The Decline of Too Big to Fail

EXTREMELY PRELIMINARY DRAFT

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Abstract

For globally systemically important banks (G-SIBs) with US headquarters, we find large post-Lehman reductions in market-implied probabilities of government bailout, along with big increases in debt financing costs for these banks after controlling for insolvency risk. The data are consistent with significant effectiveness for the official sector's post-Lehman G-SIB failure-resolution intentions, laws, and rules. G-SIB creditors now appear to expect to suffer much larger losses in the event that a G-SIB approaches insolvency. In this sense, we estimate a major decline of "too big to fail."

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1. Introduction

Crisis revelations of the costs of "too-big-to-fail" have lead to new legal methods, globally, for resolving the insolvencies of systemically important banks. Rather than bailing out these firms with government capital injections, insolvency losses are now supposed to be allocated to wholesale creditors. As a consequence, major credit rating agencies have substantially reduced or removed explicit "sovereign uplifts" to the ratings of the senior unsecured debt of the holding companies of U.S. globally systemically important banks (G-SIBs).

Many market participants believe, however, that these reforms have not eliminated the likelihood of government bailouts of these firms.[1] Our main objective is to estimate post-crisis declines in market-implied bailout probabilities, the associated increases in G-SIB bond yields, and the declines in G-SIB equity market values stemming from reductions in debt financing subsidies associated with bailout expectations.

We show that G-SIB balance sheet data and the market prices of debt and equity imply a dramatic and persistent post-crisis reduction in market-implied probabilities of government bailouts of U.S. G-SIB holding companies. We also report similar but smaller effects for domestically important non-G-SIB banks, or "D-SIBs."[2] Our sample period is 2002-2017. Our demarcation point for measuring a change in bailout probabilities is the bankruptcy of Lehman Brothers in September 2008. We refer to the prior period as "pre-Lehman" and the subsequent period as "post-Lehman." Many market participants were surprised that the U.S. government did not bail out Lehman.[3] We cannot disentangle how much of the post-Lehman reduction in investor bailout expectations is due to the effectiveness of new failure resolution methods, which have not yet been tried in practice, as opposed to a post-Lehman updating of beliefs about government bailout preferences.

Our results are based in part on a large-scale panel analysis of corporate credit spreads observed in the market for the credit default swaps (CDS) of nearly 800 public U.S. firms. Of our sample of firms, only large banks are assumed to have had a significant change in bailout probabilities. Our central

[1] See Government Accountability Office (2014).

[2] European regulators officially designate their domestically systematically important banks (D-SIBs). While there is no such official designation by U.S. regulators, we label as a "D-SIB" any publicly traded bank that is not a G-SIB and is required to undergo stress tests under the Comprehensive Capital Analysis and Review (CCAR) and the Dodd-Frank Act stress test (DFAST).

[3] See, for example, the New York Times article "Revisiting the Lehman Brothers Bailout That Never Was" by Stewart and Eavis (2018).

measure of the solvency of a firm is its "distance to default." Conceptually, the distance to default of a firm is the number of standard deviations of annual changes in its asset value by which the current asset value exceeds the insolvency level of assets. Distance to default is thus a risk-adjusted measure of a firm's capital buffer, and is a strong predictor of default.[4] Under idealized theoretical conditions, credit spreads are explained by distances to default and losses given default (LGD). The LGD of a debt claim is the risk-neutral expectation of the fraction of the claim lost at default.

For a given risk-neutral insolvency probability, credit spreads are essentially proportional to the risk-neutral probability of no bailout. For example, if the no-bailout probability of firm A is twice that of firm B then the LGD of firm A is twice that of firm B, all else equal. If the two firms have the same risk-neutral insolvency probabilities, then the credit spreads of firm A are twice those of firm B. We detect large post-Lehman changes in the risk-neutral (or "market-implied") probability of bank bailout based on changes in the observed relationship between credit spreads and distances to default. This change is far larger than that associated with the general post-Lehman increase in market premia for bearing corporate default risk. By including a large number of non-banks in our sample, we control for variation over time in corporate default risk premia, which is substantial (Berndt, Douglas, Duffie, and Ferguson, 2018). Rather than taking default risk premia for non-banks and banks to be the same, we rely only on the assumption that the average ratio of their default risk premia did not change with the post-Lehman change in bailout probabilities.

A key input to the measurement of a firm's distance to default is its equity market value. The equity market value of a G-SIB, however, is increased by bailout expectations through the associated value to shareholders of lower debt financing costs. This increases the distance to default. For example, if at the end of December 2017 one changes one's assumption of Citigroup's bailout probability from 0.8 to 0.5 while holding fixed its observed balance sheet, the fitted distance to default of Citigroup declines by about 0.5 standard deviations. This effect is measured using a structural dynamic model of debt and equity prices that extends Leland (1994a). At a modeled bailout, the government injects enough capital to return the balance sheet of the bank to a given "safe" condition. At any time before insolvency, the equilibrium prices of debt and equity reflect consistent expectations regarding the likelihood of bailout and the post-bailout capital structure of the bank. These post-bailout continuation values include the

[4] See Duffie (2011) for a summary of relevant research.

market values of subsidies associated with successive future potential bailouts. For instance, on average in the pre-Lehman period, we find that roughly two thirds of the market value of future bailout subsidies is associated with the next bailout, and the remaining one third of the subsidy value is associated with subsequent bailouts.

We face the following identification challenge. The impact on debt and equity prices of a downward shift in the assumed proportional distress cost to assets at default can be approximately offset by some common multiplicative upward shift in assumed pre-Lehman and post-Lehman bailout probabilities. Estimating the fractional distress loss of assets of a G-SIB holding company at default is extremely difficult. In essence, Lehman is the only relevant observation. Even after Lehman's default, estimating the consequent loss in its assets has been difficult.[5] So, our approach is not to provide point estimates of *both* a pre-Lehman bailout probability π_{pre} *and* a post-Lehman bailout probability π_{post}, but rather to estimate a schedule of pairs $(\pi_{\text{pre}}, \pi_{\text{post}})$ that are jointly consistent with the data. For example, when G-SIBs are assumed to have a post-Lehman bailout probability of $\pi_{\text{post}} = 0.2$, we estimate a pre-Lehman bailout probability π_{pre} of 0.58. Alternatively, for a post-Lehman bailout probability π_{post} of 0.3, our estimate of π_{pre} is 0.63. Schedules of estimated pairs of pre-Lehman and post-Lehman bailout probabilities are tabulated later in the paper. When allowing for heterogeneity across banks, we find substantial cross-sectional variation in bailout probabilities.

We find that D-SIBs have smaller post-Lehman declines in bailout probabilities than G-SIBs. This is natural, given that D-SIBs are by definition not as big as G-SIBs and thus less likely to be viewed by regulators and creditors as too big to fail. For example, for a post-Lehman D-SIB bailout probability of 0.20, the data imply a pre-Lehman D-SIB bailout probability of 0.4, much lower than the associated G-SIB pre-Lehman estimated bailout probability of 0.58.

Given our estimated post-Lehman reductions in bailout probabilities, we quantify the associated reductions in effective government subsidies provided to the shareholders of G-SIBs through lower debt financing costs. For example, we estimate that about 80% of the equity market value of G-SIBs, on average during the pre-Lehman period, can be ascribed to bailout-subsidized debt financing costs. This is based on a hypothetical reduction in the G-SIB bailout probability from the estimated pre-Lehman level of 0.58 to the estimated post-Lehman level of 0.2. At a fixed solvency buffer represented by a

[5] Kapur (2015) reveals the difficulty of this problem.

distance of default of 2 standard deviations, this reduction in bailout probability implies post-Lehman senior unsecured yield spreads that are roughly twice what they would have been had there been no post-Lehman decline in bailout probability.

The remainder of the paper is structured as follows. Section 2 reviews closely related prior research. Section 3 is a high-level preview of our empirical identification strategy. Section 4 reviews a basic theoretical model of the valuation of a bank's debt and equity that allows for bailout. Among other purposes, this model captures the effect of a given assumed bailout probability on the measured distance to default of a bank, which is a key input to our empirical estimation of bailout probabilities. Section 5 describes the data and presents descriptive statistics. Section 6 explains how we choose the model parameters that capture the influence of bailout on a big bank's measured distance to default. Section 7 presents our estimates of bailout probabilities and their implications for big-bank credit spreads and equity subsidies, among other effects. Section 8 discusses alternatives to our main hypothesis and then concludes. The appendices include additional details, both theoretical and empirical.

2. Prior Related Work

Of the large empirical literature on too-big-to-fail (TBTF) subsidies,[6] relatively few studies address the degree to which there has been a post-crisis decline in TBTF subsidies. None of these studies

[6] Years before the Great Recession, Stern and Feldman (2004) stressed the importance of the TBTF problem, arguing that a safety net provided by the government lowers creditors incentives to monitor and banks' incentive to act prudently. Mishkin (2006), however, argued that Stern and Feldman (2004) overstated the importance of the TBTF problem. Using international data, Mäkinen, Sarno, and Zinna (2018) find a risk premium associated with implicit government guarantees. They suggest that the risk premium is tied to sovereign risk, meaning guaranteed banks inherit guarantors risk. Gandhi, Lustig, and Plazzi (2016) also provide empirical evidence consistent with the idea that stock-market investors price in the implicit government guarantees that protect shareholders of the largest banks in developed countries. Minton, Stulz, and Taboada (2017), on the other hand, find no evidence that large banks are valued more highly than other firms. O'Hara and Shaw (1990) find positive wealth effects accruing to TBTF banks, with corresponding negative effects accruing to non-included banks. Kelly, Lustig, and Nieuwerburgh (2016) use options data to show that a collective government guarantee for the financial sector lowers index put prices far more than those of individual banks and explains the increase in the basket-index put spread observed during the Great Financial Crisis. Schweikhard and Tsesmelidakis (2012) investigate the impact of government guarantees on the pricing of default risk in credit and stock markets and, using a Merton-type credit model with exogenous default boundary, provide evidence of a structural break in the valuation of U.S. bank debt in the course of the 2007–2009 financial crisis, manifesting in a lowered default boundary, or, under the pre-crisis regime, in higher stock-implied credit spreads. Balasubramnian and Cyree (2011) claim that the TBTF discount on yield spreads is absent prior to the LTCM bailout. They find a paradigm shift in determinants of yield spreads after the LTCM bailout. Santos (2014) demonstrates the additional discount that bond investors offer the largest banks compared with the return they demand from the largest non-banks and non-financial corporations is consistent with the idea that investors perceive the largest U.S. banks to be too big to fail. The impact of subsidies on firms' borrowing cost has also been studied in sectors other than the banking industry (see, for example, Anginer and Warburton (2014) for the auto industry). Begenau and Stafford (2018) propose that the reliance of banks on high leverage, presumably in the supply of liquidity, appears to generate costs of financial distress that are not offset with other benefits.

estimate post-crisis changes in bailout probabilities.

Of the body of prior research on the post-crisis decline of TBTF, the closest point of comparison to our results is Atkeson, d'Avernas, Eisfeldt, and Weill (2018), who consider the extent to which TBTF affects the market-to-book ratios of banks, that is, the ratio of the market value of equity to the accounting value of equity. In principle, a post-crisis reduction in TBTF subsidies should lower market-to-book ratios. Indeed, the authors show that the equity-to-book ratio of publicly traded US banks was above two, on average, between 1996 and 2007, and declined to about one after the 2008 financial crisis.

Sarin and Summers (2016) and Chousakos and Gorton (2017) argue, however, that the post-Lehman drop in bank market-to-book ratios is due to a loss in bank franchise value or profitability. Like us, Atkeson, d'Avernas, Eisfeldt, and Weill (2018) find that a substantial reduction in bank equity market values is instead associated with the decline of TBTF. They estimate[7] that about 31% of their composite-bank market-to-book ratio was lost in the post-crisis period from a decline in government guarantees. This estimate is broadly consistent with our estimate of a 32% reduction in the market value of equity associated with the post-Lehman decline in bailout probabilities. (While these two estimated numbers are remarkably similar, the respective metrics are different.) To accomplish this, they construct a detailed dynamic model of the balance sheet and income statement of a single hypothetical composite U.S. bank, based on data for the aggregate U.S. banking sector, which consists of over 4,000 banks.[8] They do not distinguish systemically important banks from other banks.

Haldane (2010) uses a ratings-based approach. He estimates the reduction in TBTF subsidies associated with the post-Lehman reduction in sovereign uplifts of the credit ratings of systemically important banks. Roughly speaking, for a given bank, Haldane (2010) assumes that the savings in its wholesale debt financing rates associated with TBTF can be estimated as the difference in average corporate bond yields associated with ratings that include and do not include the sovereign uplifts, respectively. Thus, smaller post-Lehman sovereign ratings uplifts automatically implies smaller estimated TBTF debt subsidies.[9]

[7] Atkeson, d'Avernas, Eisfeldt, and Weill (2018) estimate that pre-crisis contribution of government guarantees to the market to book ratio was 0.91 and that the post-crisis contribution was about half of 1.19, for a reduction of about 31%.

