 10%, 5%, and 1% of levels, respectively.

**Panel A. Repo spread regression**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Intercept | 0.201*** | 0.193*** | 0.102 | 0.180*** | 0.190*** | 0.100 |
| | (4.20) | (2.84) | (1.24) | (3.89) | (2.83) | (1.12) |
| MBS dummy | 0.155*** | 0.300*** | 0.103*** | 0.148*** | 0.280*** | 0.099*** |
| | (3.95) | (3.29) | (4.31) | (3.63) | (3.21) | (4.19) |
| Counterparty' CDS spread | 0.044*** | 0.032*** | 0.045*** | 0.040*** | 0.029*** | 0.041*** |
| | (4.73) | (5.29) | (4.69) | (4.44) | (4.65) | (4.52) |
| MBS dummy x counterparty risk measure | | 0.034** | | | 0.031** | |
| | | (2.21) | | | (2.15) | |
| Crisis dummy | | | | 0.062** | 0.062** | 0.054** |
| | | | | (1.97) | (2.01) | (2.22) |
| Maturity | | 0.016*** | 0.013** | | 0.017*** | 0.013** |
| | | (2.68) | (2.31) | | (2.71) | (2.33) |
| Size | | -0.003 | -0.002 | | -0.004 | -0.002 |
| | | (-1.13) | (-0.53) | | (-1.45) | (-0.77) |
| Haircut rate | | | 0.116*** | | | 0.112*** |
| | | | (3.55) | | | (2.93) |
| MMF x counterparty fixed effect (p-value of F test) | 0.217 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| No. of observations | 4,528 | 4,427 | 4,427 | 4,528 | 4,427 | 4,427 |
| *R-squared* | *0.72* | *0.73* | *0.76* | *0.72* | *0.74* | *0.76* |

**Panel B. Haircut regression**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Intercept | 1.256 *** | 1.374 *** | 1.263 *** | 1.375 *** |
| | (23.01) | (11.00) | (21.1) | (10.64) |
| MBS dummy | 0.154 *** | 0.137 *** | 0.155 *** | 0.137 *** |
| | (3.76) | (4.01) | (3.72) | (3.90) |
| Counterparty CDS spread | 0.027 ** | 0.026 *** | 0.029 ** | 0.026 ** |
| | (2.57) | (2.75) | (2.46) | (2.48) |
| Crisis dummy | | | -0.014 | -0.001 |
| | | | (-0.91) | (-0.07) |
| Maturity | | -0.001 | | -0.001 |
| | | (-0.27) | | (-0.27) |
| Size | | -0.008 | | -0.008 |
| | | (-1.43) | | (-1.46) |
| Repo spread | | 0.056 | | 0.056 |
| | | (1.42) | | (1.37) |
| MMF x counterparty fixed effect (p-value of F test) | 0.001 | <0.0001 | <0.0001 | <0.0001 |
| No. of observations | 4,517 | 4,348 | 4,517 | 4,348 |
| *R-squared* | *0.71* | *0.71* | *0.71* | *0.71* |

**Table 5. Panel regressions using the N-MFP dataset**

This table reports the results of panel regressions. The data are from SEC's monthly form N-MFP, and the sample period is from July 2010 to December 2016. Panel A reports the results of repo spread regression (log of one plus repo spread) and Panel B reports the results of haircut rate regression (log of one plus haircut rate). We include a single dummy, which is 1 if the collateral is private-label MBS or 0, otherwise, and a multiple MBS quality indicator which is 1 if the collateral is MBS issued by Ginnie Mae, 2 by Fannie Mae or Freddie Mac, and 3 by private issuers. Counterparty CDS spread (log), maturity (log of maturity), Size (log of borrowing amount), and haircut rates (repo spreads) as explanatory variables. The MMF x counterparty fixed effect is accounted in regression and standard errors are adjusted by the MMF's clustering effect. The coefficient estimates, t-statistics (in parentheses), and R-squared are reported in this table. "*","**",and"***" indicate the 10%, 5%, and 1% of significance levels, respectively.

