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Pledgeable Collateral, Dealer Leverage, and Runs

Husnu C. Dalgic¹
Brittany Almquist Lewis²
Andrea Modena³

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¹University of Mannheim, Email: dalgic@uni-mannheim.de

²Olin School of Business, Washington Univ. St. Louis, Email: b.almquist.lewis@gmail.com

³University of Naples Federico II, Email: andrea.modena@uni-mannheim.de

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Husnu C. Dalgic[†]

University of Mannheim

Brittany Almquist Lewis[‡]

Olin School of Business

Washington Univ. St. Louis

Andrea Modena[§]

University of Naples Federico II

Abstract

We show that strengthening creditor rights can exacerbate financial instability, particularly under long debt maturities and low collateral volatility. We build a model of financial intermediaries that raise financing by pledging collateral in the sale and repurchase (repo) market. In the short term, increasing collateral pledgeability makes repo creditors safer and reduces debt rollover risk; however, it also expands long-term debt capacity and leverage, ultimately heightening run risk. This instability is a distinct feature of environments with long-term liabilities and low-volatility assets, where market discipline fails to constrain post-policy leverage. We test our model's predictions by exploiting the 2005 BAPCPA bankruptcy reform, which expanded creditor protections via repo safe harbors. Using hand-collected data on dealer repo collateral, we confirm that while the law enhanced collateral pledgeability, it fueled short-term leverage and precipitated sharper de-leveraging during the downturn.

Keywords: repo, collateral, safe harbor, bankruptcy, leverage, dealer banks, bank runs.

JEL Classification: G01, G21, G23, G28, G33.

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[†]University of Mannheim,
Email: dalgic@uni-mannheim.de URL: <https://sites.google.com/view/husnucdalgic/>.

[‡]Olin School of Business, Washington Univ. St. Louis
Email: b.almquist.lewis@gmail.com URL: <https://sites.google.com/view/brittanylewis>.

[§]University of Naples Federico II,
Email: andrea.modena@uni-mannheim.de URL: <https://sites.google.com/view/andrea-modena/>.

1 Introduction

Financial intermediaries borrow heavily against collateral. The amount of borrowing a collateral asset can support depends not only on the asset’s cash flows, but also on the creditors’ rights to the collateral in the event of default. When bankruptcy law grants the collateral super-senior bankruptcy protection, allowing the creditor to take control of the asset outside of bankruptcy court, the same asset becomes more valuable as funding collateral and facilitates borrowing. However, increased borrowing can also increase the likelihood of default. This paper studies whether stronger collateral rights expand financial intermediary leverage and increase fragility.

Large financial intermediaries borrow both via the “sale and repurchase” (repo) market and via traditional funding sources. While the Federal Reserve regulates traditional bank leverage via macroprudential policy, Congress implicitly governs the repo market by setting bankruptcy protections on repo collateral, which can in turn affect dealer-bank leverage. If the two bodies do not work together, Congressional policies have the potential to counteract macroprudential policy. In this paper, we establish empirically that, indeed, an increase in creditor rights on repo collateral increases both short-term dealer-bank leverage and rapid deleveraging in the longer-term. We then build a model of financial intermediaries who can borrow either by deposits or by collateralized repo loans and study the effect of strengthening repo creditor rights on dealer borrowing and the probability of a bank run, akin to those seen during the Global Financial Crisis.

Our main theoretical contribution is to show that bankruptcy safe harbors act as an ex-ante leverage subsidy. While granting collateral super-senior status provides immediate ex-post protection to creditors for a given contract, it endogenously expands the intermediary’s ex-ante debt capacity. When intermediaries re-optimize their balance sheets, the resulting increase in short-term leverage can override the direct safety effect, ultimately increasing the long-run probability of a bank run. We show that this instability is not universal: it is concentrated in short-term wholesale funding backed by assets with moderate historical volatility. In contrast, when debt is long-term or historical asset volatility is high, market discipline generates a self-policing effect that curbs debt capacity and preserves stability.

To test this mechanism, we exploit the Bankruptcy Abuse Prevention and Consumer Protec-

tion Act (BAPCPA) of 2005, which increased the pledgeability of mortgage-related collateral by expanding repo safe-harbor protections to mortgage loans, mortgage-related securities, and interest generated by those assets. BAPCPA increased the pledgeability of mortgage-related repo collateral for all dealers, but its balance-sheet impact was larger for dealers that held more exposed collateral at the time of the reform. We estimate a treatment intensity difference-in-differences research design centered around BAPCPA. We define dealers to be more treated if they held a larger amount of repledgeable collateral prior to the policy change. We define exposure this way because repledgeable collateral is collateral that has been permitted to be repledged by the initial counterparty who posted it with the dealer-bank. Since the collateral has already been permitted to be repledged, it is immediately redeployable once it receives super-senior bankruptcy status and creditors are willing to hold it. Thus, we define dealers who hold more repledgeable collateral in 2004 to be more treated, because they will have more collateral that is immediately redeployable post-policy change. We test whether these more treated dealers increase their reuse of collateral to borrow post-policy change and thus increase their leverage. We follow dealer leverage from 2003 through 2008, and the identifying variation is therefore cross-sectional exposure to a common change in bankruptcy treatment.

We show that dealers with greater pre-reform repledgeable collateral increased leverage more after BAPCPA and experienced larger asset contractions during the Global Financial Crisis. The evidence indicates that stronger collateral rights expanded debt capacity before the crisis and amplified balance-sheet fragility when funding conditions deteriorated. Specifically, using the continuous-treatment difference-in-differences design, we find that dealers with greater pre-reform re-pledgeable collateral increased leverage more after BAPCPA, with no differential pre-trend. The same exposure also predicts larger peak-to-trough asset contractions during the Global Financial Crisis. We interpret these contractions as a balance-sheet measure of fragility, because dealer-level runs are not directly observed. The evidence suggests that the dealers most exposed to the increase in collateral pledgeability expanded more before the crisis and contracted more when funding conditions deteriorated.

We build a model that rationalizes why stronger creditor rights can generate both findings. In our framework, the dealer holds a portfolio of risky assets, such as mortgage-backed securities, that generate a continuous cash flow. To finance this portfolio, the dealer issues

a mix of long-term debt and a mass of short-term repo contracts that mature via staggered Poisson shocks. This structure creates an ongoing rollover problem: individual repo creditors decide whether to renew funding based on their expectations about the future behavior of other creditors; namely, whether they will roll over or run.

In the model, a policy change such as BAPCPA, which alters the share of the asset portfolio that can be legally pledged to repo holders in default, affects the capital structure through two opposing channels. On the one hand, higher pledgeability provides a direct stabilizing effect by increasing repo collateral recovery values and reducing creditors' immediate incentives to run. On the other hand, by making repo debt safer, this legal protection endogenously expands the dealer's ex ante debt capacity. As the dealer bank re-optimizes its balance sheet to exploit this expanded capacity, it increases leverage by issuing more short-term, runnable debt. Under the dynamic, staggered rollover problem, future lenders exert a strategic externality on current lenders, causing inefficient runs. While safe-harbor reforms like BAPCPA are designed to neutralize this externality by making individual contracts safe, we show that they introduce a powerful ex-ante leverage feedback loop. Intermediaries privately re-optimize to take on higher leverage and ultimately exacerbate the very fragility the regulation intended to address.

The model uncovers a key tradeoff: while higher pledgeability makes short-term debt safer ex post, it induces dealers to expand leverage ex ante, which amplifies run probabilities in the long run. To resolve the indeterminacy of multiple self-fulfilling equilibria common in bank-run models, we follow [Frankel and Pauzner \(2000\)](#) and [He and Xiong \(2012\)](#) by modeling staggered Poisson debt rollovers of an asset driven by Brownian motion. This setup uniquely determines the equilibrium run threshold for a given balance sheet. We build on this framework by introducing collateral pledgeability and allowing intermediaries to endogenously choose their optimal debt capacity and leverage.

The model allows us to analyze the circumstances under which strengthening creditor rights increases or decreases financial fragility. Our continuous-time framework allows us to characterize a unique run threshold and formally decompose the impact of pledgeability into two opposing forces: a short-run stabilizing recovery effect for a given balance sheet and a long-run destabilizing leverage feedback effect. We show that whether safe-harbor protections stabilize or destabilize wholesale markets depends critically on debt maturity and historical

asset volatility at the time of the policy change, for repo contracts affected.

In the calibrated model, quantitative simulations show that the long-run leverage feedback can dominate the initial collateral recovery effect and ultimately increase overall fragility. We show that when the maturity of the repo collateral is short and historical asset volatility is moderate, the longer-term endogenous increase in dealer debt capacity overrides the short-run stabilizing effect of increased collateral recovery, leading to a build-up in dealer leverage and increasing the bank run probability by up to 33%. The effect is reversed when the repo debt carries long maturities or is collateralized by historically highly volatile assets. The model implies a self-policing effect of long-term debt: creditors are more careful when locking up their funds for the long term because it leaves them vulnerable to sudden asset price declines if a run occurs before they can withdraw their funds. We find a similar paradox with the historical volatility of the underlying asset. For a moderate increase in historical volatility, the endogenous increase in dealer debt capacity outweighs the increased safety from improved collateral recovery, and the probability of a bank run increases in response to an increase in collateral pledgeability. Intuitively, higher volatility widens the run region. However, the effect is not monotone. If the asset is too volatile historically, an increase in creditor rights decreases the run probability because creditors internalize the increased run probability in a highly volatile environment and lend less. This again resembles a self-policing effect of high volatility.

Interpreting the effect of the BAPCPA policy change through the lens of the model elucidates the reform’s effect on financial stability. The mortgage collateral affected by the reform was private-label mortgage collateral, which was historically fairly stable in price, exhibiting low to moderate volatility prior to 2005.¹ Evidence in [Srinivasan \(2026\)](#) and [Lewis \(2023\)](#) show that following the BAPCPA policy change, private-label mortgage collateral was used in the tri-party repo market, where maturities for the asset were very low, typically a few days. We use hand-collected data to parameterize the model to the pre-BAPCPA 2005 policy change, allowing us to shed light on the reform’s impact on the probability of a bank run, leading up to the repo-run at the nexus of the Global Financial Crisis ([Gorton and Metrick, 2012](#)). [Gorton \(2009\)](#) argues that the 2007 panic was a systemic run on repo collateral and

¹Home prices began to decline in 2007; however, [Lewis \(2021\)](#) shows this was driven in part by endogenous innovation in mortgage products in response to BAPCPA. Servicing behavior, amplified in crisis periods, can affect mortgage-backed security prices ([Hamdi et al., 2023](#); [Lewis et al., 2025](#)).