[8] The number of U.S. banks is reported by the FDIC. To estimate the market value of equity of their modeled composite bank, Atkeson, d'Avernas, Eisfeldt, and Weill (2018) make the simplifying assumption that there are only two possible Markov states in each time period, and that the bank chooses to default in one of these, the crisis state.

[9] Ueda and Weder di Mauro (2013) provide estimates of the value of the subsidy to SIFIs in terms of the credit ratings.

Acharya, Anginer, and Warburton (2016) conduct an event study of the impact on G-SIB credit spreads of the passage of U.S. G-SIB failure resolution legislation, Title II of the Dodd-Frank Act. They find that there was no significant impact on G-SIB CDS rates within 60 days of the passage of Dodd-Frank. They also find that between 1990 and 2012 the bond credit spreads of the largest financial institutions are insensitive to risk, and that this is not the case for smaller financial institutions or for non-financial firms.

3. A High-Level Outline of Our Identification Strategy

At a very high level, our empirical strategy is to exploit the idea that a given corporate debt credit yield spread S can be approximated as the product of the annualized risk-neutral probability p of insolvency and the risk-neutral expected fractional loss ℓ in the event of insolvency. For a firm subject to bailout with risk-neutral probability π, the expected loss given insolvency is $\ell = (1-\pi)L$, where L is the risk-neutral expected loss given insolvency with no bailout. The simple relationship $S = p(1-\pi)L$ implies the linear model

$$\log \frac{S}{1-\pi} = \log p + \log L. \tag{1}$$

We know from the results of Berndt, Douglas, Duffie, and Ferguson (2018) that the majority of the empirical variation in $\log p$ is explained by measured distance to default, at least for a large sample of US public firms. The measured distance to default depends on the observed market value of equity, among other variables. The market value of equity of large banks, however reflects the implications of bailout. Increasing the bailout probability π increases the component of observed equity market value that can be ascribed to bailout subsidized debt financing costs. Increasing the assumed bailout probability π also affects the measured distance to default because this lowers the endogenous insolvency boundary level of assets. In the next section, we develop a theoretical model that captures both of these channels for the impact of bailout on a bank's measured distance to default. For the purposes of this high-level overview, we merely let $d_{it}(\pi_{it})$ denote the distance to default of firm i at date t corresponding to some assumed bailout probability π_{it}, given this firm's observed balance sheet at time t and other relevant

They report that a one-unit increase in government support for banks in advanced economies has an impact equivalent to 0.55 to 0.90 notches on the overall long-term credit rating at the end-2007. This effect increased to 0.80 to 1.23 notches by the end-2009. Rime (2005) also examines the possible effects of TBTF expectations on issuer ratings and find that proxies of the TBTF status of a bank have a significant, positive impact on bank issuer ratings.

data.

So, based on the conceptual framework (1), we estimate bailout probabilities by fitting a model of the form

$$\log \frac{S_{it}}{1-\pi_{it}} = \alpha + \beta \log d_{it}(\pi_{it}) + \phi_{K(i),t} + \epsilon_{it}, \tag{2}$$

where α and β are coefficients to be estimated, the term $\phi_{K(i),t}$ includes various fixed effects associated with the sector $K(i)$ of firm i and the date t, and ϵ_{it} is an unexplained residual. For parsimony, our fixed effects consist of *(i)* time fixed effects, *(ii)* sectoral fixed effects, and *(iii)* a sectoral fixed effect specific to big banks that is interacted with the time fixed effects. These fixed effects allow for variation across time and across sector in both default risk premia (which affect the relationship between credit spreads and distance to default), and for variation across sector in the expected loss L at insolvency given no-bailout.

For bailout probabilities, we take π_{it} to be zero if firm i is not a big bank. For a G-SIB bank i, we take $\pi_{it} = \pi^G_{\text{pre}}$ for all pre-Lehman dates and take $\pi_{it} = \pi^G_{\text{post}}$ for all post-Lehman dates, for two parameters, π^G_{pre} and π^G_{post} to be estimated. We treat D-SIBs similarly, with respective bailout probabilities π^D_{pre} and π^D_{post}.

Within the underlying conceptual framework $S = p(1-\pi)L$, it is challenging to separately identify L and π. For G-SIBs, there are almost no data bearing reliably and directly on L. With no reasonable ability to pin down L, it is impossible to identify the average level over time of the bailout probability π_{it} for big banks. For example, doubling L is observationally equivalent to scaling up $1-\pi_{it}$ across all dates by a factor of 2. We can, however, use the observable post-Lehman change in the relationship between credit spreads S and distance to default, caused by a regime shift in bailout expectations, to identify the *relative* change from $1-\pi^G_{\text{pre}}$ to $1-\pi^G_{\text{post}}$. Thus, as discussed in the introduction, we estimate a schedule of data-consistent pairs $(\pi^G_{\text{pre}}, \pi^G_{post})$. For example, this schedule includes the pair $(0.58, 0.2)$ and also the pair $(0.63, 0.3)$. These two pairs of bailout probabilities, among other pairs, fit the data equally well. Schedules of estimated pairs of pre-Lehman and post-Lehman bailout probabilities for G-SIBs and D-SIBs, respectively, are shown in Section 7.

The linear regression coefficients in (2) and estimates of data-consistent pairs of pre-Lehman and post-Lehman big-bank bailout probabilities are chosen for the best fit of (2). We allow for heteroskedasticity and correlation in the residuals in a manner detailed in Section 7. Our numerical search for the best fitting parameters makes iterative use of the explicit solution of the theoretical model presented in the next section, which captures the dependence of distance to default $d_{it}(\pi_{it})$ on bailout probability and on various observable balance-sheet variables.

4. Valuation of Bank Equity and Debt with Bailout Subsidies

This section presents a simple model of the valuation of a bank's debt and equity, capturing the effects of a given probability of government bailout at insolvency. The model captures the impact of bailout on distance to default, credit spreads, equity market value, and the component of equity market value associated with bailout subsidized debt.

We consider a bank whose assets in place, V_t, at any time t before default, satisfy the stochastic differential equation

$$dV_t \quad = \quad V_t(r-k)\,dt + V_t\sigma\,dZ_t, \tag{3}$$

where Z is a standard Brownian motion under some risk-neutral probability measure,[10] r is the risk-free interest rate, σ is the asset volatility, and k is the total cash revenue rate as a proportion of assets in place. At any default time τ, if the bank is liquidated in a bankruptcy process, distress costs cause the value of assets in place to drop from $V_{\tau-}$ to $V_\tau = \alpha V_{\tau-}$, for some recovery coefficient $\alpha \in (0,1)$.

Our most basic model of the bank has two layers of debt, deposits and bonds. Appendix B considers an extension with three layers of debt, deposits, senior bonds, and junior bonds. With data bearing separately on the pricing of junior and senior debt, it would be possible in principle to estimate the likelihood of a bail-in failure resolution, which focuses insolvency losses more heavily on junior debt. This is beyond the scope of our current study, which lumps bail-in together with other insolvency procedures that generate losses for unsecured wholesale debt claims.

Deposits are of constant total size D and pay interest dividends at some constant rate d. Deposits are guaranteed, at no cost to the bank, by the government. Appendix A.3 extends the model and

[10]We fix a probability space $(\Omega, \mathcal{F}, \mathbb{P})$ and a filtration $\{\mathcal{F}_t : t \geq 0\}$ of sub-σ-algebras of $\mathcal{F}$ satisfying the usual conditions. For details see, for example, Protter (2005). All of our probabilistic statements in this section are relative to a probability measure $\mathbb{Q}$, equivalent to $\mathbb{P}$, under which the market value at time t of a claim to any increasing adapted cumulative cash-flow process C is $E^{\mathbb{Q}}\left(\int_t^\infty e^{-r(u-t)}\,dC_u \mid \mathcal{F}_t\right)$, where r is the given short rate. The process Z is a standard Brownian motion with respect to the probability space $(\Omega, \mathcal{F}, \mathbb{Q})$ and filtration $\{\mathcal{F}_t : t \geq 0\}$. The probability measure $\mathbb{Q}$ is called a "risk-neutral" measure.

its explicit solution so as to accommodate FDIC deposit insurance premia and the additional FDIC assessments that were introduced after the financial crisis for the liabilities of "large and complex financial institutions." The effective level of the post-crisis FDIC assessment rates for each bank is difficult to determine and not directly observable. The post-crisis assessment rates are believed by some commenters (Whalen, 2011; Pozsar, 2016) to have ranged from 10 basis points, on average, when first introduced, then declining to around 5 basis points at the end of our sample period. For simplicity, we do not include the effects of FDIC insurance assessments in our empirical estimation.

Because of imperfect competition in the deposit market, deposit rates are in practice much lower than wholesale risk-free rates, and rise very sluggishly after risk-free rates rise (Driscoll and Judson, 2013; Drechsler, Savov, and Schnabl, 2017). In our empirical implementation of the model, this is reflected in our data inputs for d and r.

The remaining class of debt consists of bonds of constant total principle P, with maturities that are exponentially distributed.[11] That is, bonds mature at some aggregate proportional rate $m > 0$, so that the fraction of the original bond principle that remains outstanding at any time t is e^{-mt}. This implies that the average bond maturity is $1/m$. The bonds have some coupon rate of c per unit of principle, for a total coupon payment rate of cP on all outstanding bonds. When any existing bond matures at time t, the same principle amount of debt is issued at its current market value, which could be at a premium or discount to par depending on V_t. The newly issued bonds have the original coupon rate c. The original exponential maturity distribution is always maintained. Interest payments are tax deductible at the corporate tax rate κ. This is the model of Leland (1994a), except that we have two classes of debt, insured deposits and bonds, and that we allow for a government bailout at default.

The bank's current shareholders choose a stopping time τ at which they will no longer service the bank's debt. That is, at time τ the current equity owners default, and stop participating in any cash flows, permanently. This time τ is chosen to maximize the market value of their equity claim. Our solution concept is the equilibrium default timing model of Décamps and Villeneuve (2014),

[11] A constant exponential maturity structure can be achieved as follows, among other assumptions. There could be initially a continuum (non-atomic measure space) of different bonds with aggregate principle P. (The principle of each bond is "infinitesimal.") The maturity date of each bond is random and exponentially distributed with parameter m. The maturity dates are pairwise independent. The measurability conditions of Sun (2006) can be used to support an application of the exact law of large numbers, under which the cross-sectional distribution of maturity dates is equal to the same exponential distribution. Each time a bond matures, it pays the investor its principle and is replaced by issuing at market value a new bond of the same principle whose maturity is exponentially distributed with the same parameter m, again independently of all else.

by which debt is issued at each time at a competitive market price that is consistent with correct investor conjectures of the default-time policy τ. We focus on an equilibrium default time of the form $\tau = \inf\{t : V_t \leq V^*\}$, for some constant asset default boundary V^*. In equilibrium, the market value of the bank's equity converges to zero as t approaches τ.

At the default time τ, the bank does not necessarily go into an insolvency process, causing distress costs and lack of bond payment. The bank could instead be "bailed out" by the government. Bailout is not predictable[12] and occurs with a given risk-neutral probability π. That is, the conditional probability at any time t of bailout at the next default is always equal to the unconditional bailout probability π. Although the original equity owners default on their debt obligations at time τ, in the event of a bailout the government injects new capital, thus avoiding any distress costs to assets. The government becomes the new equity owner. The debt continues to be serviced by the bank as originally contracted.

This is roughly what happened[13] with many of the bailouts of large European banks, with the nationalizations of, or dominant majority government equity positions taken in, Royal Bank of Scotland, Northern Rock, KBC, Fortis, Dexia, ABN Amro, SNS Reeal, Hypo Real Estate Bank, Anglo Irish Bank, and Bank of Ireland. In practice, a government might instead partially nationalize a bank before the market value of its equity reaches zero, as with some other European bailouts (including those of Lloyds, Commerzbank, UBS, ING, Bankia, Alpha Bank, Eurobank, and Piraeus Bank) and with the U.S. Troubled Asset Relief Program (TARP). For simplicity, we avoid the modeling of partial nationalization.