**Panel A. Repo spread regression**

| | Single MBS quality dummy | | Multiple MBS quality indicator | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Intercept | 0.231*** | 0.138** | 0.418*** | 0.164** |
| | (8.53) | (2.01) | (13.53) | (2.51) |
| MBS collateral credit quality | 0.248*** | 0.201*** | 0.022** | 0.007** |
| | (10.46) | (5.97) | (2.14) | (2.06) |
| Counterparty CDS spread | 2.877*** | 3.319** | 2.313** | 2.823* |
| | (2.64) | (2.20) | (2.15) | (1.79) |
| Maturity | | 0.009** | | 0.012** |
| | | (2.21) | | (2.57) |
| Size | | -0.003 | | -0.003 |
| | | (-1.27) | | (-0.93) |
| Haircut rate | | 1.744* | | 3.829*** |
| | | (1.70) | | (6.39) |
| MMF x counterparty fixed effect | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| No. of observations | 82,542 | 77,665 | 82,542 | 77,665 |
| *R-squared* | *0.79* | *0.81* | *0.72* | *0.77* |

**Panel B. Haircut regression**

| | Single MBS quality dummy | | Multiple MBS quality indicator | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Intercept | 0.051*** | 0.047*** | 0.061*** | 0.047*** |
| | (8.45) | (5.22) | (10.26) | (3.98) |
| MBS collateral credit quality | 0.020*** | 0.016*** | 0.004* | 0.003** |
| | (3.38) | (3.31) | (1.71) | (1.99) |
| Counterparty CDS spread | 0.077*** | 0.026 | 0.009 | -0.066 |
| | (3.30) | (0.38) | (0.23) | (-0.81) |
| Maturity | | 0.001*** | | 0.001*** |
| | | (3.20) | | (3.98) |
| Size | | 0.000 | | 0.000 |
| | | (-1.04) | | (-1.03) |
| Repo spread | | 0.016 | | 0.030* |
| | | (0.96) | | (1.90) |
| MMF-counterparty fixed effect | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| No. of observations | 77,680 | 77,665 | 77,680 | 77,665 |
| *R-squared* | *0.81* | *0.82* | *0.77* | *0.81* |

**Table 6. Panel regression using the N-Q dataset with the effect of relationship trading**

This table reports the results of panel regression with the effect of relationship trading. The sample period is from January 2005 to December 2015. We use two different relationship trading measures based on the concentration of trading amount, and collateral value using previous three months (rolling) repo trading data. The relationship trading measures are calculated from both MMF's (RS_Fund) and dealer's (RS_Dealer) perspectives, and they are both log value (log of one plus the concentration). We include MBS Dummy, counterparty CDS spreads, maturity, and size as explanatory variables. The MMF x counterparty is used to control for the fixed effects. The crisis dummy (1 if the sample period is from 2007/7/1 to 2009/1/4) and the European crisis dummy (1 if the sample period is from 2011/6/1 to 2012/6/1) are included to capture crisis effects, and all standard errors are adjusted by the MMF's clustering effect. Panel A reports the results of repo spread regression (log of one plus repo spread) and panel B reports results of haircut rate regression (log of one plus haircut rate). The standardized coefficient estimates, t-statistics (in parenthese), and the R-squared are reported. Intercept is not reported in these standardized regressions. *, **, and *** indicate significance at the 10%, 5%, and 1% of levels, respectively.