[Krishnamurthy et al. \(2014\)](#) find evidence that the run was concentrated in the private-label asset-backed securities (ABS) and the mortgage market. We show that the 2005 BAPCPA regulation inadvertently expanded debt capacity for mortgage-related collateral with low-to-moderate historical volatility and short-term repo contracts, inducing dealer banks to build up leverage and balance-sheet vulnerabilities and setting the stage for the repo-run observed during the Global Financial Crisis.

The safe-harbor reform in the BAPCPA policy was put in place to improve the stability of the repo market. It was thought that super-senior creditor rights on collateral would eliminate the type of financial market gridlock that prevented trades from clearing, which manifested during the LTCM crisis. However, [Lewis \(2023\)](#) shows evidence that the BAPCPA policy change led to a build-up of dealer-bank leverage, interlinked counterparties, and systemic risk, and [Gorton and Metrick \(2012\)](#) argues that a repo run was at the nexus of the Global Financial Crisis. This paper sheds light on this puzzle by showing that under some states of the world, strengthening repo creditor rights could have improved financial stability – for example, under long-term repo contracts or historically very volatile underlying assets. However, in the private-label mortgage market – featuring repo maturities as short as three days and, at the time, a traditionally stable housing market – the model suggests that the policy change increased the probability of a bank run.

1.1 Literature review

Our paper bridges and contributes to several strands of the literature: (i) collateral re-use and macroeconomic leverage, (ii) dynamic bank runs and wholesale funding fragility, and (iii) repo safe harbors and bankruptcy design.

We contribute to the literature on collateralized borrowing, re-hypothecation, and leverage cycles (e.g., [Geanakoplos, 1997](#); [Simsek, 2013](#); [Infante et al., 2020](#); [Brumm et al., 2023](#); [Lewis, 2023](#)). In particular, [Brumm et al. \(2023\)](#) show in a calibrated general equilibrium model that collateral re-use expands debt capacity and market volatility, showing that limits on collateral re-use generate non-monotone welfare effects, in a model with no default, by trading off risk-sharing benefits against excessive speculative leverage. Our paper innovates relative to this literature by analyzing the effect of collateral pledgeability on bank run probabilities in a

dynamic stopping-time game where statutory collateral pledgeability alters an intermediary’s optimal capital structure and endogenous run boundary.

Our framework builds on the large literature on bank runs, coordination failures, and wholesale funding freezes, which can be driven by information shocks ([Chari and Jagannathan, 1988](#); [Acharya et al., 2011](#)), contractual rigidity ([Diamond and Rajan, 2005](#)), coordination failures across maturities ([Goldstein and Pauzner, 2005](#); [He and Xiong, 2012](#)), macroeconomic spillovers ([Gertler and Kiyotaki, 2015](#); [Gertler et al., 2020](#)), or leverage restrictions ([Christiano et al., 2022](#); [Lewis, 2025](#)). In standard banking models with collateralized borrowing (e.g., [Ahnert et al., 2019](#)), secured debt is typically treated as risk-insensitive, such that balance-sheet fragility manifests primarily as runs by subordinated unsecured creditors. In contrast, we show that secured repo debt is itself vulnerable to runs. By introducing a collateral pledgeability constraint, which governs leverage, into the continuous-time, staggered-debt rollover framework of [He and Xiong \(2012\)](#) and [Martin et al. \(2014\)](#),² repo creditors face strategic rollover risk: even collateralized lenders run when asset fundamentals fall below a threshold to avoid fire-sale shortfalls upon default. We show that stronger creditor rights increase the probability of rollover for a given level of debt, but the resulting increase in debt safety endogenously induces higher leverage, amplifying financial fragility and increasing the long-run probability of a run. This accounts for the empirical dynamics of the 2007–2008 financial crisis, which was characterized by systemic runs across private-label securitized repo collateral ([Gorton, 2009](#); [Krishnamurthy et al., 2014](#)).

We contribute to the legal and economic literature on repo safe harbors and bankruptcy protections (e.g., [Duffie and Skeel, 2012](#); [Morrison et al., 2014](#); [Antinolfi et al., 2015](#); [Acharya et al., 2025](#)). Legal scholars have argued that expanding bankruptcy protections implicitly subsidizes short-term wholesale debt and affects resolution outcomes ([Duffie and Skeel, 2012](#); [Morrison et al., 2014](#)). By formalizing this mechanism, we demonstrate how stronger bankruptcy pledgeability provides short-run contract safety while generating incentives for higher leverage that ultimately heightens systemic fragility.

Theoretically, we are closely related to [Acharya et al. \(2025\)](#), who analyze a three-period general equilibrium model to show how repo safe harbors induce excessive ex-ante leverage, forcing ex-post collateral liquidations that spike borrowing costs and trigger real-sector credit

²We take the short-term structure of debt as given; for microfoundations, see [Brunnermeier and Oehmke \(2013\)](#).

crunches. Our paper advances this literature by studying how safe-harbor protection affects repo run probabilities and characterizing the types of collateral – associated with the repo contracts affected by the bankruptcy protections – for which the effects are largest.

Our paper makes a theoretical contribution to dynamic run models with staggered short-term debt (He and Xiong, 2012; Martin et al., 2014) by introducing a collateral pledgeability constraint, that governs the firm’s leverage, to the continuous-time structure of He and Xiong (2012).³ This allows us to show that stronger creditor rights increase the probability of rollover for a given level of debt, but the resulting increase in debt safety endogenously induces higher leverage, amplifying financial fragility and increasing the long-run probability of a run. Our continuous-time framework allows us to characterize a unique run threshold and formally decompose the impact of pledgeability into two opposing forces: a short-run stabilizing recovery effect for a given balance sheet and a long-run destabilizing leverage feedback effect. We show that whether safe-harbor protections stabilize or destabilize wholesale markets depends critically on debt maturity and collateral volatility. The model clarifies why stronger collateral rights can stabilize a given contract in the short run but become destabilizing in the long run – once intermediaries adjust their leverage – and characterizes collateral types that are more likely to exhibit these effects in response to increased bankruptcy protection.

Our empirical findings complement Lewis (2023, 2021), which use the 2005 BAPCPA reform to show how collateral pledgeability expanded mortgage credit supply on the asset side of dealer balance sheets. We innovate relative to this literature by focusing on the liability side of dealer balance sheets.

The paper is organized as follows. Section 2 presents the data. Section 3 presents the results of the empirical analysis. Section 4 develops a partial-equilibrium model of a dealer bank’s optimal leverage to rationalize our findings. Section 5 simulates the model to study how changes in creditor rights affect the bank’s optimal leverage and the probability of a repo run. Section 6 concludes.

³We assume debt is short-term; for microfoundations see Brunnermeier and Oehmke (2013).

2 Data

We utilize hand-collected data to show that collateral and dealer leverage are positively related and that institutions with greater pre-BAPCPA exposure increased their leverage more following the reform. We then test whether these institutions experienced larger balance-sheet contractions during the financial crisis.

We hand-collect dealer-bank balance-sheet data from annual and quarterly filings. The core variables are total book assets, book equity, and repurchaseable collateral. Let A_{it} denote total book assets, E_{it} book equity, and R_{it} repurchaseable collateral for dealer i in year t . Book leverage is

$$L_{it} = \frac{A_{it}}{E_{it}}. \quad (1)$$

The empirical leverage regressions utilize L_{it} as the dependent variable.⁴

The data cover December observations from 2003 through 2007, giving two pre-reform years and three post-reform years around the April 2005 passage of BAPCPA. The sample contains 19 dealer-banks:⁵ the 16 primary dealers in 2004/2005 and three additional dealers that report the necessary repurchaseable-collateral data.⁶ Eleven dealers report quarterly data; the remaining eight report annual December data only. Table 1 summarizes key variables we use in the analysis.

3 Empirical design

The empirical tests are organized around the mechanism that motivates the model. BAPCPA increased the pledgeability of mortgage-related repo collateral. In the model, a higher pledgeability has a direct stabilizing effect because it raises repo recovery values for a fixed balance sheet. At the same time, higher pledgeability relaxes debt capacity and can induce the dealer to choose more leverage. The tests below ask whether this sequence appears in the data:

⁴The analogous leverage ratio in the model is $L(h) = V(h)/E(h)$.

⁵These are Barclays, Bear Stearns, Bank of America, Citigroup, Countrywide, Credit Suisse, Deutsche Bank, Greenwich Capital, Goldman Sachs, HSBC, JPMorgan Chase, Lehman Brothers, Merrill Lynch, Bank of Montreal, Morgan Stanley, Nomura, State Street, UBS, Washington Mutual

⁶We exclude Wells Fargo, which does not report repurchaseable collateral, and GMAC, which lacks post-2005 data.

Variable	2004		2007		2008	
	Mean	Median	Mean	Median	Mean	Median
Leverage (A/E)	20.48	19.23	26.03	22.05	28.37	23.24
Repledge / Equity (R/E)	10.78	5.46	12.78	6.55	7.27	6.34
Repledge / Assets (R/A)	0.433	0.320	0.398	0.229	0.255	0.221

Table 1. Summary statistics.

Data source: Hand-collected from quarterly and annual filings; see [Lewis \(2023\)](#).

first, whether collateral and leverage are positively related; second, whether dealers with greater pre-law exposure increased leverage more after BAPCPA; and third, whether those same dealers experienced larger balance-sheet contractions during the crisis.

Figure 1 plots dealer-bank book leverage against repledgeable collateral. Dealers that report more repledgeable collateral tend to operate with higher book leverage, consistent with [Acharya et al. \(2025\)](#). This pattern is not a causal estimate, but it is the balance-sheet relationship that motivates our model: collateral that can be pledged and reused in repo markets supports debt financing and, therefore, higher leverage.

3.1 Effect of pledgeability shock on leverage

Since the BAPCPA policy change applied to all dealers, the design uses pre-law differences in dealer balance sheets to create a treatment-intensity exposure measure. Dealers with more repledgeable collateral before the law had greater exposure to the increase in pledgeability of mortgage-related repo collateral. The main exposure variable is:

$$\log(R_{i,2004}), \quad (2)$$

where $R_{i,2004}$ is a dealer’s reported repledgeable collateral in December 2004, before BAPCPA. Higher exposure to pre-period repledgeable collateral indicates that a dealer entered the post-reform period with more collateral that could support repo borrowing.