Immediately after a bailout, the government may sell its equity stake on a competitive market and the bank continues to operate, following the same policy, until at least the next such default time, and so on. The government's bailout capital injection is, for simplicity, modeled as a purchase of some quantity $\widehat{V} - V^*$ of additional assets. The quantity of additional assets is precisely enough to bring the total market value of the bonds up to some stipulated value B. In our empirical implementation, B is the market value $P(c+m)/(r+s+m)$ associated with a representative "safe enough" yield spread s over the risk-free rate. The net government bailout subsidy is thus $\widehat{V} - V^* - H(\widehat{V})$, where $H(x)$ is

[12]The event of bankruptcy or bailout is revealed precisely at time τ. That is, we can define the commonly observed information filtration $\{\mathcal{F}_t : t \geq 0\}$ by letting $\mathcal{F}_t = \sigma(\{z_s : s \leq t\} \cup \{B_1, \dots, B_n\})$, where $B_1, B_2, \dots$ is a risk-neutrally independent sequence of Bernoulli trials corresponding to successive bailouts of the bank (one if bailout, zero otherwise), and B_n is the last such trial that has occurred by time t. The trials are revealed each time that V_t reaches V^*.

[13]See "What has happened to more than 30 bailed out banks," Reuters, August 21, 2015, at https://uk.reuters.com/article/europe-banks-bailouts/factbox-what-has-happened-to-more-than-30-bailed-out-european-banks-idUKL5N10W0XJ2015

the market value of equity for a bank with initial assets in place of x and with the original liability structure (D, d, P, c).

In the event of no bailout at a default time, the bank is permanently liquidated. At liquidation, the deposits are redeemed in full, using if necessary the government's deposit guarantee, and the bond creditors receive any remaining liquidation value of assets, pro rata by principal amount. That is, per unit of the face value of their debt claims, the depositors receive one unit of value and the bond holders receive $(\alpha V^* - D)^+/P$. Government default insurance pays $(D - \alpha V^*)^+$. This allows for the possibility that $\alpha V^* - D > P$, in which case the bonds recover more than par. Although this case can be ruled out by reasonable parameter restrictions, bond recoveries above par are possible in practice.

This simple model is time-homogeneous with Markov state variable V_t. The vector of primitive model parameters is

$$\Theta \quad = \quad (c, P, B, m, d, D, r, k, \sigma, \alpha, \kappa, \pi)\,.$$

We will only consider parameters for which there is non-trivial default risk for creditors, meaning that the recovery value $(\alpha V^* - D)^+$ of bonds in bankruptcy is less than the default-risk-free market value of the bonds, which is $P(c+m)/(r+m)$. Because we have an explicit solution for V^* in terms of primitive model parameters, this non-degeneracy condition is an explicit condition on these model parameters. The model can also be solved explicitly in the degenerate case, which we avoid only for simplicity of notation.

We now turn to the market valuation of various relevant contingent claims, and a calculation of the optimal default boundary V^* and the bailout recapitalized asset level $\widehat{V}$. The detailed calculations and explicit solutions are found in Appendix A. Here, we just provide an overview of the solution method.

At first taking the default and recapitalization boundaries V^* and $\widehat{V}$ as given, we compute the total market value of all cash flows available to the bank over the time period $[0, \infty)$, including the cash flows generated by the original assets in place, government tax shields, deposit insurance payments, and bailout capital injections, net of distress costs, at all future bailouts. We then equate this total value of net available cash flows to the total market value of all of the positions held by claimants against the same net cash flows. These claimants are the original equity owners, the original depositors, the original bond holders, and the government as a contingent equity claimant at all future bailouts. From this

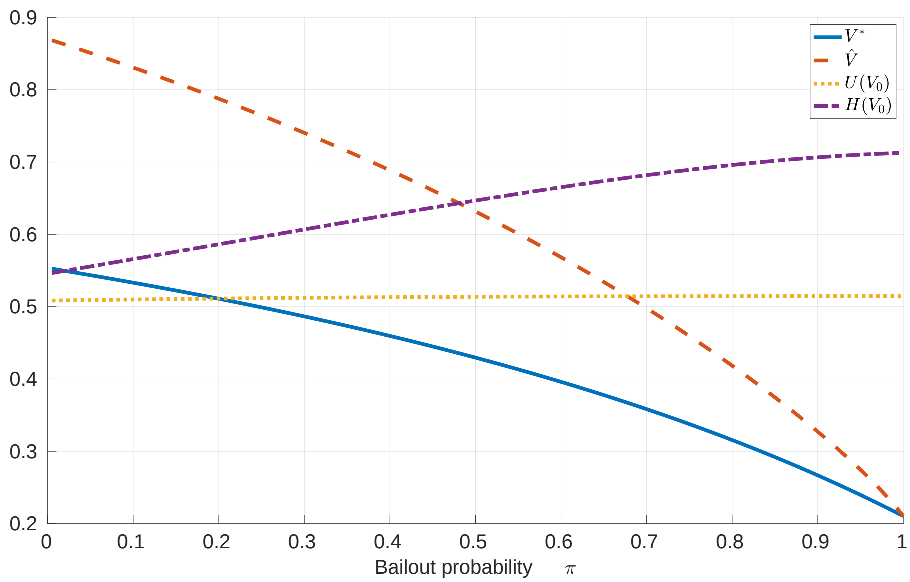

Figure 1: **Effect of bailout on theoretical claim valuations and endogenous asset boundaries.** The figure plots the explicit solutions of the model valuation $U(V_0)$ for bonds, $H(V_0)$ for equity, the asset default boundary V^*, and the bailout asset level $\hat{V}$, as functions of the bailout probability π. There are no deposits. The other underlying primitive model parameters are $V_0 = 1$, $\sigma = 0.1466$, $\alpha = 0.5$, $r = 0.0470$, $k = 0.0423$, $\kappa = 0.35$, $m = 0.4$, $P = 0.5$, $c = 0.06$, $B = P = 0.5$.

equation, taking V^* as given, we can explicitly deduce the market value of equity and the recapitalized asset level $\widehat{V}$, in terms of the default boundary V^*. Finally, using a "smooth pasting" condition for the market value of equity at the default boundary V^*, we solve explicitly for V^*.

For a simple illustrative set of parameters, Figure 1 plots the market values of bonds and equity, denoted $U(x)$ and $H(x)$ respectively, and the default and recapitalization asset boundaries, V^* and $\hat{V}$, showing how these variables depend on the assumed bailout probability π. Naturally, the market value of equity is increasing in π. As π goes up, the endogenous asset default boundary V^* goes down, reflecting the incentive of shareholders to extend the period of time over which they enjoy higher subsidies in their debt financing costs, caused by higher expectations of creditor bailout at any future default. The response of the bond market value $U(x)$ to the bailout probability is muted for the illustrated low average debt maturity $1/m$ of 2.5 years. The initial debt has low default risk, given that the initial assets in place are twice the debt principal. Most of the total value of bailout subsidies are picked up by initial equity owners, through the prospect of future and more heavily subsidized debt re-issuance prices that will be available if and when asset levels decline unexpectedly.

In prior work that incorporates government bailouts into dynamic models of endogenous default and bond pricing,[14] Chen, Glasserman, Nouri, and Pelger (2017) and Albul, Jaffee, and Tchistyi (2010) assume that the government simply guarantees (with probability one) the debt principal at default.[15] Our empirical objectives obviously require a model that allows variation in the bailout probability. Taking a "macro" approach, Gandhi, Lustig, and Plazzi (2016) assume that the government absorbs the aggregate losses of the entire financial sector, above an assumed cap, that could be caused by a "rare disaster."

5. Data and Descriptive Statistics

The focus of our analysis is systematically important banks. The Financial Stability Board (FSB), in consultation with the Basel Committee on Banking Supervision (BCBS) and national authorities, identifies "global systemically important banks" (G-SIBs). Our analysis is based on the list of G-SIBS published in November 2017.[16] Eight U.S. bank holding companies are identified as G-SIBs: Bank of New York Mellon, Bank of America, Citigroup, Goldman Sachs Group, JPMorgan Chase, Morgan Stanley, State Street and Wells Fargo.

As a separate category of big banks, we also treat those U.S. banks, beyond G-SIBS, that are sufficiently systemic to require stress tests under the Fed's Comprehensive Capital Analysis and Review (CCAR) and Dodd-Frank Act stress test (DFAST).[17] As of 2018, there are eighteen such firms: Ally Financial, American Express, BB&T, Capital One Financial Corp, CIT Group, Citizens Financial Group, Comerica, Discover Financial Services, Fifth Third Bancorp, Huntington Bancshares, KeyCorp, M&T Bank, Northern Trust, PNC Financial Services Group, Regions Financial, Suntrust Banks, U.S. Bancorp, and Zions Bancorporation, which we label "domestic systematically important banks" (D-SIBs).

In addition to G-SIBs and D-SIBs, we also collect data on all other public U.S. firms that can

[14]Other work applying variations and extensions of the Leland (1994b) framework to financial firms includes Auh and Sundaresan (2018), Diamond and He (2014), Harding, Liang, and Ross (2013), He and Xiong (2012), and Sundaresan and Wang (2014).

[15] Albul, Jaffee, and Tchistyi (2010) have perpetual debt, so, once the debt is issued at time zero, the government guarantee of debt has no effect on the default boundary or on the market valuation of equity. With Chen, Glasserman, Nouri, and Pelger (2017), on the other hand, there is issuance of new debt over time as in our model. Chen, Glasserman, Nouri, and Pelger (2017) and Albul, Jaffee, and Tchistyi (2010) allow for the risk of unexpected jumps in asset value. We have avoided jumps, merely, for simplicity.

[16]This list is based on the use of end-2016 data and on the updated assessment methodology published by the BCBS in July 2013 (Financial Stability Board, 2017; Bank of International Settlement, 2013).

[17]The FED report is available at www.federalreserve.gov/newsevents/pressreleases/bcreg20180201a.htm, and was accessed on June 25, 2018.

be matched unambiguously across the Markit CDS, Compustat and CRSP databases. Markit credit default swap (CDS) rate observations are "at-market," meaning that they represent bids or offers of the default-swap rates at which a buyer or seller of protection is proposing to enter into new default swap contracts without an up-front payment. The at-market CDS rate is in theory that for which the net market value of the contract is zero, assuming no upfront and zero dealer margins. The rates provided by Markit are composite CDS quotes, in that they are computed based on bid and ask quotes obtained from three or more anonymous CDS dealers.

We use CDS data based on a contractual definition of default known as "no restructuring." This contractual definition allows for CDS protection against losses in the event of a bankruptcy or a material failure by the obligor to make payments on its debt. Our CDS data apply to senior unsecured debt instruments, and are available for maturity horizons from one to ten years. For banks, our data cover CDS for holding-company bonds.

We only use CDS quotes for which Markit rates the data quality of the quotes as "BB" or higher. If a quote-quality rating is not available, we require a composite level of "CcyGrp," "DocAdj" or "Entity Tier." Although Markit CDS data go back as far as 2001, after cleaning the data we find few 2001 observations. We therefore restrict our sample to the period from 2002 to 2017. Lastly, we exclude firms with less than one year of CDS data.

Accounting data are available from quarterly Compustat files. Items downloaded include book assets, long-term debt, short-term debt, cash dividends, and interest expense.[18] Whenever quarterly data are missing, we use annual reports to augment the data. To avoid a forward-looking bias, on any given date we use the accounting data from the last available quarterly report. For large banks—meaning G-SIBs and D-SIBs—we use the Compustat Banks database as well as 10-Q and 10-K SEC disclosure filings to capture other data.[19]

For each large bank, we calculate a daily time series of notional-weighted average bond maturities using the maturity information provided in 10-K filings. For all other firms, we approximate by

[18]The total interest expense item XINTQ in Compustat includes the interest payments on short-term and long-term bonds and on deposits. To compute the total interest expense for bonds, we subtract Compustat item XINDCQ, which measures interest expense on deposits, from XINTQ.

[19]We have verified that the information contained in the 10-K filings of large banks closely matches that available through Compustat, especially for book assets, long-term debt, and deposits. We use Compustat as our main data source because of the consistency that it offers in terms of measuring short-term debt. The 10-K definition of short-term debt, by comparison, is inconsistent across banks and time.

treating the maturities of short-term and long-term bonds as though equal to one year and five years, respectively, then using the reported notional amounts of short-term and long-term debt to compute notional-weighted bond maturities.

Equity market data, including the number of shares outstanding and price per share, are obtained from CRSP.

The final sample contains 783 unique firms—as identified by their CRSP "permco" number—from ten industry sectors. The range of credit qualities of the firms in our data may be judged from Table 1, which categorizes firms according to their median Moody's rating over the sample period. The table shows, for each credit rating, the number of firms in our study with that median rating. As the table indicates, firms in the sample tend to be of medium credit quality. Across industry groups, ratings tend to be higher for financial, healthcare, and technology firms, and lower for telecommunication services firms.

Table 1: **Distribution of firms across sectors and by credit quality.** The table reports the distribution of firms across sectors and by median Moody's senior unsecured issuer ratings. The data include 783 public U.S. firms, over the period 2002–2017.