**Panel A. Repo Spread Regression**

| | Borrowing amount | | Collateral value | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| MBS Dummy | 0.388 *** | 0.388 *** | 0.388 *** | 0.388 *** |
| | (4.63) | (4.64) | (4.63) | (4.63) |
| Counterparty's CDS spread | 0.261 *** | 0.266 *** | 0.261 *** | 0.266 *** |
| | (6.04) | (6.31) | (6.10) | (6.36) |
| RS_Fund | 0.011 | 0.023 | 0.021 | 0.034 |
| | (0.36) | (0.65) | (0.64) | (0.93) |
| Crisis x RS_Fund | -0.085 ** | -0.088 ** | -0.088 ** | -0.091 ** |
| | (-2.06) | (-2.15) | (-2.08) | (-2.17) |
| European crisis x RS_Fund | | -0.023 | | -0.027 * |
| | | (-1.45) | | (-1.73) |
| RS_Dealer | 0.001 | -0.018 | -0.004 | -0.022 |
| | (-0.01) | (-0.52) | (-0.12) | (-0.61) |
| Crisis x RS_Dealer | -0.003 | -0.025 | -0.035 | -0.031 |
| | (-0.51) | (-0.43) | (-0.50) | (-0.49) |
| European crisis x RS_Dealer | | 0.060 *** | | 0.057 ** |
| | | (2.79) | | (2.64) |
| Crisis dummy | 0.186 ** | 0.183 ** | 0.191 ** | 0.188 ** |
| | (2.57) | (2.54) | (2.53) | (2.51) |
| European crisis dummy | | -0.024 | | -0.017 |
| | | (-0.76) | | (-0.51) |
| Maturity | 0.140 ** | 0.141 ** | 0.141 ** | 0.141 ** |
| | (2.63) | (2.66) | (2.66) | (2.69) |
| Size | -0.102 ** | -0.096 ** | -0.101 ** | -0.095 ** |
| | (-2.06) | (-2.16) | (-2.31) | (-2.14) |
| MMF x counterparty fixed effect | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| No. of Observations | 2,323 | 2,323 | 2,323 | 2,323 |
| *R-Squared* | *0.78* | *0.78* | *0.78* | *0.78* |

**Panel B. Haircut Regression**

| | Borrowing amount | | Collateral value | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| MBS Dummy | 0.209 *** | 0.209 *** | 0.200 *** | 0.201 *** |
| | (2.96) | (2.95) | (3.57) | (3.55) |
| Counterparty's CDS spread | 0.153 *** | 0.156 *** | 0.071 ** | 0.074 ** |
| | (2.90) | (2.97) | (2.03) | (2.11) |
| RS_Fund | 0.031 | 0.039 | 0.008 | 0.010 |
| | (1.34) | (1.52) | (0.35) | (0.37) |
| Crisis x RS_Fund | -0.016 | -0.018 | -0.026 ** | -0.026 ** |
| | (-1.02) | (-1.05) | (-1.99) | (-2.11) |
| European crisis x RS_Fund | | -0.017 | | -0.005 |
| | | (-1.42) | | (-0.29) |
| RS_Dealer | -0.063 ** | -0.070 ** | -0.063 *** | -0.072 *** |
| | (-2.01) | (-2.27) | (-3.26) | (-3.57) |
| Crisis x RS_Dealer | 0.048 * | 0.051 * | 0.063 * | 0.069 |
| | (1.91) | (1.93) | (1.65) | (1.61) |
| European crisis x RS_Dealer | | 0.026 * | | 0.030 * |
| | | (1.69) | | (1.72) |
| Crisis dummy | -0.054 | -0.056 | -0.006 | -0.010 |
| | (-1.54) | (-1.54) | (-0.21) | (-0.36) |
| European crisis dummy | | -0.019 | | -0.040 |
| | | (-0.83) | | (-1.11) |
| Maturity | -0.032 | -0.031 | -0.099 ** | -0.099 ** |
| | (-1.32) | (-1.31) | (-2.69) | (-2.69) |
| Size | -0.078 | -0.076 | -0.029 | -0.026 |
| | (-1.39) | (-1.32) | (-0.43) | (-0.31) |
| MMF x counterparty fixed effect | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| No. of Observations | 2,459 | 2,459 | 2,199 | 2,199 |
| *R-Squared* | *0.79* | *0.79* | *0.68* | *0.68* |