The first test asks whether dealers with higher pre-law exposure increased leverage more

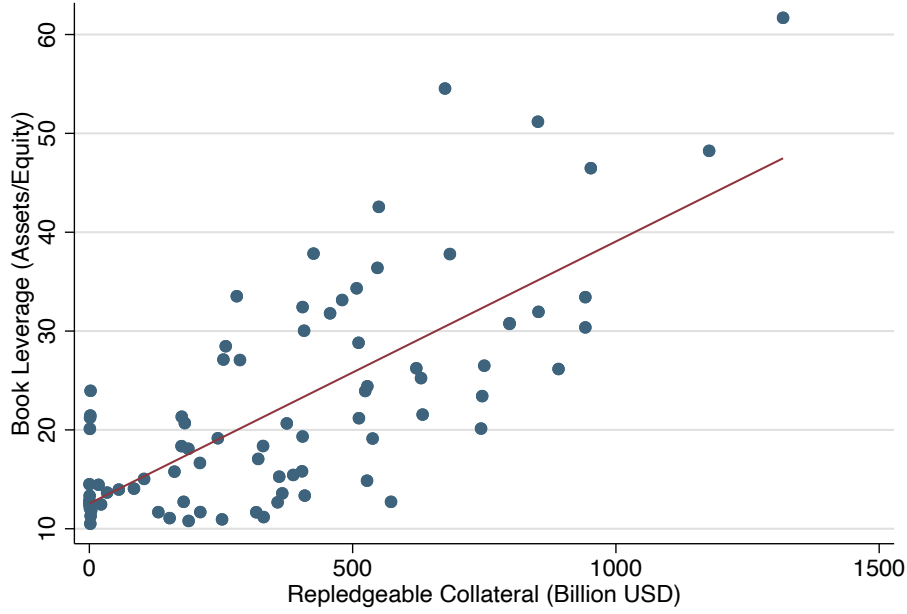


Figure 1. Dealer leverage and repledgeable collateral

Notes: The figure plots book leverage, defined as total book assets divided by book equity, against repledgeable collateral from dealer-bank annual filings.

	$\log L_{it}$
$\text{Post}_t \times \log(R_{i,2004})$	0.026** (0.010)
Dealer fixed effects	Yes
Year fixed effects	Yes
Observations	95
Dealers	19

Table 2. Effect of BAPCPA exposure on dealer leverage

Notes: The table reports the full-sample estimate of Equation 3, including State Street. The dependent variable is log book leverage, $\log L_{it}$, where $L_{it} = A_{it}/E_{it}$. The sample is a panel of December observations from 2003 through 2007. Post_t equals one for 2005 and later. Standard errors clustered by dealer are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels.

after the law. We estimate the continuous-treatment difference-in-differences specification

$$\log L_{it} = \beta \text{Post}_t \times \log(R_{i,2004}) + \alpha_i + \phi_t + \varepsilon_{it}, \quad (3)$$

where Post_t equals one for 2005 and later, α_i are dealer fixed effects, and ϕ_t are year fixed effects. Dealer fixed effects absorb time-invariant differences across dealers, including average size, business model, and leverage policy. Year fixed effects absorb aggregate changes in dealer leverage. The coefficient β therefore compares the post-BAPCPA change in leverage for dealers with higher versus lower pre-law exposure to the change. Standard errors are clustered at the dealer level to account for correlation within dealers.

Table 2 reports the full-sample static DiD estimate. The average post-period coefficient on $\text{Post}_t \times \log(R_{i,2004})$ is a significant 0.026, with a dealer-clustered standard error of 0.012. Economically, a one percent increase in pre-period repledgeable collateral drives a .026% increase in leverage after BAPCPA. The dealer fixed effects absorb dealer-specific characteristics including size, business model, or repledgeable collateral exposure relative to size. However, Appendix A.1, also estimates a regression that scales the repledgeable collateral exposure measure by dealer equity to further control for a dealer’s exposure to repledgeable collateral relative to its size and the results remain consistent. This pattern is consistent with the model’s leverage-capacity channel: when collateral pledgeability rises, the dealers with more pledgeable collateral in place disproportionately increase leverage.

The above static specification averages the post-law response across 2005–2007. We estimate the dynamic version of Equation 3 to check for differential pre-trends and to trace the timing of the leverage response:

$$\log L_{it} = \sum_{k \in \{2003, 2005, 2006, 2007\}} \beta_k \mathbb{I}\{t = k\} \times \log(R_{i,2004}) + \alpha_i + \phi_t + \varepsilon_{it}, \quad (4)$$

where 2004 is the omitted year. The coefficient for 2003 is the pre-trend diagnostic. Many dealers only begin reporting their repledgeable collateral in 2003, making a longer pre-period infeasible. The coefficients for 2005–2007 show that a unit change in repledgeable collateral significantly increases dealer leverage post-BAPCPA.

Figure 2 plots the dynamic coefficients. The 2003 coefficient is close to zero relative to 2004, which supports the parallel-trends interpretation. After BAPCPA, the coefficients rise and become economically larger in 2006 and 2007. The timing is consistent with gradual balance-sheet adjustment after the law expanded debt capacity, rather than a differential leverage trend that was already underway before the reform.

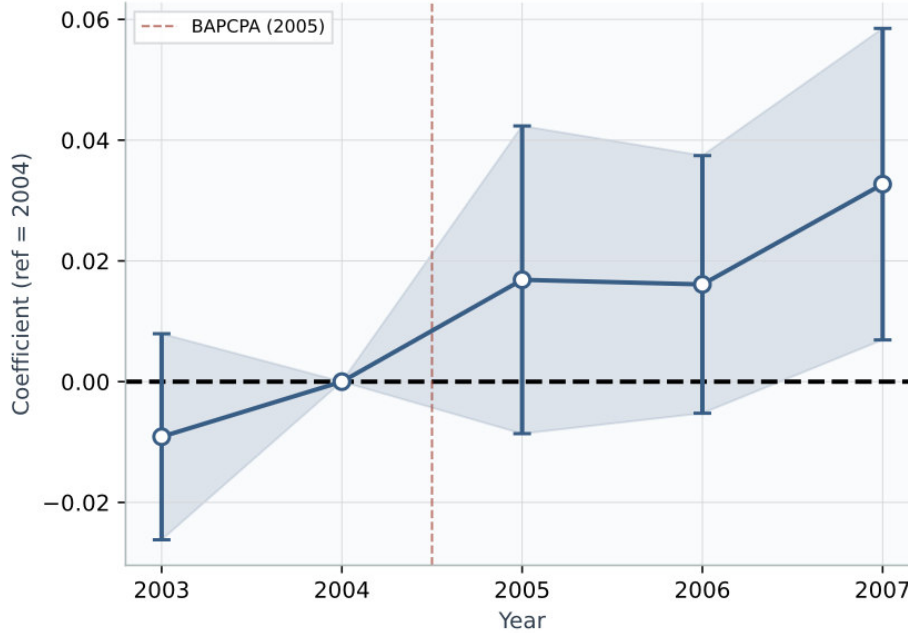


Figure 2. Dynamic effect of BAPCPA exposure on dealer leverage

Notes: The figure plots the year-by-year coefficients β_k from Equation 4, with 95% confidence intervals. The omitted year is 2004. The exposure variable is $\log(R_{i,2004})$, where repledgeable collateral is measured in December 2004 for the full sample of 19 dealers. The specification includes dealer and year fixed effects. Confidence intervals are 95% intervals based on standard errors clustered by dealer.

3.2 Exposure to pledgeability shock and deleveraging

Tuckman (2010) states that dealers prefer to use borrowed capital to finance their security holdings rather than their own scarce capital. Thus dealers repledge, or rehypothecate, collateral received in one repo transaction, in another repo transaction (Copeland et al., 2014) to finance their assets. Repo borrowing is short-term, runnable funding, and the asset class that the BAPCPA policy change affected was private-label mortgage-backed collateral, which is not implicitly backed by the US government and is therefore susceptible to large price declines.

We investigate whether the increased exposure to the collateral-pledgeability shock increases dealer-bank exposure to bank runs by increasing their runnable debt holdings. To quantify dealer deleveraging, we use the severity of crisis balance-sheet contraction as the observable fragility outcome, since dealer-level repo-run probabilities and exact run arrival times are not directly observed. For the crisis-time deleveraging tests, we use the same 19 dealers

and measure each dealer's peak-to-trough asset contraction after 2005Q1, using quarterly observations when available and annual observations otherwise.

For each dealer, define peak-to-trough asset growth after 2005Q1 as

$$\Delta A_i^{\text{crisis}} = \frac{A_i^{\text{trough}} - A_i^{\text{peak}}}{A_i^{\text{peak}}}, \quad (5)$$

where A_i^{peak} is the maximum value of total assets observed after 2005Q1, and A_i^{trough} is the minimum value observed after the peak. More negative values of $\Delta A_i^{\text{crisis}}$ indicate larger balance-sheet contractions. We estimate the following cross-sectional regression

$$\Delta A_i^{\text{crisis}} = \kappa + \beta \log \left(\frac{R_{i,2004}}{E_{i,2004}} \right) + u_i. \quad (6)$$

Where $\frac{R_{i,2004}}{E_{i,2004}}$ represents the value of the dealer-bank's repledgeable collateral in December 2004 scaled by book value of equity in December 2004. Since this is a cross sectional regression with only one peak-to-trough value per dealer, dealer fixed effects cannot be included and thus the equity scaling accounts for repledgeable collateral as a fraction of dealer size.

Figure 3 displays the scatter plot and fitted OLS line. Table 3 reports the regression results. The results indicate that a one-unit increase in pre-law exposure is associated with a 3 percentage point more severe peak-to-trough decline in assets during the crisis.

The finding that dealer-banks with greater exposure to BAPCPA increased their leverage following the reform and subsequently contracted more sharply when funding markets came under stress is consistent with a leverage-feedback mechanism. Exposure to pre-period repledgeable collateral increases post-period dealer leverage after BAPCPA increases pledgeability. The same exposure also predicts larger crisis-period deleveraging.

In Section 4, we develop a dynamic model that captures this mechanism and shows that under certain parameters, greater collateral pledgeability can increase dealer-banks' long-term vulnerability to runs by inducing them to take on more leverage.