	Aaa	Aa	A	Baa	Ba	B	Caa	Ca-C	NR	All
Basic Materials	0	0	11	19	15	6	0	0	1	52
Consumer Goods	0	3	15	48	25	17	7	0	3	118
Consumer Services	0	2	12	45	21	24	12	2	5	123
Energy	1	1	6	38	12	15	1	1	3	78
Financials	1	10	29	59	8	4	0	0	8	119
Healthcare	1	1	10	21	10	6	1	0	7	57
Industrials	1	3	18	35	18	12	4	0	6	97
Technology	1	2	10	15	5	10	1	0	10	54
Telecommunications Services	0	0	5	7	4	5	3	0	2	26
Utilities	0	0	8	33	7	7	1	0	3	59
All	5	22	124	320	125	106	30	3	48	783

Appendix Figure D.1 shows time series of median five-year CDS, for G-SIBs, D-SIBs and all other firms. Median CDS rates are substantially higher following WorldCom's default in July 2002, during the 2008-09 financial crisis, and during the latter half of 2011, when there were severe concerns about European peripheral sovereign debt and faltering negotiations over the U.S. government debt ceiling. The increase in CDS rates in late 2011 was particularly pronounced for G-SIBs.

Table 2 reports summary statistics for certain key accounting variables for G-SIBs, D-SIBs and other firms. We consider two sub-periods: the "pre-Lehman" period from January 1, 2002 to the date of

Lehman Brothers bankruptcy on September 15, 2008, and the "post-Lehman" period from September 16, 2008 to December 31, 2017. As shown, large banks tend to have much higher accounting leverage than other firms, yet tend to have much lower market rates for CDS protection, especially before the financial crisis. Our leverage data include only conventional debt liabilities, and not the liabilities associated with over-the-counter derivatives, repurchase agreements, and other qualified financial contracts (QFCs). Several of the G-SIBs, Goldman Sachs, Morgan Stanley, J.P. Morgan, Citigroup, and Bank of America have substantial amounts of QFCs.

In our current empirical estimation, we have not captured the effects some significant mergers. During our sample period, J.P. Morgan acquired Bank One (2004) and Bear Stearns (2008), Bank of America acquired Merrill Lynch (2008), and Wells Fargo acquired Wachovia (2008) These mergers have relatively little impact on our post-Lehman data set, so should not have a large impact on our estimates of post-Lehman versus pre-Lehman bailout probabilities. Nevertheless, our failure to capture the effects of these mergers may somewhat bias our results, and add noise. In a future revision, we plan to build pro-forma merged datasets for these firms.[20]

Table 2: **Accounting measures** This table reports averages statistics for book assets (BVA), book debt (BVD), short-term debt (STD), long-term debt (LTD), deposits (Dpst), market capitalization (MC), cash dividends (CD), and interest expense (IE), in billions of U.S. dollars. Book leverage (Lev) is the ratio of the sum of book debt and deposits to book assets. (Unconventional liabilities, such as those associated with over-the-counter derivatives, are not included.) Sample-average five-year CDS rates are reported in basis points. Moody's ratings (Rtg) are coarse letter ratings. Notional-weighted average bond maturities (Mat) are shown in years. The pre-Lehman period (Pre) is January 1, 2002 to September 15, 2008. The post-Lehman period (Post) is September 16, 2008 to December 31, 2017.

	BVA	BVD	STD	LTD	Dpst	MC	CD	IE	Lev	CDS	Rtg	Mat	Firms
						G-SIBs							
Pre	859	339	225	113	290	109	3.64	11.43	0.73	38	Aa	2.58	8
Post	1,578	481	251	230	682	131	3.60	7.27	0.69	127	A	2.99	7
						D-SIBs							
Pre	120	36	12	24	45	29	0.71	1.14	0.67	72	A	3.66	12
Post	210	42	9	33	78	39	0.84	1.02	0.53	164	Baa	4.17	10
						Other firms							
Pre	28	13	6	7	–	18	0.35	0.14	0.48	141	Baa	3.30	745
Post	38	14	6	8	–	27	0.74	0.11	0.49	208	Baa	3.48	563

[20] Accounting data for debt liabilities and market values of equity can simply be added together. We can construct pro-forma estimates of CDS rates, as weighted averages of the pre-merger CDS rates of the constituent firms, weighting by principle amounts P of non-deposit debt.

6. Model Parameters

As explained in Section 3, we use a panel-regression approach to estimate bailout probabilities from debt credit spreads and estimated distances to default. The distance to default of a generic firm in our theoretical setting is defined by

$$d_t = \frac{\log(V_t) - \log(V^*)}{\sigma}, \tag{4}$$

where V_t is current assets in place, V^* is the endogenous asset default boundary, and σ is the volatility of assets. In order to calculate the distance to default corresponding to a given assumed bailout probability π, we need to select inputs for all of the remaining theoretical model parameters $(c, P, B, m, d, D, k, r, \sigma, \alpha, \kappa)$.

In practice, any model is mis-specified to some extent. We face a tension between the restrictive theoretical assumption that these primitive model parameters are treated by agents in the model as though constant over time and the practical need in our non-stationary setting to allow some of these parameters to vary across observation dates for the purpose of estimating distance to default and bailout probabilities. This section is a summary of how each of the model parameters other than π, which is a fitted variable, is chosen as an input to the theoretical model for the purpose of computing distance to default. Further details on parameter selection are provided in Appendix C.

The proportional asset recovery α at bankruptcy and the corporate tax rate κ are fixed for the entire panel study at 50% and of 35%, respectively, common to all firms. The resulting panel average[21] of the fitted-model bond recovery rate $(\alpha V^* - D)^+/P$ is 49%, quite close to Moody's Investor Services (2018) reported historical issuer-average ultimate recovery rate for senior unsecured bonds, for 1987 to 2017, of 47.9%. Moody's reported average recovery rate, over 1983-2017, as measured instead by the market prices of bonds immediately after default, was only 37.7%.

For bank i on date t, the quantity D_{it} of deposits and the average deposit interest rate d_{it} are obtained from accounting disclosure for the corresponding quarter. Of course, for non-banks, there are no deposits. The total principle P_{it} of non-deposit debt (both short-term and long-term) and the notional-weighted average bond maturity $1/m_{it}$ are also obtained, quarter by quarter, from public firm

[21] Across 11 industry sectors, the within-sector mean implied bond recovery ratios range from 0.88 to 1.12. The medians range from 0.90 to 1.04.

disclosure, in the manner described in the previous section. The risk-free rate r_{it} that we use as a theoretical model input for firm i on date t is the constant-maturity treasury (CMT) rate interpolated to the average maturity $1/m_{it}$ of the firm's non-deposit debt. [22]

For each firm, on each individual date, the modeled non-deposit debt coupon rate c_{it} is taken to be the sum of *(i)* the risk-free rate r_{it} and *(ii)* an estimate of the bond yield spread for that firm, that date. The estimated bond yield spread is the firm's at-market credit default swap (CDS) rate, as linearly interpolated from the data to the firm's average non-deposit debt maturity $1/m_{it}$, net of the CDS-bond basis.[23]

For large banks, the market value B_{it} of non-deposit debt immediately after a bailout is chosen to achieve a given post-bailout bond yield spread s, by setting $B_{it} = P_{it}(c_{it} + m_{it})/(r_{it} + s + m_{it})$. This is based on the idea that a government bailout would target a given level of creditworthiness of a large bank as judged in wholesale credit markets. In all cases, we take $s = 100$ basis points (bps), which is reasonable but still somewhat arbitrary. [In a robustness check to be added in a future revision, we will check the effect of varying s from 50 bps to 150 bps.]

The volatility parameter σ_{it} of a given firm i on a given date t is assumed to be constant across dates within the pre-Lehman period, and in the post-Lehman period to be constant at a different level. Within each of these two periods, σ_{it} is taken to be the annualized sample standard deviation of first differences of the logarithm of the model-implied assets V_{it} of firm i within that sub-period. The model-implied asset level V_{it} in turn depends on the assumed volatility σ_{it}, so this calibration involves an iterative search for σ_{it}.

The firm payout rate k_{it} is set at some multiple ρ_{it} of the risk free rate r_{it}. We impose an over-identifying restriction by assuming that ρ_{it} is constant within each of the pre-Lehman and post-Lehman periods. The constant level of ρ_{it} within a given period (whether pre-Lehman or post-Lehman) is chosen to match the within-period average of k_{it} to the within-period average ratio[24] of *(i)* the sum of cash dividends and interest expenses to *(ii)* the model-implied assets V_{it}. The model-implied asset level V_{it}

[22] We download the constant-maturity treasury rate from the website of Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/categories/115.

[23] If at time t firm i has investment-grade (IG) status, we subtract the Markit IG CDX basis. If the firm has high-yield (HY) status, we subtract the Markit HY CDX basis.

[24] That is, letting p denote a given sub-period, whether pre-Lehman or post-Lehman, ρ_{it} is constant across t in that sub-period, and set so that $\sum_{t \in p} \rho_{it} r_{it} - C_{it}/V_{it} = 0$, where C_{it} is the sum of cash dividends and interest expense for firm i on date t, and V_{it} is the firm's model-implied assets on date t.

depends in turn on ρ_{it}, so we conduct a joint iterative search for σ_{it} and ρ_{it} for consistency of the resulting time series of V_{it} with our fitting equations for σ_{it} and ρ_{it}. Further details are provided in Appendix C.

7. Model Estimation and Empirical Results

For any given assumed bailout probability π, for each firm i and date t, the structural model associated with the parameters described in Section 6 has an associated distance to default of

$$d_{it}(\pi) = \frac{\log V_{it}(\pi) - \log V^*_{it}(\pi)}{\sigma_{it}(\pi)}, \tag{5}$$

where we show the dependence of the model-implied asset level $V_{it}(\pi)$, asset insolvency boundary $V^*_{it}(\pi)$, and asset volatility $\sigma_{it}(\pi)$ on the assumed bailout probability π.

Following the strategy previewed in Section 3, we now describe more precisely our estimation of pre-Lehman bailout probabilities, π^G_{pre} for G-SIBs and π^D_{pre} for D-SIBs, for various assumed values of the corresponding post-Lehman bailout probabilities π^G_{post} and π^D_{post}.

Our basic empirical model is

$$\begin{aligned} \log \frac{S_{it}}{1-\pi_{it}} \quad = \quad & \alpha + \beta\, d_{it}(\pi_{it}) + \sum_{\text{sector } j} \delta_j\, D_j(i) + \sum_{\text{month } m} \delta_m\, D_m(t) + \sum_{\text{month } m} \delta^G_m\, D_m(t)\, D^G(i) \\ & + \sum_{\text{month } m} \delta^D_m\, D_m(t)\, D^D(i) + \epsilon_{it}, \end{aligned} \tag{6}$$

where S_{it} is the 5-year CDS rate of firm i on date t;

$$C_L = (\alpha, \beta, \{\delta_j : j \in \text{sectors}\}, \{(\delta_m, \delta^G_m, \delta^D_m) : m \in \text{months}\})$$

are the linear-model coefficients to be estimated; $D_j(i)$ is the indicator (0 or 1) for whether firm i is in a non-bank sector j; $D_m(t)$ indicates whether date t is in month m; $D^G(i)$ indicates whether firm i is a G-SIB; $D^D(i)$ indicates whether firm i is a D-SIB; and ϵ_{it} is an uncertain residual.

We take π_{it} to be zero if firm i is not a large bank. If firm i is a G-SIB, we take π_{it} to be π^G_{pre} for any pre-Lehman date t and π^G_{post} for any post-Lehman date t. Likewise, if firm i is a D-SIB, we take π_{it} to be π^D_{pre} for any pre-Lehman date t and π^D_{post} for any post-Lehman date t. Holding π^G_{post} and π^D_{post}

fixed as model parameters, we search for $\pi^G_{\rm pre}$ and $\pi^D_{\rm pre}$ with the property that the fitted version of (6) satisfies

$$\overline{\delta}^G_{\rm post} - \overline{\delta}^G_{\rm pre} \quad = \quad \overline{\delta}^D_{\rm post} - \overline{\delta}^D_{\rm pre} = 0, \tag{7}$$

where $\overline{\delta}^G_{\rm post}$ denotes the average across months in the post-Lehman period of the coefficient δ^G_m, and likewise for $\overline{\delta}^G_{\rm pre}$, $\overline{\delta}^D_{\rm post}$, and $\overline{\delta}^D_{\rm pre}$. Our model thus allows for temporal variation in default risk premia over months, and allows this variation to be different across G-SIBs, D-SIBs, and the non-bank sectors. However, (7) forces the degree to which default risk premia for G-SIBs differ proportionately from default risk premia in the non-bank sector to be the same on average in the pre-Lehman and as in the post-Lehman period, and likewise for D-SIBs. This condition is achieved by choice of the bailout probabilities $\pi^G_{\rm pre}$ and $\pi^D_{\rm pre}$.