**Table 7. Time-series repo spread regressions**

This table reports time-series regression results for overnight, 2 week-, 1 month-, and 3 month agency CMO repo spreads, respectively. The data are at daily frequency, and the sample period is from 2006/9/21 to 2014/12/31. We include collateral risk (delinquency rate of residential mortgages), counterparty risk measure, VIX, illiquidity, ABX, ten-year treasury rate, and the slope of term structure as explanatory variables. All variables are as defined in Table 3. The coefficient estimates, t-statistics (in parentheses), and R-squared are reported. "*","**",and "***" indicate significance at the 10%, 5%, and 1% of levels, respectively.

| | Overnight CMO repo spread | | | 2 Week CMO repo spread | | | 1 Month CMO repo spread | | | 3 Month CMO repo spread | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| ΔDelinquency rate on residential mortgage (Coll) | 0.009*** | 0.007** | 0.020*** | 0.013*** | 0.011*** | 0.026*** | 0.031*** | 0.027*** | 0.049*** | 0.054*** | 0.049*** | 0.075*** |
| | (2.63) | (2.21) | (6.26) | (3.71) | (3.10) | (8.12) | (7.48) | (6.60) | (12.56) | (10.65) | (9.77) | (16.17) |
| MMF counterparty CDS spreads (CP1) | 0.016*** | | | 0.028*** | | | 0.043*** | | | 0.057*** | | |
| | (5.90) | | | (9.61) | | | (12.07) | | | (13.26) | | |
| Primary dealer CDS spreads (CP2) | | 0.017*** | | | 0.029*** | | | 0.046*** | | | 0.060*** | |
| | | (6.54) | | | (10.71) | | | (14.06) | | | (15.35) | |
| LIBOR-OIS (CP3) | | | 0.034*** | | | 0.049*** | | | 0.064*** | | | 0.090*** |
| | | | (12.76) | | | (18.51) | | | (19.92) | | | (23.52) |
| VIX | 0.011 | 0.002 | -0.001 | 0.046*** | 0.035*** | 0.019** | 0.085*** | 0.065*** | 0.055*** | 0.140*** | 0.118*** | 0.086*** |
| | (1.43) | (0.33) | (-0.14) | (5.92) | (4.42) | (2.39) | (8.97) | (6.78) | (5.88) | (12.43) | (10.29) | (7.87) |
| ΔIlliquidity index | 0.034*** | 0.034*** | 0.032*** | 0.044*** | 0.044*** | 0.043*** | 0.024*** | 0.024*** | 0.022*** | 0.043*** | 0.044*** | 0.040*** |
| | (5.25) | (5.30) | (4.97) | (6.58) | (6.65) | (6.61) | (2.91) | (3.01) | (2.75) | (4.46) | (4.58) | (4.23) |
| ΔABX-BBB | 0.004 | 0.002 | 0.009 | 0.001 | -0.001 | 0.007 | 0.004 | 0.001 | 0.009 | 0.001 | -0.003 | 0.007 |
| | (0.49) | (0.28) | (1.19) | (0.17) | (-0.07) | (0.85) | (0.35) | (0.01) | (0.88) | (0.02) | (-0.28) | (0.58) |
| ΔTen-year Treasury rate | 0.059** | 0.06** | 0.063** | 0.031 | 0.031 | 0.037 | -0.026 | -0.027 | -0.021 | 0.022 | 0.021 | 0.026 |
| | (2.18) | (2.22) | (2.32) | (1.08) | (1.11) | (1.32) | (-0.76) | (-0.79) | (-0.63) | (0.54) | (0.51) | (0.64) |
| Slope of term structure | -0.027*** | -0.03*** | -0.011*** | -0.027*** | -0.031*** | -0.008*** | -0.032*** | -0.038*** | -0.009*** | -0.032*** | -0.039*** | -0.008** |
| | (-9.65) | (-10.47) | (-4.38) | (-8.99) | (-10.1) | (-3.14) | (-8.73) | (-10.51) | (-3.01) | (-7.27) | (-8.96) | (-2.14) |
| (Intercept) | 0.116*** | 0.085*** | 0.06*** | 0.177*** | 0.18*** | 0.06*** | 0.254*** | 0.266*** | 0.072*** | 0.332*** | 0.348*** | 0.085*** |
| | (9.14) | (11.89) | (12.26) | (13.11) | (14.51) | (12.06) | (15.54) | (17.85) | (11.86) | (16.99) | (19.41) | (11.89) |
| *Adjusted R-squared* | *0.09* | *0.10* | *0.12* | *0.15* | *0.16* | *0.20* | *0.20* | *0.23* | *0.24* | *0.26* | *0.28* | *0.32* |