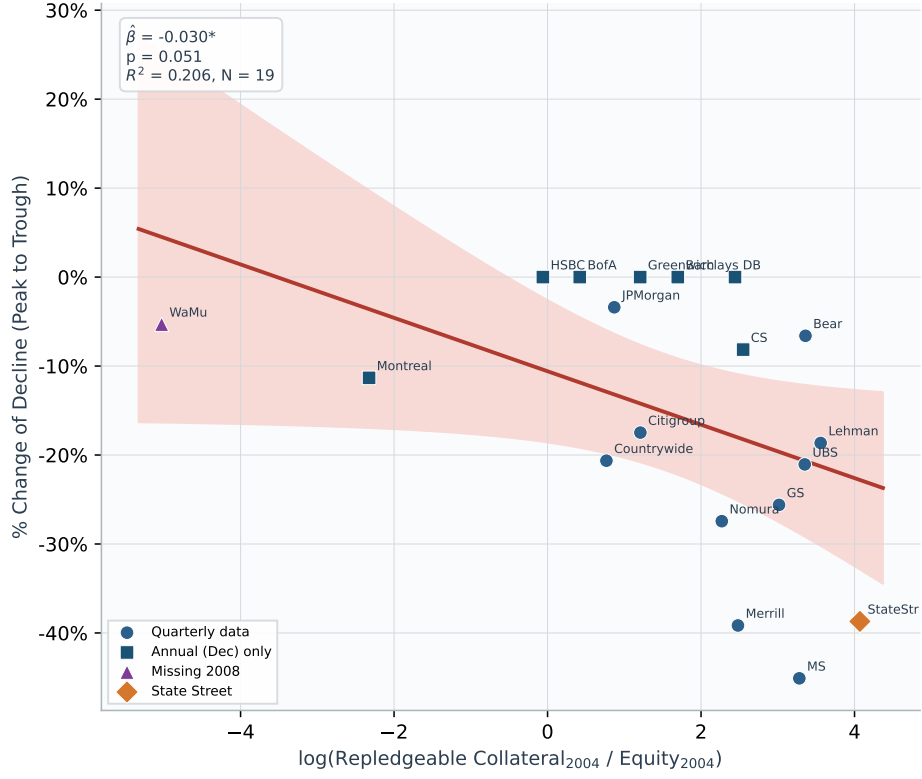


Figure 3. Crisis deleveraging and pre-law repledgeable-collateral exposure.

Notes: The figure plots peak-to-trough asset growth, $\Delta A_i^{\text{crisis}} = (A_i^{\text{trough}} - A_i^{\text{peak}})/A_i^{\text{peak}}$, against pre-law exposure, $\log(R_{i,2004}/E_{i,2004})$. The fitted line is from an OLS regression. Circles denote dealers with quarterly data; squares denote dealers with annual December data only; triangles denote dealers missing 2008 data; diamonds denote State Street.

	$\Delta A_i^{\text{crisis}}$
$\log(R_{i,2004}/E_{i,2004})$	-0.030^* (0.014)
R^2	0.206
Observations	19

Table 3. BAPCPA exposure and crisis deleveraging

Notes: The dependent variable is peak-to-trough asset growth, $\Delta A_i^{\text{crisis}} = (A_i^{\text{trough}} - A_i^{\text{peak}})/A_i^{\text{peak}}$, measured after 2005Q1. More negative values indicate larger balance-sheet contractions. The exposure variable is $\log(R_{i,2004}/E_{i,2004})$. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels.

4 Model

In this section, we develop a partial equilibrium model of a dealer-bank's optimal leverage in which a fraction of its assets can be pledged as collateral to support the issuance of short-term (repo) and long-term debt.

4.1 Assumptions

Time $t \in [0, \infty)$ is continuous. Agents are risk-neutral and discount future cash flows at a constant rate $r \in \mathbb{R}^+$. Uncertainty is modelled by using a complete probability space $(\Omega, \mathbb{P}, \mathcal{F})$ satisfying the usual conditions.

We consider an infinitely-lived financial firm ("bank" henceforth) investing in a portfolio of securities (e.g., Mortgage-backed Securities). The portfolio generates instantaneous cash flows

$$\beta H_t, \tag{7}$$

where $\beta \in \mathbb{R}^+$ is a constant parameter. The process $(H_t)_{t \geq 0}$ denotes the market value of the portfolio, which follows a geometric Brownian motion:⁷

$$dH_t = H_t (\mu dt + \sigma dW_t), \quad H_0 = h \in \mathbb{R}^+, \tag{8}$$

where $0 < \mu < r$ and $\sigma \in \mathbb{R}^+$ are constant parameters and $(W_t)_{t \geq 0}$ is a standard Brownian motion defined on $(\Omega, \mathbb{P}, \mathcal{F})$. The value of the portfolio is observable to all agents.

Minimum capital requirements are implemented as a regulatory threshold h_d , such that the firm must cease its activity if $H_t \leq h_d$. We can thus define the bank's fundamental default time as

$$\tau_d := \inf \{t \geq 0 : H_t \leq h_d\}. \tag{9}$$

Following a fundamental default, the regulator liquidates the portfolio at a fire-sale price (after-tax) $\alpha \in (0, 1)$ and uses the proceeds to reimburse the bank's creditors.

The bank pays taxes on its income and therefore has an incentive to use debt, as coupon

⁷Alternatively, one can think of H_t as the market value of the real estate backing the MBS portfolio.

payments are tax-deductible. The debt consists of a “representative” long-term (consol) bond and a unit mass of short-term (repo) debt contracts.

As in [Leland \(1994\)](#), long-term debt takes the form of a perpetual (“consol”) bond with constant principal D_d . These bonds pay continuous coupons at the fixed instantaneous rate $\rho_d \in \mathbb{R}^+$ until either fundamental or financial default by the firm. Repo debt has face value D_r and pays coupons at the instantaneous rate ρ_r . Each contract has a random maturity driven by an independent Poisson shock with parameter $\lambda \in \mathbb{R}^+$, as in [He and Xiong \(2012\)](#).⁸ Over a short time interval, a fraction λdt of the aggregate repo stock matures, generating staggered rollover opportunities across repo holders, who choose whether to roll over or withdraw their funding. In the event of an aggregate withdrawal, the bank must replace the missing funding in imperfect capital markets. If it fails to do so, it faces premature (“financial”) default. The instantaneous probability of not finding liquidity during an aggregate repo withdrawal is given by $1 - e^{-\eta dt} \approx \eta dt$, where $\eta \in \mathbb{R}^+$ denotes the arrival intensity of a “panic” event in the form of a standard Poisson process $(J_t)_{t \geq 0}$ defined on $(\Omega, \mathbb{P}, \mathcal{F})$.

As shown below, under these assumptions, repo holders choose to withdraw only if the price of the asset portfolio shrinks below a “run” threshold $h_r \geq h_d$, which is determined in equilibrium. For a given couple (h_d, h_r) , we can thus define the bank’s financial default time

$$\tau_r := \inf \{t \geq 0 : h_d < H_t \leq h_r, dJ_t = 1\}. \quad (10)$$

After a financial default, the bank must liquidate its assets at the fire-sale price α and use the proceeds to reimburse its creditors. The bank may pledge a share $\theta \in (0, 1)$ of its assets as collateral to protect repo debtholders and reduce the likelihood of financial default. The remaining share $1 - \theta$ accrues to the long-term bondholder.

The parameter θ captures the safe harbor status of repo collateral. When θ is low, a dealer default triggers the automatic stay, freezing the assets in bankruptcy court. Creditors must then wait for a court decision, facing illiquidity and potential price drops before they can recover anything. Conversely, when θ is high, creditors can instantly seize and liquidate the collateral outside of bankruptcy.

In this framework, BAPCPA provides a natural mapping into safe-harbor status, as it rep-

⁸This assumption implies exponentially distributed contract lengths and an average maturity of $1/\lambda$.

resents a binary legal shock that granted safe-harbor protection to private-label mortgage collateral. In practice, the pledgeability of bank assets is measured by the haircut. A highly pledgeable asset has a low haircut because lenders expect to recover their investment more easily in the event of default. [Lewis \(2023\)](#) shows that BAPCPA lowered haircuts on private-label MBS, making them more “pledgeable” as collateral for financing and directly supporting the interpretation of BAPCPA as a positive shock to θ .

4.2 Securities valuation and repo runs

In this section, we derive the value of the bank’s equity and debt for a given repo withdrawal threshold h_r . Then, following [He and Xiong \(2012\)](#), we characterize the threshold h_r^* associated with the symmetric equilibrium in which all repo creditors adopt the same run strategy based on the price of the bank’s asset portfolio.

4.2.1 Equity valuation

We start by determining the value of equity, which is given by the present value of all cash flows generated by the asset portfolio in [Equation 7](#) minus the present value of the cash flows accruing to debt holders after taxes, until either fundamental or financial default. Denoting by $\mathbb{E}_{\mathbb{P}}$ the conditional expectation operator under the measure $\mathbb{P}$, we can write this value as

$$E(h) = \mathbb{E}_{\mathbb{P}} \left[\int_0^{\tau} e^{-rt} (1 - T) (\beta H_t - \rho_d D_d - \rho_r D_r) dt \middle| H_0 = h \right] + \\ + \mathbb{E}_{\mathbb{P}} \left[e^{-r\tau} \max \{ \alpha h_{\tau} - D_d - D_r, 0 \} \middle| H_0 = h \right]. \quad (11)$$

where $\tau = \min \{ \tau_d, \tau_r \}$ and $T \in (0, 1)$ is the tax rate.

Under the conjecture that financial and fundamental defaults occur only when the bank’s portfolio value after liquidation is insufficient to repay repo creditors and total creditors in full (we assume that this is the case and verify it in the simulations), the value of equity can be expressed analytically as a piecewise function of the time-zero portfolio value h , the repo withdrawal threshold h_r , and the model parameters over the intervals (h_d, h_r) and (h_d, ∞) .

Proposition 1. (*Equity*) *Let the price dynamics of the asset portfolio be given by [Equa-](#)*

tion 8. Let θ denote the fraction of the asset portfolio pledged as collateral to repo creditors. Assume further that there exists a repo withdrawal threshold $h_d < h_r \leq \tilde{h} := (D_r + D_d)/\alpha$. Then, for given amounts of short- and long-term debt (D_r, D_d) , the value of the bank's equity is given by

$$E(h) = \begin{cases} (1 - T) \left[\frac{\beta}{r + \eta - \mu} h - \frac{\rho_d D_d + \rho_r D_r}{r + \eta} \right] + \sum_{i=1}^2 A_i h^{\gamma_i}, & h \in (h_d, h_r), \\ (1 - T) \left[\frac{\beta}{r - \mu} h - \frac{\rho_d D_d + \rho_r D_r}{r} \right] + B_1 h^{\Psi_1}, & h \in (h_r, \infty). \end{cases} \quad (12)$$

The constants $(A_1, A_2, B_1, \gamma_1, \gamma_2, \Psi_1) \in \mathbb{R}^6$ are expressed as functions of the model's parameters and the repo withdrawal threshold h_r in Appendix B.1.

Next, we derive the value of a repo contract, which equals the present value of its coupon payments before maturity or default (financial or fundamental), plus its terminal payoff.