For any given bailout probability parameters, we estimate the coefficients C_L of the linear model (6) as a standard panel regression. Figure 2 shows the resulting estimates for $\overline{\delta}^G_{\rm post} - \overline{\delta}^G_{\rm pre}$ and $\overline{\delta}^D_{\rm post} - \overline{\delta}^D_{\rm pre}$, as a function of various pre-Lehman bailout probabilities $\pi^G_{\rm pre}$ and $\pi^D_{\rm pre}$, for the special case in which the post-Lehman bailout probabilities for large banks are set to 0.2. As shown, the identifying constraints (7) are satisfied for $\pi^G_{\rm pre} = 0.58$ and $\pi^D_{\rm pre} = 0.40$. Alternatively, when the post-Lehman bailout probability is set to zero, the identifying constraints are satisfied for $\pi^G_{\rm pre} = 0.48$ and $\pi^D_{\rm pre} = 0.26$.

The resulting coefficient estimates are equivalent to those obtained when estimating all of the parameters $(C_L, \pi^G_{\rm pre}, \pi^D_{\rm pre})$ of the non-linear model (6), subject to (7), by non-linear least squares. All of the coefficient estimates and standard errors are reported in Appendix E. The root mean squared error (RMSE) for the fitted relationship is xx. While the CDS data are noisy in this sense, the relationship between the log CDS rate and the distance to default is highly significant. Variation in distance to default, sector and month fixed effects explain a sizable fraction—an R^2 of about zz%—of variation in log CDS rates. [These statistics should be updated to the latest fit. A table of estimated coefficients should be added to Appendix E.]

The solid blue line plotted in Figure 3 shows the fitted credit spread (5-year CDS rate) for G-SIB holding company senior unsecured bonds at a distance to default of 2.0. As shown, the cost of debt financing for G-SIBs at this fixed level of insolvency risk is on average much higher after the crisis. The dashed red line in Figure 3 indicates that some of this post-Lehman increase in debt financing costs, at

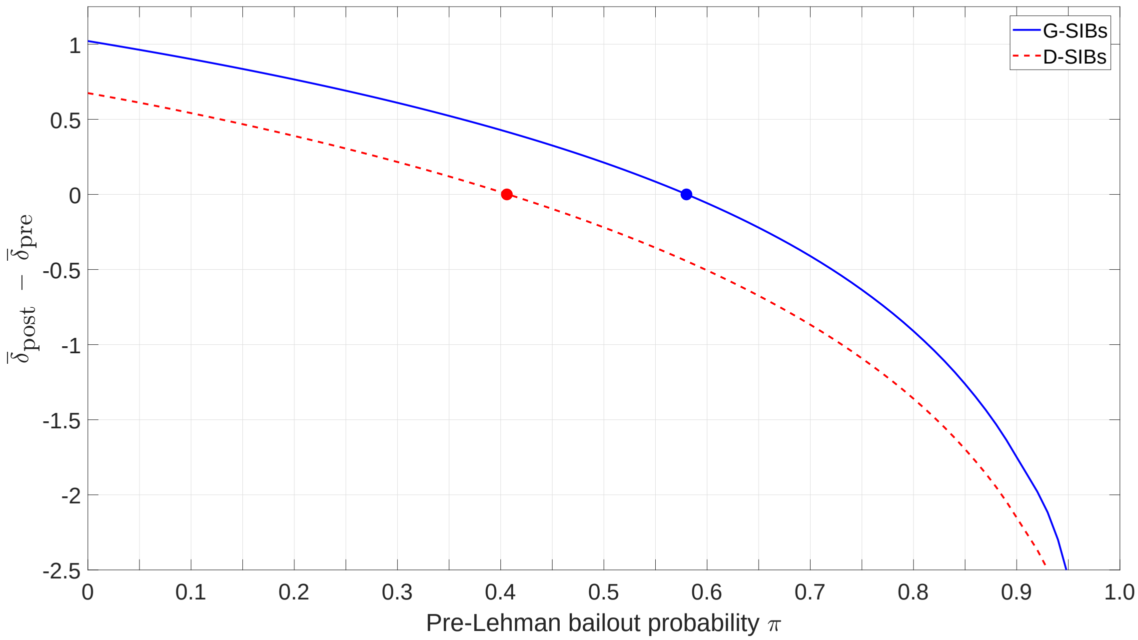

Figure 2: **Average post-Lehman change in big-bank time fixed effects.** This figure shows the estimates for $\overline{\delta}^G_{\text{post}} - \overline{\delta}^G_{\text{pre}}$ and $\overline{\delta}^D_{\text{post}} - \overline{\delta}^D_{\text{pre}}$ in the panel regression (6), as a function of the pre-Lehman bailout probability π^G_{pre}. The post-Lehman bail-out probabilities for large banks are set to 0.2. As shown, the identification condition (7) implies pre-Lehman bailout probability estimates of $\pi^G_{\text{pre}} = 0.58$ and $\pi^D_{\text{pre}} = 0.40$.

a fixed distance to default, is caused by a general post-Lehman increase in market default risk premia. That is, the red line is the fitted G-SIB credit spread for the counterfactual case in which bailout probabilities did not go down after the crisis. The remainder of the post-Lehman increase in big-bank debt financing costs, the difference between the blue and red lines, reflects the impact of a substantial post-Lehman drop in the fitted bailout probability. As shown in the figure, at a fixed insolvency risk, post-crisis credit spreads were roughly double what they would have been had pre-Lehman bailout probabilities been maintained in the post-crisis period.

Taylor and WIlliams (2009) point out that there was actually a significant increase in big-bank credit spreads about a year *before* the failure of Lehman. Their metric for big-bank credit spreads is the spread between 3-month LIBOR and the 3-month overnight index swap (OIS) swap rate, a proxy for close-to-risk-free borrowing rates. In August 2007, this 3-month credit spread for large banks rose from about 20 basis points to about 80 basis points, most likely on news about heightened default risks in the U.S. residential mortgage market. In the context of our model and its motivating hypothesis, this pre-Lehman elevation in big-bank credit spreads can most easily be viewed as an increase in the insolvency probabilities of big banks, while holding bailout expectations at their high pre-Lehman levels. For example, at a risk-neutral bailout probability π of 0.6 and a loss in the event of insolvency and no bailout of $L = 0.5$, the risk-neutral expected loss given default is $(1 - \pi)L = 0.2$. An increase in credit spreads of 60 basis points can then be interpreted as an increase in the risk-neutral annualized default probability of big banks in August 2007 of about 300 basis points. Berndt, Douglas, Duffie, and Ferguson (2018) estimate that annualized risk-neutral default probabilities in mid-200 were roughly double actual default probabilities, for firms with 5-year CDS rates near those of the largest US banks at that time. At this ratio, a 3% increase in risk-neutral default probability translates into an increase in the annualized actual default probability of big banks of roughly 1.5%, which seems a plausible investor reaction to the first hints of a major mortgage crisis. Big-bank default risk is highly systematic, so 2-to-1 probably understates the ratio of risk-neutral default probabilities to actual probabilities for big banks. This numerical example is not intended to be quantitatively precise, but rather to shed light on whether the August 2007 run-up in credit spreads could reasonably be related to changes in insolvency risk rather than changes in bailout expectations. We are not aware of any discussion in 2007 of changes in the perceived implicit support by the government of big banks. Major rating agencies maintained large sovereign uplifts in their credit ratings of big banks until after the failure of Lehman.

Table 3 shows, for several fitted pairs of pre-Lehman and post-Lehman bailout probabilities, the average across G-SIBs of the decomposition of the market values of total future bank cash flows into various components, as fractions of the market value of equity. As fitted, with an increase in bailout probability, the estimated level of total assets in place is lower, the default threshold is lower, and the market value of debt is higher. Appendix Table D.1 reports similar results for D-SIBs. Appendix Tables D.2 and D.3 report these value components as fractions of the market value of total future firm cash flows.

Irrespective of the assumed post-Lehman bailout probability, the market value y_3 of all future government subsidies is about 86% of the value of market equity. The market value of the next bailout subsidy alone, $U_r(x)\pi(\widehat{V} - V^*)$, is about 59% of the market value of equity, leaving about 27% as the market value of subsidies at subsequent bailouts. These subsidies are benefits to both creditors and to equity shareholders. However, at the issuance of the debt, the creditors pay for the value of these

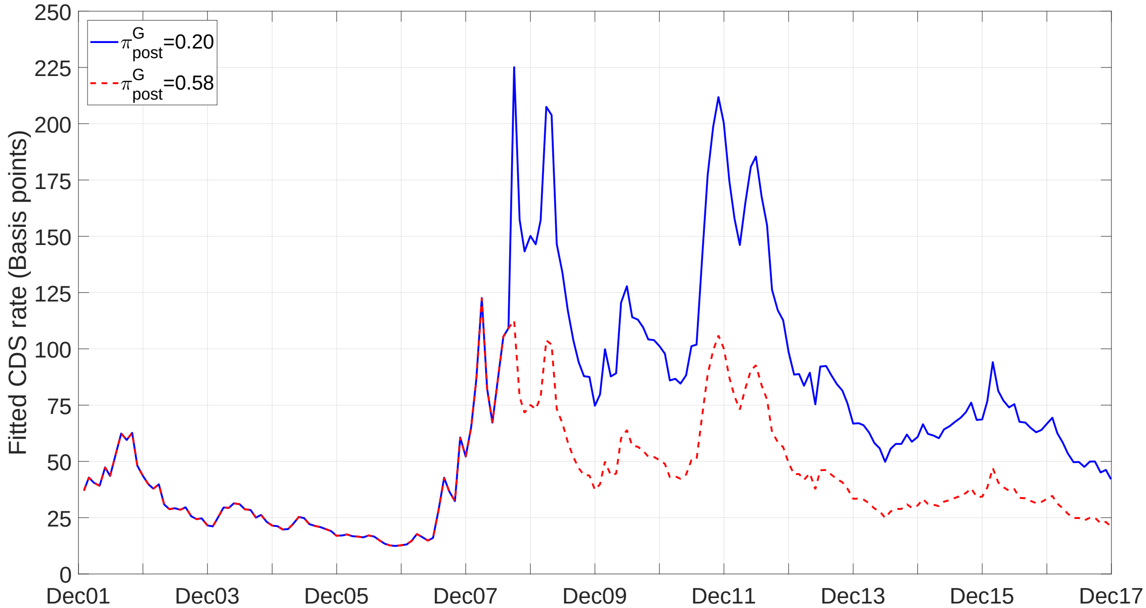

Figure 3: **Fitted CDS rates.** This figure shows fitted credit spreads (5-year CDS rates) for G-SIBs at a distance to default of two standard deviations. The solid blue line is based on the fitted pre-Lehman bailout probability of $\pi^G_{\text{pre}} = 0.58$, and an assumed post-Lehman bail-out probability $\pi^G_{\text{post}} = 0.2$. The red line is based on the counterfactual assumption that there is no post-Lehman change in bailout probability, taking $\pi^G_{\text{post}} = 0.58$.

Table 3: **Firm value components of G-SIBs, scaled by market equity** This table reports on the components of total net cash flows, for the average G-SIB during the pre-Lehman period. The components are reported as fractions of market equity. The total market value of all net cash flows available to the firm's current claimants is $Y = V_0 - y_1 + y_2 + y_3 + y_4 = v_1 + v_2 + v_3 + H$, where V_0 is the current level of assets in place, y_1 is the market value of all future distress costs, y_2 is the market value of all future tax shields, y_3 is the market value of all future cash flows injected by the government, y_4 is the liquidation deposit guarantee from the government, v_1 is the total value of the claims of all current depositors, v_2 is the market value of all claims by current bondholders, and v_3 is the government's claim in return for all of its future successive bailout injections. Here, H and P are the observed market equity and notional of bonds, V^* is the default threshold, and $\widehat{V} - V^*$ is the government's capital injection at default in the event of a bailout. The bailout recapitalization achieves a desired credit yield spread $s = 100$ basis points by taking $B = P(c + m)/(r + s + m)$.

π_{post}	π_{pre}	V_0/H	y_1/H	y_2/H	y_3/H	y_4/H	v_1/H	v_2/H	v_3/H	P/H	V^*/H	$\widehat{V}/H$
					pre-Lehman bailout probability is fitted							
0.30	0.63	4.809	0.702	1.100	1.618	0.462	1.909	2.919	1.459	3.104	3.482	5.905
0.20	0.58	4.995	0.802	1.038	1.595	0.481	1.943	2.878	1.486	3.104	3.674	6.376
0.10	0.53	5.172	0.902	0.980	1.556	0.494	1.975	2.836	1.490	3.104	3.853	6.835
0.00	0.48	5.342	1.002	0.924	1.501	0.504	2.007	2.793	1.469	3.104	4.023	7.281
					Bailout probabilities are artificially set to zero							
0.00	0.00	6.795	2.073	0.438	0.000	0.487	2.301	2.346	0.000	3.104	5.473	11.269

subsidies in the form of higher bond prices (lower yield spreads), to the benefit of shareholders. In a subsequent draft of this paper, we will report the fraction of the current market value of equity that can be ascribed to these subsidized financing costs.