**Table 8. Time-series MBS yield spread regressions**

This table reports the regression results for agency MBS/CMO spreads with different maturities. The 3-year agency MBS index is the M1AO index tracking the performance of agency MBS with average three-year life. The 0-3, 3-5, and 5-7 year agency MBS indexes track the performance of US agency CMOs with maturity less than three years, three to five years and five to seven years, respectively. All indexes are constructed by Bank of America Merrill Lynch. The data are at daily frequency, and the sample period is from 2006/9/21 to 2014/12/31. We include collateral risk (delinquency rate), counterparty risk measure, VIX, illiquidity, ABX, ten-year treasury rate, and the slope of term structure as explanatory variables. The coefficient estimates, t-statistics (in parentheses), and adjusted R-squared are reported in this table. The signs of "*","**", and "***" indicate the 10%, 5%, and 1% of significance levels, respectively.

| | 0-3 Year Agency MBS spread | | | 3 Year Agency MBS spread | | | 3-5 Year Agency MBS spread | | | 5-7 Year Agency MBS spread | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| ΔDelinquency rate on residential mortgage (Coll) | 0.637*** | 0.635*** | 0.734*** | 0.744*** | 0.745*** | 0.868*** | 0.427*** | 0.425*** | 0.576*** | 0.546*** | 0.542*** | 0.621*** |
| | (32.80) | (32.48) | (41.41) | (39.50) | (39.00) | (47.90) | (23.27) | (22.83) | (34.11) | (40.73) | (40.23) | (48.69) |
| MMF counterparty CDS spreads (CP1) | 0.317*** | | | 0.319*** | | | 0.424*** | | | 0.27*** | | |
| | (21.27) | | | (22.06) | | | (30.14) | | | (26.25) | | |
| Primary dealer CDS spreads (CP2) | | 0.29*** | | | 0.284*** | | | 0.385*** | | | 0.254*** | |
| | | (21.01) | | | (21.00) | | | (29.23) | | | (26.71) | |
| LIBOR-OIS (CP3) | | | 0.39*** | | | 0.375*** | | | 0.509*** | | | 0.268*** |
| | | | (27.10) | | | (25.46) | | | (37.04) | | | (25.88) |
| VIX | 0.461*** | 0.46*** | 0.24*** | 0.475** | 0.487** | 0.447** | 0.595*** | 0.594*** | 0.458*** | 0.499*** | 0.485*** | 0.434*** |
| | (10.7) | (10.35) | (5.78) | (11.36) | (11.20) | (10.54) | (14.61) | (14.01) | (11.57) | (16.77) | (15.83) | (14.53) |
| ΔIlliquidity index | 0.043 | 0.042 | 0.018 | 0.136*** | 0.133*** | 0.116*** | 0.059* | 0.056 | 0.02 | 0.04 | 0.04 | 0.023 |
| | (1.16) | (1.11) | (0.50) | (3.75) | (3.64) | (3.16) | (1.67) | (1.57) | (0.6) | (1.56) | (1.54) | (0.91) |
| ΔABX-BBB | -0.096** | -0.101** | -0.068 | -0.087** | -0.094** | -0.054 | -0.104** | -0.114*** | -0.058 | -0.026 | -0.031 | -0.009 |
| | (-2.08) | (-2.19) | (-1.57) | (-1.96) | (-2.08) | (-1.2) | (-2.41) | (-2.60) | (-1.4) | (-0.82) | (-0.98) | (-0.27) |
| ΔTen-year Treasury rate | 0.477*** | 0.491*** | 0.433*** | 0.649*** | 0.672*** | 0.648*** | 0.513*** | 0.538*** | 0.506*** | 0.129 | 0.135 | 0.12 |
| | (3.01) | (3.09) | (2.86) | (4.22) | (4.32) | (4.19) | (3.42) | (3.55) | (3.51) | (1.18) | (1.24) | (1.1) |
| Slope of term structure | -0.048*** | -0.048*** | 0.077*** | -0.182*** | -0.176*** | -0.031** | -0.175*** | -0.174*** | 0.017 | -0.026** | -0.031*** | 0.048*** |
| | (-2.90) | (-2.79) | (5.75) | (-11.28) | (-10.58) | (-2.28) | (-11.16) | (-10.73) | (1.36) | (-2.27) | (-2.62) | (5.02) |
| (Intercept) | 2.701*** | 2.583** | 1.111*** | 2.496*** | 2.338*** | 1.081*** | 3.428*** | 3.251*** | 1.445*** | 2.579*** | 2.509*** | 1.253*** |
| | (39.12) | (40.14) | (43.02) | (37.22) | (37.16) | (40.92) | (52.5) | (53.02) | (58.72) | (54.04) | (56.6) | (67.45) |
| *Adjusted R-squared* | *0.51* | *0.51* | *0.57* | *0.61* | *0.60* | *0.61* | *0.54* | *0.53* | *0.58* | *0.62* | *0.62* | *0.63* |