At maturity, the repo holder either receives the contract's face value, if the position is withdrawn, or a newly issued security with identical ex-ante characteristics. In the event of default, the repo holder receives the pledged share of the fire-sale liquidation value of the asset portfolio. The value of the repo contract is given by

$$D_1(h) = \mathbb{E}_{\mathbb{P}} \left[\int_0^{\min\{\tau, \tau_\lambda\}} e^{-rt} \rho_r D_r dt + e^{-r \min\{\tau, \tau_\lambda\}} \mathbb{I} \{ \tau_\lambda \leq \tau \} \max \{ D(H_{\tau_\lambda}), D_r \} \middle| H_0 = h \right] + \\ + \mathbb{E}_{\mathbb{P}} \left[e^{-r \min\{\tau, \tau_\lambda\}} \mathbb{I} \{ \tau_\lambda > \tau \} \min \{ \alpha \theta H_\tau, D_r \} \middle| H_0 = h \right], \quad (13)$$

where τ_λ denotes its (random) maturity time.

Similarly to the value of equity, under the assumption that financial and fundamental defaults occur only when the value of the asset portfolio after liquidation is insufficient to repay repo creditors in full, the repo value can be written as a piecewise function of the parameters over the intervals (h_d, h_r) and (h_r, ∞) .

Proposition 2. (Repo) Assume that there exists a repo withdrawal threshold $h_d < h_r \leq \tilde{h}$, and let θ denote the fraction of the asset portfolio with dynamics in Equation 8 pledged as collateral to the repo creditors. Then, the value of a repo with face value D_r that pays coupons

at the constant rate ρ_r is given by

$$D_1(h) = \begin{cases} \frac{\rho_r + \lambda}{r + \lambda + \eta} D_r + \frac{\eta \theta \alpha}{r + \lambda + \eta - \mu} h + \sum_{i=1}^2 C_i h^{\nu_i}, & h \in (h_d, h_r), \\ \frac{\rho_r}{r} D_r + F_1 h^{\Psi_1}, & h \in (h_r, \infty). \end{cases} \quad (14)$$

The constants $(C_1, C_2, F_1, \nu_1, \nu_2) \in \mathbb{R}^5$ are expressed as functions of the model's parameters and the repo withdrawal threshold h_r in Appendix B.2.

By the same logic applied to price equity and repo debt, we can derive the value of the long-term bond.

Proposition 3. (Consol bond) Assume that there exists a repo withdrawal threshold $h_d < h_r \leq \tilde{h}$, and let $1 - \theta$ denote the fraction of the asset portfolio with dynamics in Equation 8 pledged as collateral to long-term creditors. Then, the value of a consol bond with face value D_d that pays coupons at the constant rate ρ_d until default is given by

$$D_2(h) = \begin{cases} \frac{\rho_d D_d}{r + \eta} + \frac{\eta \theta \alpha (1 - \theta)}{r + \eta - \mu} h + \sum_{i=1}^2 G_i h^{\gamma_i}, & h \in (h_d, h_r), \\ \frac{\rho_d}{r} D_d + H_1 h^{\Psi_1}, & h \in (h_r, \infty). \end{cases} \quad (15)$$

The constants $(G_1, G_2, H_1) \in \mathbb{R}^3$ are expressed as functions of the model's parameters and the repo withdrawal threshold h_r in Appendix B.3.

Having derived the values of equity, repo debt, and long-term debt, we can write the value of a bank with asset value h in the absence of arbitrage as

$$V(h) = E(h) + \sum_{i=1}^2 D_i(h). \quad (16)$$

4.3 Repo withdrawal threshold: existence and optimality

Following He and Xiong (2012), we characterize the repo withdrawal threshold h_r^* as the symmetric monotone equilibrium threshold: if all other repo investors adopt $h_r = h_r^*$, an individual investor's optimal response is to choose the same threshold, implying the indiffer-

ence condition

$$D_1(h_r^*) = D_r. \quad (17)$$

The existence of such a threshold and the optimality of the associated withdrawal strategy are outlined in the following proposition.

Proposition 4 (Repo threshold). *Let $\mu < r + \lambda + \eta$, $\rho_r > r$, and $D_r > \alpha\theta h_d$. Let the value of the repo contract with face value D_r satisfy the pricing equation in Proposition 2. Then, the following holds:*

1. *There exists a threshold $h_r^* > h_d$ satisfying Equation 17, which solves the algebraic equation*

$$\frac{\rho_r}{r} D_r + F_1(h_r^*) h_r^{*\Psi} = D_r. \quad (18)$$

The constants $(F_1, \Psi) \in \mathbb{R}^2$ are expressed as functions of the repo withdrawal threshold h_r and the model's parameters in Appendix B.2.

2. *The repo withdrawal strategy associated with the threshold h_r^* is optimal for each creditor if every other creditor also uses this threshold.*

Proof. See Appendix B.4. □

5 Optimal leverage and collateral pledgeability

In this section, we parametrize and simulate the model to study how changes in creditor rights over repo collateral affect the bank's optimal leverage and, in turn, the probability of a repo run.

5.1 Parametrization

Our simulations adopt the following parameters, summarized in Table 4. The risk-free interest rate $r = 0.035$ lies between the 1- and 12-month LIBOR rates in 2005. The repo yield $\rho_r = 0.041$ equals the risk-free rate plus 0.006, which corresponds to the minimum

spread observed in our data. We set the repo maturity $1/\lambda = 0.067$ to match the 3-day tri-party and 30–60-day bilateral contracts in our data. The fire-sale price $\alpha = 0.89$ corresponds to an 11% haircut on mortgage repo. $\eta = 0.36$ corresponds to a $1 - e^{-0.36 \times 1} \approx 30\%$ one-year panic probability conditional on $h \leq h_r$, within the range established in [Greenwood et al. \(2022\)](#).

The asset price growth rate is $\mu = 0.015$ and asset volatility is $\sigma = 0.12$. The tax rate $T = 0.15$ is a standard value in the corporate finance literature (see, e.g., [Leland, 1994](#)). For simplicity, we assume that the total face value of the bank debt is $D_r + D_d = D$. We parameterize $D_r = \phi D$ and $D_d = (1 - \phi)D$. While D is chosen to maximize the bank's ex-ante value as explained below, $\phi = 0.84$ is set to match the share of repo in total debt observed in the data. Similarly to [Hackbarth et al. \(2006\)](#), the return rate on the bank's asset $\beta = 0.03$ is chosen so that the implied dividend yield

$$\frac{(1 - T)\beta h + T(D_d \rho_d + D_r \rho_r)}{E(h)} \approx 4\%. \quad (19)$$

We select the initial price level used in the optimization, $h = 1.335$, to match the empirical one-year repo run probability in the data:⁹

$$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1 \mid H_0 = h) \approx 0.03. \quad (20)$$

The minimum capital requirement $h_d = 1$ is a normalization. Finally, we set the share of the bank's portfolio pledged to repo debt $\theta = 0.7$ so that the bank's optimal leverage equals 11, which is within the range found in our data and referenced in [Gertler and Kiyotaki \(2015\)](#).

Given these parameters, [Figure 4](#) displays the bank's equity, $E(h)$, repo debt, $D_1(h)$, and consol bond value, $D_2(h)$, for different levels of the asset portfolio value h and the debt face value D . The solid (dashed) lines depict the values above (below) the repo withdrawal threshold h_r^* . The figure highlights four features.

First, the equity function is concave above the threshold h_r^* and convex below. Intuitively, the reason is that the possibility of a panic event and thus a repo run induces risk-shifting. Second, increasing the face value of debt (and thus interest payments) shifts the equity value

⁹Details of the computation of [Equation 20](#) appear in [Appendix B.5](#).

Parameter	Meaning	Value	Source/Target
r	risk-free rate	0.035	2005 LIBOR 3.09 1mo, 3.69 12mo
ρ_r	repo yield	0.041	1 month min spread 0.6 (HomeBanc)
ρ_d	consol bond yield	0.07	3 p.p. term premium (3mo, 10y), FRED
λ	runnable debt maturity	14.93	3-day tri-party, 30/60-day bilateral
α	fire-sale price	0.89	11% HC on mtg repo
η	panic event (intensity)	0.36	30% cond repo run prob
μ	assets growth (rate)	0.015	House price growth
σ	asset volatility	0.12	Standard
β	assets cash flow	0.058	Target: dividend yield
T	income tax rate	0.15	Standard
h_d	min capital requirement	1.00	Normalization
h	initial price level	1.335	Target: 1-year uncond run prob
ϕ	Share repo debt	0.84	84.3%
θ	Share repo-pledge assets	0.7	Target: optimal leverage

Table 4. Model parameters

Notes: The table reports the model parameters adopted in the numerical simulations.

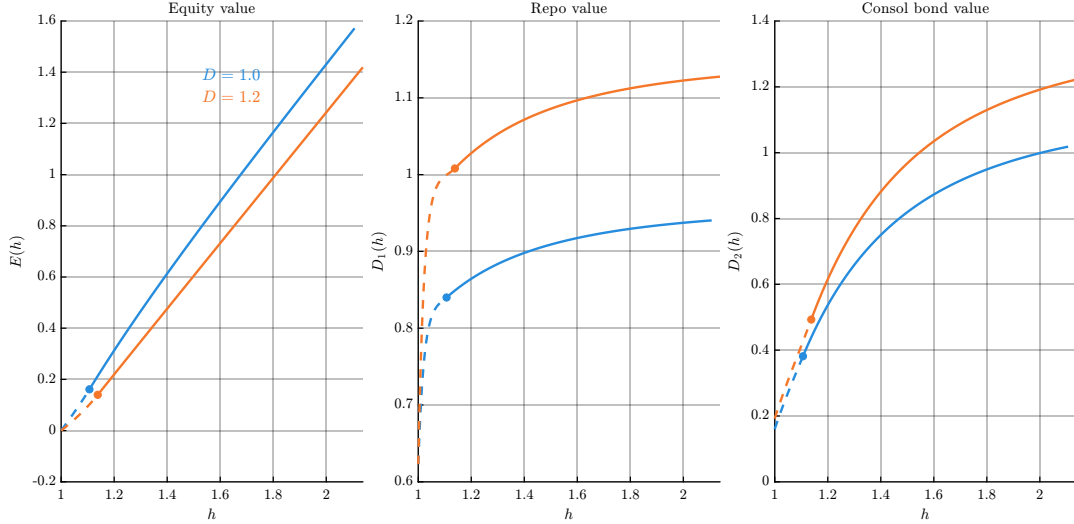


Figure 4. Equity, repo, and long-term debt value

Notes: The figure displays the bank's equity, repo debt, and consol bond value for different levels of the asset portfolio value h and the debt face value D . The solid (dashed) lines depict the values above (below) the repo withdrawal threshold h_r^* .

and the repo withdrawal threshold to the right. Third, higher debt face value re-scales the value of repo for all levels of h . Repo creditors receive higher cash flows, but they also choose to run earlier if h becomes too low. Fourth, the effect on consol bonds is ambiguous because long-term debt holders cannot choose to run. On the one hand, debt holders receive higher cash flows but may lose everything due to a run. When h is high (low), the first (second) effect dominates.