8. Discussion and Concluding Remarks

As we have shown, high pre-Lehman bailout probabilities for big banks imply large subsidies of their debt financing costs. In order to maximize the market value of equity, these large banks would therefore have grown large balance sheets. Indeed, Figure 4 shows the rapid pre-Lehman growth of total assets of nine systemically important U.S. financial institutions, both banks and investment banks. After the crisis, we find that the reduced the bailout prospects of big banks raised their cost of debt financing by roughly one half, at a given level of solvency. This in turn reduced the incentives of these firms to grow large balance sheets. As shown in Figure 4, post-Lehman asset growth is much more muted. Asset growth was also discouraged after the crisis by large increases in regulatory capital requirements, because, from the viewpoint of legacy equity shareholders, equity is a more costly source of financing than debt.

Sarin and Summers (2016) suggest that the high credit spreads of large US banks that prevailed in 2015 reflect high levels of default risk at that time, and that these firms were then about as likely to default as they were before the crisis. Our analysis suggests, instead, that high big-bank credit spreads in 2015, relative to pre-crisis years, are due to reduced bailout expectations. Buttressing our interpretation of the data, Figure 5 shows significant improvements by 2015 in the asset-weighted average solvency ratios of the largest U.S. financial institutions, the same firms whose assets are depicted in Figure 4. We define the solvency ratio of a firm to be the firm's accounting tangible common equity divided by the estimated standard deviation of the annual change of its asset value. The improved solvency of large banks is due to significantly higher regulatory bank capital requirements, especially for G-SIBs. Rosengren (2014), Carney (2014), and Tucker (2014) describe the very large increases in capital buffers of the largest banks that were induced by post-crisis reform of bank capital regulations. In summary, the credit spreads of big banks were much higher after the crisis than before *despite* major increases in their capital buffers, and were apparently due to increased expected losses to creditors in the event of insolvency, rather than by high probabilities of insolvency. Our primary hypothesis that the post-crisis increase in expected insolvency losses are the result of a decline of "too-big-to-fail," that is, lower reliance by big-bank creditors on the prospect of a government bailout.

An alternative, behavioral, explanation for high post-crisis big-bank credit spreads is that, before the crisis, big-bank creditors had little awareness that these banks could actually fail. The idea that

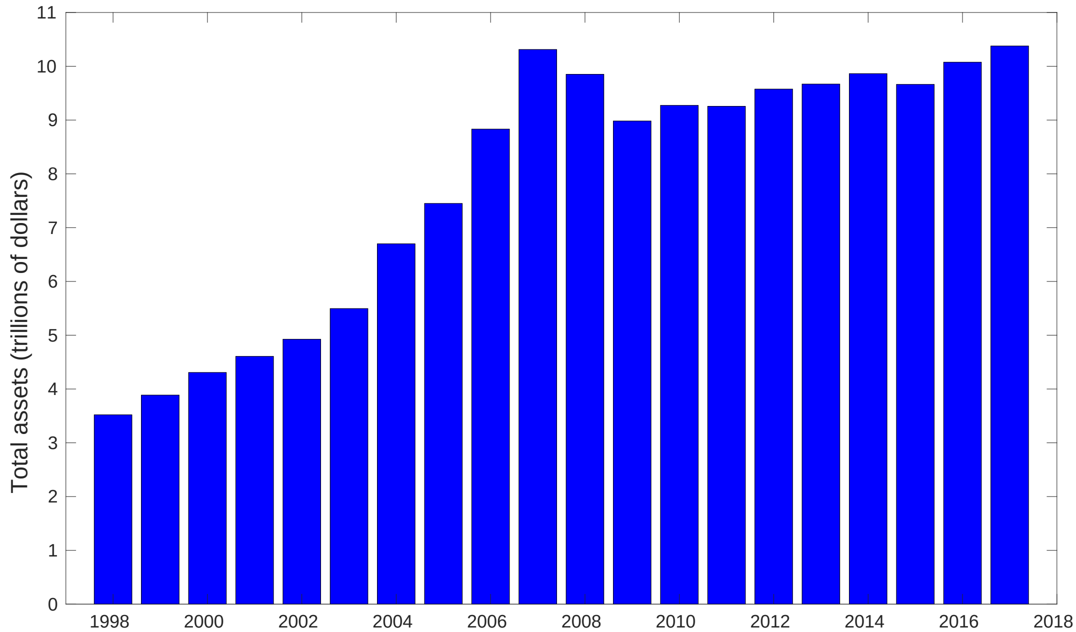

Figure 4: **The total assets of nine systemically important financial firms.** The total assets of the nine largest banks and investment banks, J.P. Morgan, Bank of America, Citibank, Wells Fargo, Goldman Sachs, Lehman Brothers, Merrill Lynch, and Bear Stearns. Source: 10K filings.

market participants and regulators placed unduly low weight on the likelihood of a financial crisis is supported by Gennaioli and Shleifer (2018). By this line of reasoning, once Lehman failed and several other big banks had close calls, creditors could have became much more aware of risks of failure that were already elevated well before the crisis, but had been badly under-estimated. This would have caused wholesale bank credit spreads to remain elevated after the crisis. This story does not rely on changes in the likelihood of bailout, but rather on changes in the perceived likelihood of insolvency. The fact that post-crisis solvency buffers eventually got much higher than their pre-Lehman levels implies that the updating of insolvency probabilities after the crisis cannot reasonably have been based on a rational updating of beliefs based on new information.

If this alternative story applies, then the fact that big-bank credit spreads have remained high relative to their pre-Lehman levels would imply that the crisis-induced increase in the perception of bank failure risk would need to have persisted for some years after the crisis. Historically, however, we are not aware of previous financial crises in which a large crisis-induced jump in wholesale big-bank credit spreads persisted well beyond the end of the crisis. For example, Gorton and Tallman

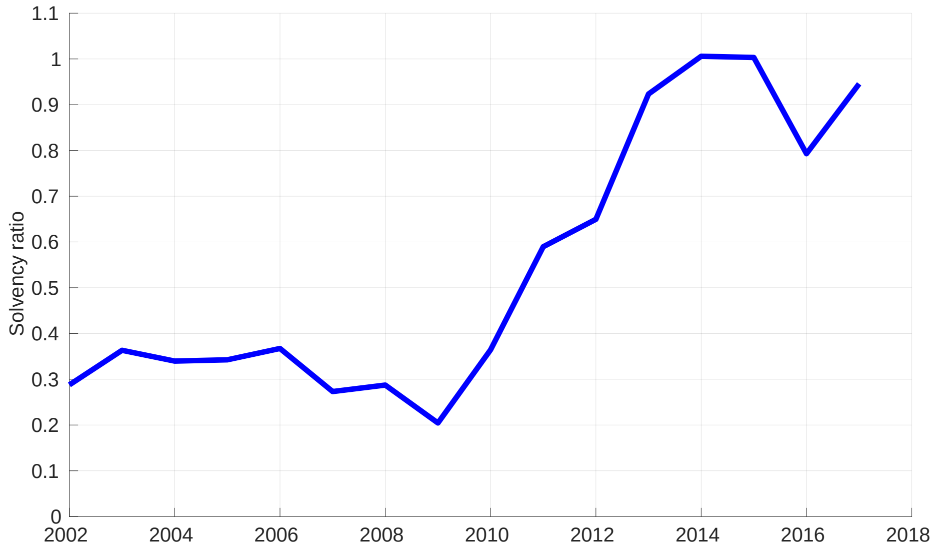

Figure 5: **Solvency ratios of the largest U.S. banks.** Tangible equity divided by an estimate of the standard deviation of the annual change in asset value. Asset-weighted average of J.P. Morgan, Bank of America, Citibank, Wells Fargo, Goldman Sachs, Lehman Brothers, Merrill Lynch, and Bear Stearns. Tangible equity date are obtained from 10K filings.

(2018) use the "currency premium" as a gauge of wholesale bank (Clearinghouse) paper, around 19th century banking crises. Regarding the banking panic of 1893, for example, they write: "As gold inflows helped to restore reserve levels following suspension of convertibility on August 3, reports of redeposit of funds in New York Clearing House banks (presumably by interior correspondents) all contributed to an improvement to the financial setting. The key indicators for the banking system—the reserve deficit and the currency premium—become noticeably benign in newspaper articles. By August 31, the currency premium was less than one percent (0.625% in New York Tribune page 3, column 1). We find evidence from both the stock and bond markets that is consistent with the hypothesis." This quote and the data analysis supporting it, shown in Figures 7 and 8 of Gorton and Tallman (2018), suggest that credit spreads jumped up during the 1893 crisis and then quickly went back down again within weeks after the panic.

In the setting of our research, were it not for a post-Lehman drop in the creditor-perceived probability π of a government bailout, we would have expected big-bank wholesale credit spreads to go back down (at a given level of solvency) with a general improvement in the economy and bank solvency. That is not what we find.

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A. Model Solution

This appendix provides explicit solutions for the basic model of valuation of bank debt and equity claims, including the asset default boundary V^*.

The conditional Laplace transform of the default time $\tau = \inf\{t : V_t \leq V^*\}$ evaluated at any positive constant θ is

$$U_\theta(V_t) \quad = \quad E^{\mathbb{Q}}\left(e^{-\theta(\tau-t)} \middle| V_t\right) = \left(\frac{V_t}{V^*}\right)^{-\Gamma(\theta)}, \tag{A.1}$$

where

$$\Gamma(\theta) = \frac{r - k - \sigma^2/2 + \sqrt{(r-k-\sigma^2/2)^2 + 2\theta\sigma^2}}{\sigma^2}.$$

In particular, the market value at any time $t < \tau$ of receiving one unit of account at the default time τ is $U_r(V_0)$.

A.1 Solution for the values of bank contingent claims, given the default boundary

When the current level of assets in place is x, we obtain the following market values of various respective contingent claims, taking V^* as given. First, the market value of the claim to all cash flows associated with a zero-debt version of the bank is

$$y_0(x) \quad = \quad x.$$

The market value of all future distress costs, including those associated with potential subsequent defaults, is

$$y_1(x) \quad = \quad U_r(x)\left[(1-\pi)\,(1-\alpha)V^* + \pi\, y_1(\widehat{V})\right], \tag{A.2}$$

where, solving for the special case of $x = \widehat{V}$, we have

$$y_1(\widehat{V}) = \frac{U_r(\widehat{V})(1-\pi)\,(1-\alpha)V^*}{1 - \pi U_r(\widehat{V})}.$$

The market value of all future tax shields, making the most basic tax assumptions of Leland (1994a), is

$$y_2(x) \quad = \quad \kappa \frac{cP + dD}{r} (1 - U_r(x)) + \pi\, U_r(x) y_2(\widehat{V}), \tag{A.3}$$

where

$$y_2(\widehat{V}) = \frac{\kappa \frac{cP+dD}{r}(1 - U_r(\widehat{V}))}{1 - \pi U_r(\widehat{V})}.$$

The market value of all future bailout cash flows injected by the government (gross of the government's equity claims) is

$$y_3(x) \quad = \quad U_r(x)\, \pi \left[\widehat{V} - V^* + y_3(\widehat{V})\right], \tag{A.4}$$

where

$$y_3(\widehat{V}) = \frac{\pi\, U_r(\widehat{V})\, (\widehat{V} - V^*)}{1 - \pi U_r(\widehat{V})}.$$

The liquidation deposit guarantee requires cash flows from the government with a current market value of

$$y_4(x) \quad = \quad U_r(x) \left[(1 - \pi)(D - \alpha V^*)^+ + \pi y_4(\widehat{V})\right], \tag{A.5}$$

where

$$y_4(\widehat{V}) = \frac{(1 - \pi)\, U_r(\widehat{V})(D - \alpha V^*)^+}{1 - \pi U_r(\widehat{V})}.$$

The total market value of all cash flows available to the firm's current claimants is thus

$$Y(x) \quad = \quad y_0(x) - y_1(x) + y_2(x) + y_3(x) + y_4(x). \tag{A.6}$$

The market value of the claims of current depositors is

$$v_1(x) \quad = \quad D \frac{d}{r}(1 - U_r(x)) + U_r(x) \left[\pi v_1(\widehat{V}) + (1 - \pi) D\right], \tag{A.7}$$

where

$$v_1(\widehat{V}) = \frac{D\frac{d}{r}(1-U_r(\widehat{V})) + (1-\pi)DU_r(\widehat{V})}{1-\pi U_r(\widehat{V})}.$$

Extending the integration-by-parts argument of Leland (1994a), the market value of the claims of current bondholders is,

$$v_2(x) \quad = \quad W(1-U_{r+m}(x)) + U_{r+m}(x)\left(\pi B + (1-\pi)(\alpha V^* - D)^+\right), \tag{A.8}$$

where

$$W \quad = \quad P\frac{c+m}{r+m} \tag{A.9}$$

is the total market value of bonds that are default free but otherwise equivalent to those issued by the bank. We always take $B \leq W$ because it is impossible for the bonds to be worth more than their risk-free value W.