**Table 9. Repo and MBS spread regressions with crisis dummy**

This table reports the panel regression results for pooled time-series data of different maturities. We pool all the CMO repo spreads with six different maturities (overnight, 1 week-, 2 week-, 3 week-, 1 month-, and 3 month) and agency MBS yield spreads with four different maturities (0-3, 3, 3-5, and 5-7 years) from 2006/9/21 to 2014/12/31. We control for the maturity fixed effect and time (year-month) fixed effect. We report the result of interaction variables of crisis dummy and collateral and counterparty risks. The crisis dummy is equal to 1 if the sample period is from 2007/7/1 to 2009/1/4. The coefficient estimates, t-statistics (in parentheses), and R-squared are reported. The signs of "*","**", and "***" indicate the 10%, 5%, and 1% of significance levels, respectively.

| | Repo spread regression | | | MBS spread regression | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ΔDelinquency rate on residential mortgage | 8.650*** | 8.511*** | 7.791*** | 16.233*** | 12.085*** | 5.270** |
| | (10.21) | (9.89) | (10.78) | (5.57) | (4.22) | (2.33) |
| MMF counterparty CDS spreads | 0.041** | | | 0.371*** | | |
| | (2.86) | | | (6.23) | | |
| Primary dealer CDS spreads | | 0.064* | | | 0.229*** | |
| | | (2.31) | | | (3.31) | |
| LIBOR-OIS | | | 0.012 | | | 0.111** |
| | | | (1.07) | | | (2.11) |
| Collateral risk x crisis dummy | 0.359** | 0.556*** | 0.109* | 1.487*** | 0.747*** | 0.200*** |
| | (3.96) | (5.35) | (2.50) | (4.86) | (2.84) | (3.53) |
| Counterparty risk x crisis dummy | 0.065* | 0.131*** | 0.111*** | 0.345*** | 0.154* | 0.042 |
| | (2.26) | (4.94) | (4.40) | (3.83) | (1.90) | (0.69) |
| VIX | 0.075*** | 0.061** | 0.068*** | 0.03 | 0.043 | 0.112*** |
| | (5.84) | (3.61) | (5.74) | (0.96) | (1.26) | (3.71) |
| ΔIlliquidity index | 0.011* | 0.010* | 0.012* | 0.013 | 0.016 | 0.023* |
| | (2.17) | (2.02) | (2.24) | (1.04) | (1.35) | (1.92) |
| ΔABX-BBB | 0.001 | 0.001 | 0.001 | -0.017 | -0.014 | -0.007 |
| | (0.46) | (-0.10) | (-0.03) | (-1.40) | (-1.14) | (-0.56) |
| ΔTen-year Treasury rate | 0.006 | 0.007 | 0.021 | 0.176*** | 0.199*** | 0.234*** |
| | (0.41) | (0.45) | (1.31) | (3.44) | (3.91) | (4.74) |
| Slope of term structure | 0.053 | 0.043 | 0.031 | 0.348*** | 0.253*** | 0.151*** |
| | (1.91) | (1.48) | (1.15) | (8.26) | (6.34) | (4.31) |
| (Intercept) | 3.794*** | 3.932*** | 3.278*** | 9.141*** | 6.718*** | 2.889*** |
| | (11.25) | (8.51) | (12.76) | (6.85) | (5.05) | (3.10) |
| Maturity Fixed Effect (p-value) | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Time Fixed Effect (p-value) | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| No. of Observations | 11012 | 11012 | 11012 | 7979 | 7979 | 7461 |
| R-Squared | 0.50 | 0.50 | 0.51 | 0.83 | 0.82 | 0.82 |