5.2 Leverage, collateral pledgeability, and repo runs: short vs long run

We now turn to the analysis of the optimal leverage decisions and how changes in the collateral pledgeability parameter θ affect them. Within our setting, the bank's leverage ratio is defined as

$$L(h) := \frac{V(h)}{E(h)}.$$

The optimal leverage is selected by choosing the face value of total debt

$$D^*(\theta) := \arg \max_D V(\cdot; D, \theta), \quad (21)$$

as in [Leland \(1994\)](#). We assume that the solution to [Equation 21](#) is unique and verify the conjecture in the simulations.

Along the dealer's optimal debt choice $D^*(\theta)$, the total effect of pledgeability on run risk can be decomposed as follows:

$$\frac{d\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)(\theta, D^*(\theta))}{d\theta} = \left. \frac{\partial \mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)(\theta, D)}{\partial \theta} \right|_{D=D^*(\theta)} + \left. \frac{\partial \mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)(\theta, D)}{\partial D} \right|_{D=D^*(\theta)} \frac{dD^*(\theta)}{d\theta}. \quad (22)$$

The first term is the direct recovery effect: for a fixed balance sheet, stronger collateral rights make repo creditors safer and reduce run risk. The second term is the leverage feedback: higher pledgeability increases optimal debt, and additional debt raises run risk. The empirical results speak to this second channel. Dealers more exposed to the pledgeability shock increased leverage more and later contracted more severely.

To quantify the effects described in [Equation 22](#), the top panel (A) of [Table 5](#) reports the bank's optimal debt $D^*(\theta)$, leverage $L^*(\theta)$, repo withdrawal threshold $h_r^*(\theta)$, and one-year

probability of a repo run, $\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$ for different levels of collateral pledgeability. The “short-run” columns keep debt fixed at its optimal level under the baseline parametrization ($\theta = 0.7$). The “long-run” columns allow debt to adjust to its new optimal level after a 10% ($\theta = 0.77$) and a 20% ($\theta = 0.84$) increment in θ . The results reveal two opposing effects. Holding debt fixed, a 10% (20%) increase in θ reduces the one-year run probability by more than 50% (60%), from 3.07% to 1.51% (1.02%). Once debt adjusts, however, optimal leverage rises well above its baseline level, pushing the run probability up to 3.64% (4.12%). Notably, the effects are nonlinear: a larger increase in pledgeability produces a stronger short-run reduction in run risk, but also a larger endogenous leverage response that more than offsets this reduction and raises long-run run risk further above its baseline level. This mechanism is akin to the one discussed in [Duffie and Skeel \(2012\)](#), which argues that strengthening the creditor rights on repo collateral can lead to a buildup of leverage among systemic players in equilibrium.

The remaining panels of the table examine the magnitude of these effects across different repo maturities, governed by λ , and levels of underlying asset volatility, σ .

A decrease in λ , corresponding to a longer average repo maturity, reduces the bank’s optimal leverage but increases the ex ante run probability because creditors who roll over remain locked in for longer. Accordingly, both the short-run reduction and the long-run increase in run probability induced by greater pledgeability are smaller (Panels B and C). Moreover, when repo maturity is sufficiently long and pledgeability is sufficiently high, the direct stabilising effect dominates the endogenous leverage response, so that greater pledgeability reduces run risk even in the long run (Panel C). Thus, stronger creditor rights are more likely to be stabilising when repo funding is longer-term, whereas short-term funding generates a stronger leverage response. This leverage effect is reminiscent of [Della Seta et al. \(2020\)](#), who show that short-term debt creates incentives for risk-taking.

Higher fundamental asset volatility, at the time leverage decisions are taken, increases the baseline probability of a run and magnifies both its short-run reduction and long-run increase following greater pledgeability (Panels D and E). At the same time, higher volatility, at the time leverage decisions are taken, dampens the endogenous leverage response in relative terms, as the bank expands leverage by less following an increase in pledgeability. This disciplining effect of volatility is reminiscent of the “volatility paradox” in [Brunnermeier and](#)

	$\theta = 0.70$	$\theta = 0.77$		$\theta = 0.84$	
		Short run	Long run	Short run	Long run
Panel A – Baseline (2 weeks)					
L^*	10.74	10.41	16.44	10.08	28.78
D^*	1.43	-	1.57	-	1.71
h_r^*	1.20	1.16	1.21	1.14	1.22
$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$	3.07%	1.51%	3.64%	1.02%	4.12%
Panel B – $\lambda = 6.0$ (40 days)					
L^*	6.21	5.99	7.88	5.84	10.19
D^*	1.16	-	1.28	-	1.40
h_r^*	1.23	1.18	1.15	1.24	1.25
$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$	4.89%	2.24%	5.13%	1.33%	5.43%
Panel C – $\lambda = 4.0$ (60 days)					
L^*	5.26	5.04	6.52	5.14	8.23
D^*	1.08	-	1.19	-	1.30
h_r^*	1.24	1.18	1.237	1.15	1.24
$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$	5.44%	2.43%	5.28%	1.28%	5.35%
Panel D – $\sigma = 0.132$ (+10%)					
L^*	9.06	8.92	13.43	8.45	20.27
D^*	1.38	-	1.54	-	1.67
h_r^*	1.23	1.17	1.24	1.15	1.24
$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$	5.07%	2.40%	5.93%	1.7%	5.94%
Panel E – $\sigma = 0.144$ (+20%)					
L^*	8.72	8.47	12.43	8.00	15.97
D^*	1.37	-	1.52	-	1.65
h_r^*	1.26	1.19	1.27	1.17	1.26
$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$	7.05%	3.91%	8.25%	2.68%	8.09%

Table 5. Collateral pledgeability, leverage, and runs: short v long run

Notes: The table reports the effects of an increase in the collateral pledgeability parameter θ on the bank's optimal debt D^* , leverage L^* , repo withdrawal threshold h_r^* , and the one-year repo run probability $\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1)$, for different repo maturities λ and underlying volatility σ . The “short-run” columns keep debt fixed at its optimal level under $\theta = 0.7$ (baseline), while the “long-run” columns allow debt to adjust to its new optimal level after a 10% ($\theta = 0.77$) and 20% ($\theta = 0.84$) increment in the asset pledgeability parameter θ . The baseline parameters refer to [Table 4](#).

[Sannikov \(2014\)](#): greater fundamental risk restrains leverage-taking and thereby weakens the leverage-feedback mechanism.

6 Conclusions

BAPCPA increased the bankruptcy pledgeability of mortgage-related repo collateral. Dealers with greater pre-law exposure to replodgeable collateral increased leverage more after the reform, and those same dealers experienced larger balance-sheet contractions during the financial crisis. A model with endogenous repo-financed leverage explains why the sign of the pledgeability effect depends on the time horizon. In the short run, higher pledgeability improves repo recovery values and lowers run incentives for a fixed balance sheet. In the long run, it raises debt capacity. When dealers lever up, the leverage feedback can dominate the direct recovery effect and increase run fragility.

The main lesson is that bankruptcy safe harbors are not only resolution rules; they are also ex ante leverage rules. By changing which collateral is pledgeable and how quickly creditors can seize it, safe harbors link bankruptcy policy to macroprudential regulation.

Finally, our model offers a key macroprudential lesson on the interaction between bankruptcy law, debt maturity, and asset risk. Safe harbor exemptions can be destabilizing when granted to short-term funding instruments backed by low-volatility assets. Conversely, for long-term debt or high-volatility assets, market discipline naturally checks leverage growth. Regulators considering safe-harbor reforms must therefore evaluate collateral pledgeability not in isolation, but alongside the maturity structure of dealer liabilities and the underlying risk of the pledged assets.

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Online Appendix

A Empirical robustness

A.1 Alternative Functional Form and Excluding Dealers

This appendix reports robustness exercises for [Section 3](#). It tests a second exposure measure, the log ratio:

$$\log \left(\frac{R_{i,2004}}{E_{i,2004}} \right), \quad (23)$$

where both the numerator and denominator are measured in December 2004, before BAPCPA. Equity scaling matches the equity denominator in book leverage,¹⁰ to which replendgeable collateral is compared. High exposure to replendgeable collateral means that the dealer entered the post-reform period with more collateral that could support repo borrowing relative to equity. We estimate the following specification:

$$\log L_{it} = \beta \text{Post}_t \times \log \left(\frac{R_{i,2004}}{E_{i,2004}} \right) + \alpha_i + \phi_t + \varepsilon_{it}, \quad (24)$$

where Post_t equals one for 2005 and later, α_i are dealer fixed effects, and ϕ_t are year fixed effects. Dealer fixed effects absorb time-invariant differences across dealers, including average size, business model, and leverage policy. Year fixed effects absorb aggregate changes in dealer leverage. The coefficient β therefore compares the post-BAPCPA change in leverage, for dealers with higher pre-law exposure versus dealers with lower exposure to the change. Standard errors are clustered at the dealer level to account for correlation of values within dealer.

[Table A1](#) reports the results for Equation 24 and shows that the results remain similar to the results in [Table 2](#).

¹⁰Note the dealer banks in our sample operate with very large values of leverage, indicating that equity is small relative to total assets. The typical conversion of firm book assets to market value of assets replaces book equity with the common equity value; however, given the small size of equity relative to assets, we do not expect this to make a large difference in our estimates or their mapping to the model.

	$\log L_{it}$
$\text{Post}_t \times \log(R_{i,2004}/E_{i,2004})$	0.020* (0.012)
Dealer fixed effects	Yes
Year fixed effects	Yes
Observations	95
Dealers	19

Table A1. Effect of BAPCPA exposure on dealer leverage: equity-normalized exposure

Notes: The table reports the estimate of Equation (3), using the leverage-normalized exposure measure $\log(R_{i,2004}/E_{i,2004})$ in place of $\log(R_{i,2004})$. The sample includes State Street. The panel contains December observations from 2003 through 2007, and Post_t equals one for 2005 and later. Standard errors clustered by dealer are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels.