The condition $v_2(\widehat{V}) = B$ implies that

$$\widehat{V} \quad = \quad h(V^*) \equiv V^*\left(\frac{W-B}{W-\pi B-(1-\pi)(\alpha V^*-D)^+}\right)^{-\frac{1}{\eta}}, \tag{A.10}$$

where $\eta = \Gamma(r+m)$.

In return for all of its future successive bailout injections, the government has a claim with a market value of

$$v_3(x) \quad = \quad U_r(x)\,\pi\left[H(\widehat{V}) + v_3(\widehat{V})\right], \tag{A.11}$$

where

$$v_3(\widehat{V}) = \frac{\pi\, U(\widehat{V})H(\widehat{V})}{1-\pi U(\widehat{V})}.$$

The total market value of all claims on the bank's net future cash flows is equal to the market value of total cash flows available, so the market value of the bank's equity is

$$H(x) \quad = \quad Y(x) - v_1(x) - v_2(x) - v_3(x), \quad x \geq V^*. \tag{A.12}$$

By definition, $H(x) = 0$ for $x < V^*$. We can rewrite Equation (A.12) as

$$H(x) = x + a + b(V^*)U_{r+m}(x) + g(V^*)U_r(x), \quad x \geq V^*, \tag{A.13}$$

where

$$\begin{aligned}
a &= \kappa \frac{cP + dD}{r} - \frac{dD}{r} - W \\
b(V^*) &= W - \pi B - (1-\pi)(\alpha V^* - D)^+ \qquad \text{(A.14)} \\
g(V^*) &= -(1-\pi)(1-\alpha)V^* - \pi\, y_1(h(V^*)) - \kappa \frac{cP + dD}{r} + \pi y_2(h(V^*)) \\
&\quad + \pi\left[h(V^*) - V^* + y_3(h(V^*))\right] + (1-\pi)(D - \alpha V^*)^+ + \pi y_4(h(V^*)) + D\frac{d}{r} \\
&\quad - \pi v_1(h(V^*)) - (1-\pi)D - \pi\left[H(h(V^*)) + v_3(h(V^*))\right]. \qquad \text{(A.15)}
\end{aligned}$$

A.2 Default Boundary

The default boundary V^* can be conjectured and then verified from the smooth pasting condition, namely that the market value of equity is continuously differentiable at V^*, implying that

$$H'(V^*) = 0. \tag{A.16}$$

The smooth-pasting condition (A.16) reduces to

$$0 = V^* - \eta b(V^*) - \gamma g(V^*), \tag{A.17}$$

where $\gamma = \Gamma(r)$. Expression (A.17) provides an equation for the default boundary V^* that we can now solve explicitly, thus providing explicit solutions for $\hat{V}$ and, in turn, all of the contingent claim market valuation functions $y_1, y_2, y_3, y_4, v_1, v_2, v_3$, and H that we have considered.

There are two cases to consider when solving for V^*.

Case 1: Non-zero bond recovery in bankruptcy. For the case $\alpha V^* > D$, Equation (A.17) implies that

$$
\begin{aligned}
(1+\gamma)V^* &= \left(\eta - \gamma\pi U_{r+m}(\widehat{V})\right)[W - \pi B - (1-\pi)(\alpha V^* - D)] && \text{(A.18)}\\
&\quad + \gamma(1-\pi)\left[\frac{Dd}{r} - \kappa\frac{Pc+Dd}{r} + (\alpha V^* - D) + (D - \alpha V^*)^+\right] - \gamma\pi a && \text{(A.19)}\\
&= \left(\gamma + \gamma\pi U_{r+m}(\widehat{V}) - \eta\right)(1-\pi)(\alpha V^* - D) + \left(\eta - \gamma\pi U_{r+m}(\widehat{V})\right)(W - \pi B)\\
&\quad + \gamma(1-\pi)\left[\frac{Dd}{r} - \kappa\frac{Pc+Dd}{r}\right] - \gamma\pi a. && \text{(A.20)}
\end{aligned}
$$

Collecting terms in V^* on the left-hand side yields

$$
\begin{aligned}
\left[1+\gamma - \left(\gamma + \gamma\pi U_{r+m}(\widehat{V}) - \eta\right)(1-\pi)\alpha\right]V^* &= -\left(\gamma + \gamma\pi U_{r+m}(\widehat{V}) - \eta\right)(1-\pi)D\\
+\left(\eta - \gamma\pi U_{r+m}(\widehat{V})\right)(W - \pi B) + \gamma(1-\pi)\left[\frac{Dd}{r} - \kappa\frac{Pc+Dd}{r}\right] - \gamma\pi a. && \text{(A.21)}
\end{aligned}
$$

We can use (A.10) to get

$$
U_{r+m}(\widehat{V}) = \frac{B - W}{\pi B + (1-\pi)(\alpha V^* - D) - W}.
$$

Substituting this into Equation (A.21) provides a quadratic equation for V^* with explicit coefficients.

Case 2: Zero bond recovery in bankruptcy. For the case $\alpha V^* \leq D$, Equation (A.14) states that

$$
b(V^*) = W - \pi B,
$$

which allows us to rewrite Equation (A.17) as

$$
(1+\gamma)V^* = \left(\eta - \gamma\pi U_{r+m}(\widehat{V})\right)(W - \pi B) + \gamma(1-\pi)\left(D\frac{d}{r} - \kappa\frac{Pc+Dd}{r}\right) - \gamma\pi a.
$$

In this case, (A.10) implies that

$$
U_{m+r}(\widehat{V}) = \frac{W - B}{W - \pi B}.
$$

Thus,

$$V^* = \frac{1}{1+\gamma}\left[\left(\eta - \gamma\pi\frac{W-B}{W-\pi B}\right)(W-\pi B) + \gamma(1-\pi)\left(D\frac{d}{r} - \kappa\frac{Pc+Dd}{r}\right) - \gamma\pi a\right].$$

The assumption $\alpha V^* \leq D$ translates into the following restriction on model parameters:

$$(\eta - \gamma\pi)W + (\gamma - \eta)\pi B + \gamma(1-\pi)\left[D\frac{d}{r} - \kappa\frac{Pc+Dd}{r}\right] - \gamma\pi a \leq \frac{D}{\alpha}(1+\gamma). \tag{A.22}$$

In a subsequent draft, we will report the set of parameters consistent with Case 1.

A.3 Extending the model to incorporate liability insurance assessments

Our model can accommodate deposit and other liability insurance premiums, as follows. We suppose a deposit insurance rate i_D and an insurance assessment rate i_P on other liabilities. Given V^*, the total market value of future insurance premia is

$$y_5(x) = \frac{Pi_P + Di_D}{r}(1 - U_r(x)) + U_r(x)\pi y_5(\hat{V}).$$

As with the other value components, this implies a linear equation for $y_5(\hat{V})$, and thus an explicit solution for $y_5(x)$ at any x. The valuation of total available bank cash flows is now extended from (A.6) to

$$Y(x) = y_0(x) - y_1(x) + y_2(x) + y_3(x) + y_4(x) - y_5(x). \tag{A.23}$$

From this point, the solution method for the boundary V^* and, from that, all of the value components, is just as for the basic model. The solution is again explicit.

B. A Model With Senior Bonds and Bail-in Junior Bonds

This appendix generalizes the basic model to allow for senior and junior bonds, with the objective of separate identification of the risk-neutral probabilities π of bail-out, ψ of bail-in, and $1 - \pi - \psi$ of liquidation at bankruptcy. The dynamic Equation (3) for V_t is maintained. We have the same non-bond parameters $D, d, r, \sigma, k, \alpha$ and κ as for the basic version of the model. The senior and junior bonds have the same maturity parameter m. As with the basic model, the senior bonds have principal P and coupon rate c. At a bailout, the assets in place are increased to some level $\widehat{V}$ by a capital injection that increases the market value of the senior bonds to B, as before. The junior bonds have principal J, coupon rate j, and at a bailout have whatever market value is implied by the capital injection. At a bail-in, the junior bonds are given all of the equity in the bank, and the bank emerges with only its original senior bonds. From that point, for simplicity, we assume that only bailout and liquidation are possible. The values of all elements of the capital structure are then given by the basic version of the model. The default boundary V^* for the basic model without junior debt will therefore apply after a bail-in. This is different from the default boundary V^* that initially applies when there is bail-in junior debt. An alternative and more complicated version of the model would have a bail-in design that restructures the liabilities so as to introduce after bail-in a given new amount of senior and junior bonds.

When any existing bond matures at time t, the same principle amount of the same type of debt is issued at its current market value, which could be at a premium or discount to par depending on V_t. Newly issued senior and junior bonds have the original coupon rates c and j, respectively. The original exponential maturity distribution is always maintained.

The primitive parameters of the model are $c, P, B, J, j, m, D, d, r, \sigma, k, \alpha$ and κ.

We first take the default boundary V^* and first bail-out level $\widehat{V}$ for assets in place as given, and later derive the associated value-consistency and smooth-fit condition determining these two boundaries.

When the current level of assets in place is x, we obtain the following market values of various respective contingent claims. First, the market value of the claim to all cash flows associated with a zero-debt version of the bank is

$$y_0(x) = x.$$

The market value of all future distress costs, including those associated with potential subsequent defaults, is

$$y_{1b}(x) = U_r(x)[(1-\pi-\psi)(1-\alpha)V^* + \pi y_{1b}(\widehat{V}) + \psi y_1(V^*)],$$

where $y_1(\,\cdot\,)$ is the solution for the value of distress costs in the basic model for a bank with parameters

$c, P, B, m, D, d, r, \sigma, k, \alpha, \pi$ and κ. This equation implies an explicit solution for $y_{1b}(\widehat{V})$.

The market value of all future tax shields is

$$y_{2b}(x) \quad = \quad \kappa \frac{Pc + Dd + Jj}{r}(1 - U_r(x)) + U_r(x)[\pi y_2(\widehat{V}) + \psi y_2(V^*)].$$

This implies an explicit solution for $y_{2b}(\widehat{V})$.

The market value of all future cash flows injected by the government, before considering the effect of government equity claims, is

$$y_{3b}(x) \quad = \quad U_r(x)[\pi\,(\widehat{V} - V^* + y_{3b}(\widehat{V})) + \psi y_3(V^*)]. \tag{B.1}$$

Again, we have an explicit solution for $y_{3b}(\widehat{V})$.

The liquidation deposit guarantee requires cash flows from the government with a current market value of

$$y_{4b}(x) \quad = \quad U_r(x)\left[(1 - \pi - \psi)\,(D - \alpha V^*)^+ + \pi y_{4b}(\widehat{V}) + \psi y_4(V^*)\right]. \tag{B.2}$$

Again, we have an explicit solution for $y_{4b}(\widehat{V})$.

The total market value of all net cash flows available to the firm's *current* claimants is

$$Y_b(x) = y_0(x) - y_{1b}(x) + y_{2b}(x) + y_{3b}(x) + y_{4b}(x). \tag{B.3}$$

The total value of the claims of all current depositors is

$$v_{1b}(x) \quad = \quad D\frac{d}{r}(1 - U_r(x)) + U_r(x)\left(\pi v_{1b}(\widehat{V}) + (1 - \pi - \psi)D + \psi v_1(V^*)\right). \tag{B.4}$$

We can solve explicitly for $v_{1b}(\widehat{V})$.

The market value of all claims by current senior bondholders is

$$\begin{aligned} v_{2b}(x) \quad = \quad & \frac{cP + mP}{r + m}(1 - U_{r+m}(x)) \\ & + U_{r+m}(x)[\pi B + (1 - \pi - \psi)\max(\alpha V^* - D)^+, P) + \psi v_2(V^*)]. \end{aligned}$$

We have the consistency condition

$$v_{2b}(\widehat{V}) = B, \tag{B.5}$$

which determines $\widehat{V}$ uniquely given V^*.

In return for all of its future successive bailout injections, the government has a claim with a market value of

$$v_{3b}(x) \quad = \quad U_r(x)\,[\pi G(\widehat{V}) + \pi v_{3b}(\widehat{V}) + \psi v_3(V^*)], \tag{B.6}$$

where $G(x)$ is the equity value of the original bank with assets in place of x.