**Table 10. The direct and indirect effects of collateral and counterparty risks**

This table reports the results from the path analysis that examines how collateral risk and counterparty risk affect MBS spreads using four paths: overnight, 2-week, 1-month, and 3-month CMO repo spreads. We estimate the following structural model:

$$YRP = a \cdot Coll + b \cdot CP + \delta \cdot Controls + \varepsilon_1$$
$$YMBS = c \cdot YRP + a' \cdot Coll + b' \cdot CP + \delta' \cdot Controls + \varepsilon_2$$

*YMBS* is the yield spread of agency MBS with average 3-year maturity (M1A0 index). *YRP* is the repo spreads with different maturities. The counterparty risk measure *CP* is the MMF counterparty CDS spread. The collateral risk measure *Coll* is the change of delinquency rates on single-family residential mortgages. We include all control variables used in Tables 6 and 7 but for brevity their coefficient estimates are omitted. The data are at daily frequency and the sample period is from 2006/9/21 to 2014/12/31. The standardized path coefficient estimates and z-statistics are reported. The signs of "*","**", and "***" indicate the 10%, 5%, and 1%of significance levels, respectively.

| | Repo spreads with different maturity as the path of indirect effect | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Overnight | | 2-Week | | 1-Month | | 3-Month | |
| | Coefficient | *z-stat* | Coefficient | *z-stat* | Coefficient | *z-stat* | Coefficient | *z-stat* |
| ***Direct Effect*** | | | | | | | | |
| P(Coll, MBSs) = $\hat{a}'$ | 0.713 *** | *38.48* | 0.706 *** | *38.12* | 0.696*** | *37.27* | 0.664 *** | *35.46* |
| P(CP, MBSs) = $\hat{b}'$ | 0.326 *** | *21.08* | 0.319 *** | *19.92* | 0.313*** | *19.32* | 0.286 *** | *17.91* |
| ***Indirect Effect*** | | | | | | | | |
| ***P(Coll,Path)*P(Path,MBSs)=*** $\hat{a} \cdot \hat{c}$ | 0.002 | *1.36* | 0.011 *** | *3.40* | 0.025*** | *5.39* | 0.054 *** | *8.12* |
| ***P(CP,Path)*P(Path,MBSs)=*** $\hat{b} \cdot \hat{c}$ | 0.003 | *1.55* | 0.022 *** | *5.39* | 0.030*** | *6.03* | 0.052 *** | *8.55* |
| P(Coll,Path) = $\hat{a}$ | 0.009 ** | *2.57* | 0.014 *** | *3.98* | 0.034*** | *8.52* | 0.057 *** | *11.84* |
| P(CP,Path) = $\hat{b}$ | 0.016 *** | *5.89* | 0.028 *** | *9.51* | 0.041*** | *12.14* | 0.055 *** | *13.32* |
| P(Path, MBSs) = $\hat{c}$ | 0.201 | *1.60* | 0.803 *** | *6.54* | 0.723*** | *6.95* | 0.946 *** | *11.15* |