B Mathematical appendix: proofs and derivations

B.1 Proof of Proposition 1

By applying Ito's lemma and Fubini's theorem, and using the associated Feynman-Kac representation, one can show that Equation 11 must satisfy the following ODE:

$$rE(h) = (1 - T)(\beta h - \rho_d D_d - \rho_r D_r) + E'(h)h\mu + \frac{\sigma^2}{2}E''(h)h^2 + \eta \mathbb{I}\{h \leq h_r\} [\max\{\alpha h_\tau - D_d - D_r, 0\} - E(h)], \quad (25)$$

with boundary conditions

$$\lim_{h \rightarrow h_d^+} E(h) = \max\{\alpha h_d - D_d - D_r, 0\}, \text{ and } \lim_{h \rightarrow \infty} E(h) \propto h. \quad (26)$$

To solve Equation 25, we adopt a guess-and-verify approach over the intervals (h_d, h_r) and

(h_r, ∞) , where it holds following holds:

$$\begin{cases} (1-T)(\beta h - \rho_d D_d - \rho_r D_r) + E'(h)h\mu + \frac{\sigma^2}{2}E''(h)h^2 - (r+\eta)E(h) = 0, & h \in (h_d, h_r), \\ (1-T)(\beta h - \rho_d D_d - \rho_r D_r) + E'(h)h\mu + \frac{\sigma^2}{2}E''(h)h^2 - rE(h) = 0, & h \in (h_r, \infty). \end{cases} \quad (27)$$

Substituting the guess function

$$E(h) = A_{00} + A_{01}h + \sum_{i=1}^2 A_i h^{\gamma_i} \quad (28)$$

over the first-interval ODE and matching coefficients yields

$$A_{00} = -(1-T) \frac{\rho_d D_d + \rho_r D_r}{r + \eta}, \quad (29)$$

$$A_{01} = (1-T) \frac{\beta}{r + \eta - \mu}, \quad (30)$$

as well as the characteristic equation

$$r + \eta = \gamma\mu + \frac{\sigma^2}{2}\gamma(\gamma - 1), \quad (31)$$

whose real roots identify $\gamma_1 < 0 < \gamma_2$. Guessing $E(h) = B_{00} + B_{01}h + \sum_{i=1}^2 B_i h^{\Psi_i}$ and following analogous steps (which we omit for brevity), we get $B_{00} = -(1-T)(\rho_d D_d + \rho_r D_r)/r$ and $B_{0,1} = \beta(1-T)/(r - \mu)$, while $\Psi_1 < 0$ is the negative root of

$$r = \Psi\mu + \frac{\sigma^2}{2}\Psi(\Psi - 1). \quad (32)$$

Given $(A_{00}, A_{01}, B_{00}, B_{01}, \gamma_1, \gamma_2, \Psi_1) \in \mathbb{R}^7$, the remaining coefficients are uniquely identified by imposing the boundary conditions in [Equation 26](#) and the following value-matching and smooth-pasting conditions at h_r :

$$\lim_{h \rightarrow h_r^-} E(h) = \lim_{h \rightarrow h_r^+} E(h), \quad (33)$$

$$\lim_{h \rightarrow h_r^-} E'(h) = \lim_{h \rightarrow h_r^+} E'(h). \quad (34)$$

The conditions require that $B_2 = 0$, and pin down $(A_1, A_2, B_1) \in \mathbb{R}^3$ as the unique solutions of the following linear system:

$$\begin{cases} (1-T) \left[\frac{\beta}{r+\eta-\mu} h_d - \frac{\rho_d D_d + \rho_r D_r}{r+\eta} \right] + \sum_{i=1}^2 A_i h_d^{\gamma_i} = 0, \\ (1-T) \left[\frac{\rho_d D_d + \rho_r D_r}{r+\eta} \frac{\eta}{r} - \frac{\eta\beta}{(r+\eta-\mu)(r-\mu)} h_r \right] + \sum_{i=1}^2 A_i h_r^{\gamma_i} - B_1 h_r^{\Psi_1} = 0 \\ -(1-T) \frac{\eta\beta}{(r+\eta-\mu)(r-\mu)} + \sum_{i=1}^2 A_i \gamma_i h_r^{\gamma_i-1} - B_1 \Psi_1 h_r^{\Psi_1-1} = 0. \end{cases} \quad (35)$$

B.2 Proof of Proposition 2

By the same logic of Appendix B.1, and under the conjecture that repo holders withdraw when the price of the asset portfolio shrinks below h_r , one can show that the value in Equation 13 satisfies the following ODE:

$$rD_1(h) = \rho_r D_r + D_1'(h)h\mu + \frac{\sigma^2}{2} D_1''(h)h^2 + \lambda [\max \{D_1(h), D_r\} - D_1(h)] + \eta \mathbb{I} \{h \leq h_r\} [\min \{h\theta\alpha, D_r\} - D_1(h)], \quad (36)$$

with boundary conditions

$$\lim_{h \rightarrow h_d^+} D_1(h) = \min \{D_r, h_d^+ \theta \alpha\}, \text{ and } \lim_{h \rightarrow \infty} D_1(h) = \frac{\rho_r}{r} D_r, \quad (37)$$

where $\rho_r D_r / r$ is the present value of a perpetuity with constant payment flow $\rho_r D_r$.

Following the logic of Appendix B.1 and using that $\max(D_h(h), D_r) = D_h$ if $h \leq h_r$ (i.e., withdrawing repo financing is optimal if the portfolio price is below h_r and vice versa), the value of the bank's repo over the intervals (h_d, h_r) and (h_r, ∞) satisfies

$$\begin{cases} (\rho_r + \lambda) D_r + \eta h \theta \alpha + D_1'(h)h\mu + \frac{\sigma^2}{2} D_1''(h)h^2 - (r + \lambda + \eta) D_1(h), & h \in (h_d, h_r), \\ \rho_r D_r + D_1'(h)h\mu + \frac{\sigma^2}{2} D_1''(h)h^2 - r D_1(h) = 0, & h \in (h_r, \infty), \end{cases} \quad (38)$$

Guessing the same functional form in Equation 28 and imposing the right-hand side boundary

condition in Equation 37, one can verify that $D_1(h)$ satisfies Equation 14, where $\nu_1 < 0 < \nu_2$ are given by the real roots of the characteristic equation:

$$r + \lambda + \eta = \nu\mu + \frac{\sigma^2}{2}\nu(\nu - 1). \quad (39)$$

Given these constants, we impose the left-hand boundary condition in Equation 37, together with the following value-matching and smooth-pasting conditions at h_r , and determine the unique tuple $(C_1, C_2, F_1) \in \mathbb{R}^3$ as the solution of the following linear system:

$$\begin{cases} \frac{\rho_r + \lambda}{r + \lambda + \eta} D_r + \frac{\eta\theta\alpha}{r + \lambda + \eta - \mu} h_d + \sum_{i=1}^2 C_i h_d^{\nu_i} - \alpha\theta h_d = 0, \\ \left(\frac{\rho_r + \lambda}{r + \lambda + \eta} - \frac{\rho_r}{r} \right) D_r + \frac{\eta\theta\alpha}{r + \lambda + \eta - \mu} h_r + \sum_{i=1}^2 C_i h_r^{\nu_i} - F_1 h_r^{\Psi_1} = 0, \\ \frac{\eta\theta\alpha}{r + \lambda + \eta - \mu} + \sum_{i=1}^2 \nu_i C_i h_r^{\nu_i - 1} - F_1 \Psi_1 h_r^{\Psi_1 - 1} = 0. \end{cases} \quad (40)$$

Uniqueness follows from the fact that the determinant of the linear system is strictly positive:

$$\Delta = h_r^\Psi \left[(\nu_2 - \Psi) h_d^{\nu_1} h_r^{\nu_2} + (\Psi - \nu_1) h_d^{\nu_2} h_r^{\nu_1} \right] > 0, \quad \forall h_r \in (h_d, \infty). \quad (41)$$

under the ordering

$$\nu_1 < \Psi < 0 < \nu_2, \quad (42)$$

The unique coefficients are given by:

$$C_1 = \frac{K_1(\nu_2 - \Psi) h_r^{\nu_2} + h_d^{\nu_2}(\Psi K_2 + B_1 h_r)}{h_d^{\nu_1} h_r^{\nu_2}(\nu_2 - \Psi) + h_d^{\nu_2} h_r^{\nu_1}(\Psi - \nu_1)} \cdot h_d^{-\nu_1}, \quad (43)$$

$$C_2 = \frac{-h_d^{\nu_1}(\Psi K_2 + B_1 h_r) + K_1(\Psi - \nu_1) h_r^{\nu_1}}{h_d^{\nu_1} h_r^{\nu_2}(\nu_2 - \Psi) + h_d^{\nu_2} h_r^{\nu_1}(\Psi - \nu_1)} \cdot h_d^{-\nu_2}, \quad (44)$$

$$F = \frac{-h_d^{\nu_1} h_r^{\nu_2} (B_1 h_r + \nu_2 K_2) + h_d^{\nu_2} h_r^{\nu_1} (B_1 h_r + \nu_1 K_2) + K_1 h_r^{\nu_1 + \nu_2} (\nu_2 - \nu_1)}{h_r^\Psi [h_d^{\nu_1} h_r^{\nu_2} (\nu_2 - \Psi) + h_d^{\nu_2} h_r^{\nu_1} (\Psi - \nu_1)]}, \quad (45)$$

where

$$K_1 = \alpha\theta h_d - \frac{\rho_r + \lambda}{r + \lambda + \eta} D_r - \frac{\eta\theta\alpha}{r + \lambda + \eta - \mu} h_d, \quad (46)$$

$$K_2 = \left(\frac{\rho_r}{r} - \frac{\rho_r + \lambda}{r + \lambda + \eta} \right) D_r - \frac{\eta\theta\alpha}{r + \lambda + \eta - \mu} h_r, \quad (47)$$

$$B_1 = \frac{\eta\theta\alpha}{r + \lambda + \eta - \mu}. \quad (48)$$

To verify Equation 42, let $x_-(a)$ and $x_+(a)$ denote the negative and positive roots of

$$\frac{\sigma^2}{2}x^2 + \left(\mu - \frac{\sigma^2}{2} \right) x - a = 0,$$

and apply Vieta's formulas to Equation 31 and Equation 32, which imply that $x_-(a)x_+(a) = -2a/\sigma^2$. Hence, $x_-(a)$ is strictly decreasing in a . Since $r + \lambda + \eta > r$, it follows that $\nu_1 = x_-(r + \lambda + \eta) < x_-(r) = \Psi$ and $\Psi < 0 < \nu_2$.