The market value of all claims by current junior bondholders is

$$v_{4b}(x) \quad = \quad \frac{Jj + mJ}{r+m}(1 - U_{r+m}(x)) + U_{r+m}(x)\left[\pi v_{4b}(\widehat{V}) + (1-\pi-\psi)(\alpha V^* - D - P)^+ + \psi H(V^*)\right].$$

By definition, $G(x) = 0$ for $x \leq V^*$. The total market value of all claims on the bank's net future cash flows is equal to the market value of total cash flows available, so

$$G(x) \quad = \quad Y_b(x) - v_{1b}(x) - v_{2b}(x) - v_{3b}(x) - v_{4b}(x), \quad x \geq V^*. \tag{B.7}$$

Given the assets in place $\widehat{V}$ after the first bailout, the default boundary V^* can be conjectured and then verified from the smooth pasting condition, namely that the market value of equity is continuously differentiable at V^*, implying that

$$\mathcal{G}(V^*, \widehat{V}) \equiv G'(V^*) \quad = \quad 0. \tag{B.8}$$

We can calculate $\mathcal{G}(V^*, \widehat{V})$ explicitly as a function of V^* and $\widehat{V}$. We have reduced the solution of equilibrium for the model to the two equations (B.5) and (B.8) to solve for the two boundaries V^* and $\widehat{V}$.

C. Model Calibration

The key input variables for the model calibration and their sources are described in Table C.1. We also list the model outputs and the restrictions through which they are identified.

Table C.1: **Model input and output variables** The table describes the input and output variables for the model calibration and explains how they are sourced.

Parameter	Definition	Source/Value/Identifying assumption
	Inputs	
P	Sum of long- and short-term debt	Compustat and 10-K/Q
D	Deposits	Compustat and 10-K/Q
m	Inverse of notional-weighted maturity	Compustat and 10-K
r	Risk-free rate	1-year Treasury rate as reported by Gurkaynak, Sack, and Wright (2007)
d	Deposit rate	$d = r$
c	Coupon rate	$c = r +$ cash bond spread
$1 - \alpha$	Fractional bankruptcy cost at default	0.50
κ	Corporate tax rate	0.35
u	Parameter that determines assets provided by gvmt and market value of debt at bailout	0.1
H	Market value of equity	CRSP
CD	Cash dividend	Compustat
IE	Interest expense for long- and short-term debt	Compustat and 10-K/Q
	Outputs	
V	Assets in place	Model-implied market equity in (A.13) matches observed market equity
σ	Asset volatility	$\sigma_p = \frac{1}{\sqrt{h}} \mathrm{StdDev}\left(\log(V_{t+h}) - \log(V_t^i) \middle| t \in p\right)$
k	Payout rate	$k_p = \mathrm{Mean}\left((\mathrm{CD}_t + \mathrm{IE}_t)/V_t \middle| t \in p\right)$

For a given bank i, period p and bailout probability π_p^i, the calibration proceeds as follows:

1. Set $k_t^i = \rho_p^i r_t$,

$$\rho_p^i = \frac{\mathrm{Mean}\left\{\left(\mathrm{CD}_t^i + \mathrm{IE}_t^i\right)/\mathrm{BVA}_t^i \middle| t \in p\right\}}{\mathrm{Mean}\left\{r_t \middle| t \in p\right\}}, \tag{C.1}$$

$$\sigma_p^i = \frac{1}{\sqrt{h}} \mathrm{StdDev}\left\{\log(\mathrm{BVA}_{t+h}^i) - \log(\mathrm{BVA}_t^i) \middle| t \in p\right\}, \tag{C.2}$$

where BVA stands for book value of assets and h measures daily time steps.

2. For each date $t \in p$, find the default threshold $V_t^{*,i}$ as the solution to the smooth-pasting condition $H'(V_t^{*,i}) = 0$ by solving Equation (A.17). Closed-form solutions are provided in Appendix **??**.

3. For each date $t \in p$, find x_t^i such that $H(x_t^i)$ computed according to Equation (A.12) matches the observed market value of equity.

4. Re-compute k_p^i in Equation (C.1) and σ_p^i in Equation (C.2), after replacing BVA_t^i by x_t^i. If k_p^i or σ_p^i have changed, return to Step 2. Otherwise, stop.

D. Additional Tables and Figures

Table D.1: **Firm value components of D-SIBs, scaled by market equity** This table reports the decomposition of total net cash flows, as a fraction of market equity, for the average D-SIB in the pre-Lehman period. The total market value of all net cash flows available to the firm's current claimants is $Y = y_0 - y_1 + y_2 + y_3 + y_4 = v_1 + v_2 + v_3 + H$. Here, y_0 is the current level of assets in place, y_1 is the market value of all future distress costs, y_2 is the market value of all future tax shields, y_3 is the market value of all future cash flows injected by the government., y_4 is the liquidation deposit guarantee from the government, v_1 is the total value of the claims of all current depositors, v_2 is the market value of all claims by current bondholders, and v_3 is the government' claim in return for all of its future successive bailout injections. In addition, H and P are the observed market equity and notional of bonds. V^* is the bankruptcy boundary, and $\widehat{V} - V^*$ is the government's capital injection such that bonds are priced to a certain value B.

π_{post}	π_{pre}	V_0/H	y_1/H	y_2/H	y_3/H	y_4/H	v_1/H	v_2/H	v_3/H	P/H	V^*/H	$\widehat{V}/H$
					pre-Lehman bailout probability is fitted							
0.30	0.48	0.720	0.067	0.163	0.124	0.109	0.355	0.315	0.110	0.329	0.412	0.808
0.20	0.40	0.741	0.080	0.152	0.113	0.122	0.365	0.310	0.104	0.329	0.438	0.884
0.10	0.33	0.757	0.091	0.144	0.101	0.131	0.372	0.305	0.096	0.329	0.457	0.945
0.00	0.26	0.775	0.104	0.135	0.086	0.140	0.381	0.300	0.083	0.329	0.476	1.013
					Bailout probabilities are artificially set to zero							
0.00	0.00	0.839	0.153	0.102	0.000	0.171	0.411	0.280	0.000	0.329	0.542	1.266

Table D.2: **Firm value components of G-SIBs, scaled by total net cash flow** This table reports on the components of total net cash flows, for the average G-SIB during the pre-Lehman period. The components are reported as fractions of total net cash flows. The total market value of all net cash flows available to the firm's current claimants is $Y = y_0 - y_1 + y_2 + y_3 + y_4 = v_1 + v_2 + v_3 + H$. Here, y_0 is the current level of assets in place, y_1 is the market value of all future distress costs, y_2 is the market value of all future tax shields, y_3 is the market value of all future cash flows injected by the government., y_4 is the liquidation deposit guarantee from the government, v_1 is the total value of the claims of all current depositors, v_2 is the market value of all claims by current bondholders, and v_3 is the government's claim in return for all of its future successive bailout injections. In addition, H and P are the observed market equity and notional of bonds. V^* is the default threshold and $\widehat{V} - V^*$ is the government's capital injection at default in the event of a bailout.

π_{post}	π_{pre}	V_0/H	y_1/H	y_2/H	y_3/H	y_4/H	v_1/H	v_2/H	v_3/H	P/H	V^*/H	$\widehat{V}/H$
					pre-Lehman bailout probability is fitted							
0.30	0.63	0.660	0.096	0.151	0.222	0.063	0.262	0.401	0.200	0.426	0.478	0.810
0.20	0.58	0.684	0.110	0.142	0.218	0.066	0.266	0.394	0.203	0.425	0.503	0.873
0.10	0.53	0.708	0.123	0.134	0.213	0.068	0.271	0.388	0.204	0.425	0.528	0.936
0.00	0.48	0.735	0.138	0.127	0.207	0.069	0.276	0.384	0.202	0.427	0.554	1.002
					Bailout probabilities are artificially set to zero							
0.00	0.00	1.203	0.367	0.078	0.000	0.086	0.408	0.415	0.000	0.550	0.969	1.996

Table D.3: **Firm value components of D-SIBs, scaled by total net cash flow** This table reports on the components of total net cash flows, for the average D-SIB during the pre-Lehman period. The components are reported as fractions of total net cash flows. The total market value of all net cash flows available to the firm's current claimants is $Y = y_0 - y_1 + y_2 + y_3 + y_4 = v_1 + v_2 + v_3 + H$. Here, y_0 is the current level of assets in place, y_1 is the market value of all future distress costs, y_2 is the market value of all future tax shields, y_3 is the market value of all future cash flows injected by the government., y_4 is the liquidation deposit guarantee from the government, v_1 is the total value of the claims of all current depositors, v_2 is the market value of all claims by current bondholders, and v_3 is the government' claim in return for all of its future successive bailout injections. In addition, H and P are the observed market equity and notional of bonds. V^* is the default threshold and $\widehat{V} - V^*$ is the government's capital injection at default in the event of a bailout.

π_{post}	π_{pre}	V_0/H	y_1/H	y_2/H	y_3/H	y_4/H	v_1/H	v_2/H	v_3/H	P/H	V^*/H	$\widehat{V}/H$
pre-Lehman bailout probability is fitted												
0.30	0.48	0.687	0.064	0.155	0.118	0.104	0.339	0.300	0.105	0.313	0.394	0.771
0.20	0.40	0.708	0.077	0.145	0.108	0.116	0.349	0.296	0.100	0.314	0.418	0.845
0.10	0.33	0.727	0.088	0.138	0.097	0.126	0.358	0.293	0.092	0.315	0.438	0.908
0.00	0.26	0.751	0.101	0.130	0.083	0.136	0.369	0.291	0.081	0.318	0.461	0.982
Bailout probabilities are artificially set to zero												
0.00	0.00	0.875	0.160	0.107	0.000	0.178	0.429	0.292	0.000	0.343	0.566	1.320

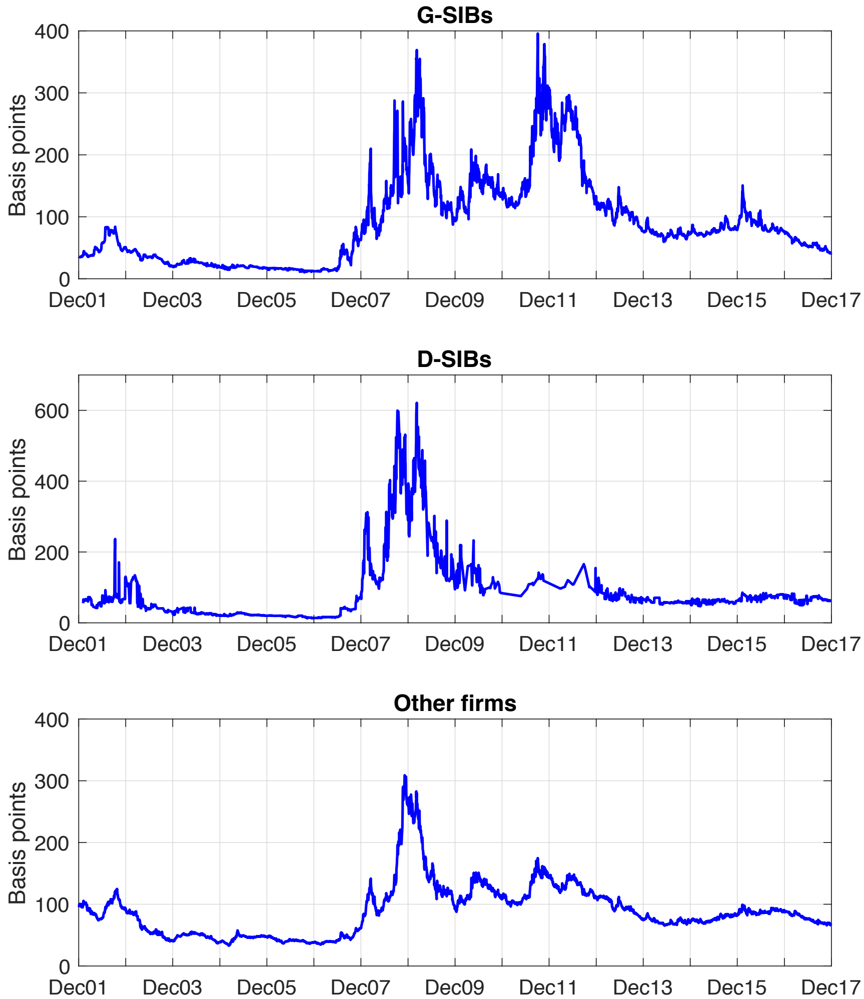

Figure D.1: **Median five-year CDS rates** The figure shows the daily times series of median five-year CDS rates. For G-SIBs and D-SIBs, only those days on which CDS rates are available for four or more firms are shown. For other firms, only days on which CDS rates are available for 50 or more firms are shown.