B.3 Proof of Proposition 3

Consistent with the discussion in Section 4.2, the value of long-term debt is given by

$$D_2(h) = \mathbb{E}_{\mathbb{P}} \left[\int_0^\tau e^{-rt} \rho_d D_d dt + e^{-r\tau} \min \{ \alpha (1 - \theta) H_\tau, D_d \} \middle| H_0 = h \right], \quad (49)$$

and must satisfy the following piece-wise ODE:

$$\begin{cases} \rho_d D_d + D'_2(h) h \mu + \frac{\sigma^2}{2} D''_2(h) h^2 + \eta \min \{ \alpha (1 - \theta) h, D_d \} - (r + \eta) D_2(h) = 0, & h \in (h_d, h_r), \\ \rho_d D_d + D'_2(h) h \mu + \frac{\sigma^2}{2} D''_2(h) h^2 - r D_2(h) = 0, & h \in (h_r, \infty), \end{cases} \quad (50)$$

with boundary conditions

$$\lim_{h \rightarrow h_d^+} D_2(h) = \min \{ D_d, h_d^+ (1 - \theta) \alpha \}, \text{ and } \lim_{h \rightarrow \infty} D_2(h) = \frac{\rho_d}{r} D_d. \quad (51)$$

Guessing a solution and verifying the same functional form as in [Equation 28](#), and imposing [Equation 51](#) together with the value-matching and smooth-pasting conditions

$$\lim_{h \rightarrow h_r^+} D_2(h) = \lim_{h \rightarrow h_r^-} D_2(h), \quad \lim_{h \rightarrow h_r^+} D_2'(h) = \lim_{h \rightarrow h_r^-} D_2'(h),$$

yields $\gamma_1 < 0 < \gamma_2$ and $\Psi_1 < 0$, as in [Equation 31](#), and leads to the following system of linear equations:

$$\begin{cases} \frac{\rho_d D_d}{r+\eta} + \frac{\eta\theta\alpha(1-\theta)}{r+\eta-\mu} h_d + G_1 h_d^{\gamma_1} + G_2 h_d^{\gamma_2} = \min\{\alpha(1-\theta)h_d, D_d\}, \\ \frac{\rho_d D_d}{r+\eta} + \frac{\eta\theta\alpha(1-\theta)}{r+\eta-\mu} h_r + G_1 h_r^{\gamma_1} + G_2 h_r^{\gamma_2} = \frac{\rho_d}{r} D_d + H_1 h_r^{\Psi_2}, \\ \frac{\eta\theta\alpha(1-\theta)}{r+\eta-\mu} + G_1 \gamma_1 h_r^{\gamma_1-1} + G_2 \gamma_2 h_r^{\gamma_2-1} = H_2 \Psi_1 h_r^{\Psi_1-1}. \end{cases} \quad (52)$$

which determines the coefficients $(G_1, G_2, H_1) \in \mathbb{R}^+$.

B.4 Proof of Proposition 4

Point 1 For each candidate threshold $h_r > h_d$, let $(C_1(h_r), C_2(h_r), F(h_r))$ denote the unique solution of the linear system derived in [Appendix B.2](#). Define

$$\Phi(h_r) := D(h_r; h_r) - D_r. \quad (53)$$

The system determining (C_1, C_2, F) is linear with coefficients that depend continuously on h_r , and has a non-singular coefficient matrix for all $h_r > h_d$. Hence $C_1(h_r)$, $C_2(h_r)$, and $F(h_r)$ are continuous in h_r , implying that Φ is continuous on (h_d, ∞) .

By construction,

$$\Phi(h_d) = D(h_d) - D_r = \alpha\theta h_d - D_r < 0, \quad (54)$$

where the inequality follows from the assumption $D_r > \alpha\theta h_d$.

Using the explicit representation of $F(h_r)$ in [Equation 45](#), we analyze the numerator and denominator separately. The denominator satisfies

$$\text{Den}(h_r) \sim h_d^{\nu_1} (\nu_2 - \Psi) h_r^{\nu_2 + \Psi}.$$

The numerator is dominated by its highest-order term,

$$\text{Num}(h_r) \sim -h_d^{\nu_1} B_1(1 - \nu_2) h_r^{\nu_2+1},$$

with $B_1 > 0$ by $\mu < r + \lambda + \eta$. Combining these expansions and multiplying by h_r^Ψ yields

$$F(h_r)h_r^\Psi \sim -\frac{B_1(\nu_2 - 1)}{\nu_2 - \Psi} h_r > 0, \quad (55)$$

since $\nu_2 > 1$ by $\mu < r + \lambda + \eta$ and $\Psi < 0$. Then, evaluating $D(h_r; h_r)$ at $h = h_r$ gives

$$D(h_r; h_r) = \frac{\rho_r}{r} D_r + F(h_r)h_r^\Psi \sim \frac{\rho_r}{r} D_r - \frac{B_1(\nu_2 - 1)}{\nu_2 - \Psi} h_r.$$

Hence,

$$\lim_{h_r \rightarrow \infty} D(h_r; h_r) = +\infty, \quad \text{and therefore} \quad \lim_{h_r \rightarrow \infty} \Phi(h_r) = +\infty. \quad (56)$$

Since Φ is continuous on (h_d, ∞) and satisfies [Equation 54](#) and [Equation 56](#), the Intermediate Value Theorem implies the existence of $h_r^* \in (h_d, \infty)$ such that

$$\Phi(h_r^*) = 0, \quad \text{and thus} \quad D(h_r^*; h_r^*) = D_r.$$

Given [Equation 14](#), the threshold is identified by the solution of the algebraic equation

$$D(h_r; h_r) = \frac{\rho_r}{r} D_r + F(h_r)h_r^\Psi = D_r, \quad (57)$$

as it appears in the main text.

Point 2 To verify that the repo rollover strategy associated with h_r^* is optimal for an individual creditor, it suffices to show that $\max\{D_1(h), D_r\} = D_1(h)$ for all $h > h_r^*$, and vice versa for all $h_d < h \leq h_r^*$. First, we show that $D_1(h) < D_r$ for all $h \in (h_d, h_r^*)$.

Suppose that there exists $h_0 < h_r^*$ such that $D_1(h_0) > D_r$. Then, since $D_1(h_d) < D_r$ and $D_1(h_r^*) = D_r$, continuity implies that D_1 must attain a local maximum at some point $h_0 \in (h_d, h_r^*)$ satisfying $D_1'(h_0) = 0$ and $D_1''(h_0) < 0$. Substituting these conditions in

Equation 36 and rearranging, we obtain

$$D_1(h_0) < \frac{(\rho_r + \lambda)D_r + \eta\theta\alpha h_0}{r + \lambda + \eta} < \frac{(\rho_r + \lambda)D_r + \eta\theta\alpha h_r^*}{r + \lambda + \eta} < \frac{(\rho_r + \lambda + \eta)D_r}{r + \lambda + \eta} < D_r,$$

which is a contradiction because $\rho_r > r$.

Next, suppose that $D_1(h)$ is not monotone on (h_r^*, ∞) . Then there exist points $h_r^* < h_1 < h_2$ such that h_1 is a local maximum and h_2 is a local minimum; that is, $D_1'(h_1) = D_1'(h_2) = 0$ and $D_1''(h_1) < 0 < D_1''(h_2)$. Substituting these conditions in Equation 36 yields

$$D_1(h_i) = \frac{(\rho_r + \lambda)D_r + \eta\theta\alpha h_i + \frac{\sigma^2}{2}h_i^2 D_1''(h_i)}{r + \lambda + \eta}, \quad i = 1, 2.$$

Since $h_1 < h_2$ and $D_1''(h_1) < 0 < D_1''(h_2)$, it follows that

$$D_1(h_1) < D_1(h_2),$$

which is a contraction.

B.5 Repo run probability

For a given region (h_d, h_r) , run withdrawals take place with intensity $\eta \mathbb{I}\{h_d < H_t < h_r\}$, where H_t satisfies Equation 8. Accordingly, conditional on the path of $(H_t)_{t \in [0,1]}$, the survival probability of the bank in 1 year is given by:

$$\mathbb{P}_{\mathbb{R}}(\tau_r > 1 \mid (H_t)_{0 \leq t \leq 1}) = \exp \left(-\eta \int_0^1 \mathbb{I}\{h_d < H_t < h_r\} dt \right),$$

where

$$\omega := \int_0^1 \mathbb{I}\{h_d < H_t < h_r\} dt,$$

is the occupation time of the repo withdrawal region. Then, the (exact) probability of a financial default conditional on $H_0 = h$ is

$$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1 \mid H_0 = h) = 1 - \mathbb{E}_{\mathbb{R}} \left[e^{-\eta\omega} \mid H_0 = h \right]. \quad (58)$$

Since the distribution of ω cannot be derived in closed form, we approximate the right-hand side of [Equation 58](#) as

$$\mathbb{E}_{\mathbb{R}} [e^{-\eta\omega} \mid H_0 = h] \approx \exp(-\eta \mathbb{E}_{\mathbb{R}}[\omega \mid H_0 = h]). \quad (59)$$

Using Fubini's theorem, the expected occupation time can be written as:

$$\mathbb{E}_{\mathbb{R}}[\omega \mid H_0 = h] = \int_0^1 \mathbb{P}_{\mathbb{R}}(h_d < H_t < h_r \mid H_0 = h) dt.$$

Then, since H_t is lognormally distributed, we can obtain:

$$\mathbb{P}_{\mathbb{R}}(h_d < H_t < h_r \mid H_0 = h) = \Phi(d_2(t, h)) - \Phi(d_1(t, h)),$$

where $\Phi(\cdot)$ is a cumulative normal distribution with

$$d_1(t; h) = \frac{\ln(h_d/h) - (\mu - \frac{1}{2}\sigma^2)t}{\sigma\sqrt{t}}, \quad d_2(t; h) = \frac{\ln(h_r/h) - (\mu - \frac{1}{2}\sigma^2)t}{\sigma\sqrt{t}}.$$

Combining these results yields

$$\mathbb{P}_{\mathbb{R}}(\tau_r \leq 1 \mid H_0 = h) \approx 1 - \exp\left(-\eta \int_0^1 [\Phi(d_2(t, h)) - \Phi(d_1(t, h))] dt\right). \quad (60)$$

To compute the integral, we adopt a standard trapezoid quadrature

$$\int_0^1 [\Phi(d_2(t, h)) - \Phi(d_1(t, h))] dt \approx \frac{1-\epsilon}{N} \left[\frac{1}{2}f(\epsilon) + \sum_{k=1}^{K-1} f(\epsilon + \frac{k}{N}(1-\epsilon)) + \frac{1}{2}f(1) \right], \quad (61)$$

where $f(s) = \Phi(d_2(s, h)) - \Phi(d_1(s, h))$. We use $K = 1,000$ and $\epsilon = 10^{-6}$.