The Decline of Too Big to Fail

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Antje Berndt, Darrell Duffie, and Yichao Zhu*

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Abstract

For U.S. globally systemically important banks (G-SIBs), we find large post-crisis 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-crisis G-SIB failure-resolution laws and rules. G-SIB creditors now appear to expect 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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*Berndt is a Professor of Finance, RSFAS, Australian National University. Duffie is the Dean Witter Distinguished Professor of Finance at the Graduate School of Business, Stanford University and a research fellow of the National Bureau of Economic Research. Between October 2008 and April 2018, Duffie was on the board of Directors of Moody's Corporation, which generously provided data used in this research Zhu is a post-doctoral fellow, RSFAS, Australian National University.

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 drops 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 costs connected with lower bailout expectations.

We find that G-SIB balance sheet data and the market prices of debt and equity reveal 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. Many market participants were surprised that the U.S. government did not bail out Lehman.[3] We cannot disentangle how much of the post-crisis reduction in investor bailout expectations is due to the effectiveness of new failure resolution methods, which have not yet been tried in practice, versus 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 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

[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 for which we have the necessary matching data.

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

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. If the two firms have the same risk-neutral insolvency probability, the credit spreads of firm A are twice those of firm B, for each respective type of debt instrument. We can detect post-Lehman changes in the risk-neutral (or "market-implied") probability of bank bailout from changes in the observed relationship between credit spreads and distances to default. Including a large number of non-banks in our sample allows us to control for the substantial variation over time in corporate default risk premia that have been shown by Berndt, Douglas, Duffie, and Ferguson (2018), which also affect the relationship between credit spreads and distance to default. Rather than taking default risk premia for non-banks and banks to be the same, we rely only on the assumption that the relative difference in 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 also affected by bailout through the associated value to shareholders of lower debt financing costs. Similarly, the insolvency level of assets is influenced by bailout expectations, because equity owners optimally wait longer to default if their debt financing costs are subsidized by higher bailout expectations. We capture these two channels for the impact of bailout on distance to default and equity values within a structural dynamic model of debt and equity prices that extends Leland (1994a) by incorporating bailouts. 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 of the future bailout-conditional continuation market values of legacy debt and new equity. These post-bailout continuation values include the market values of subsidies associated with successive future potential bailouts. For instance, on average in the pre-crisis 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

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

subsidy value is associated with subsequent bailouts.

We also find that a change in one's assumption about bailout probability has a big effect on one's estimate of distance to default for a bank with a given balance sheet, and thus a big effect on predicted credit spreads and default probabilities. 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.

We face the following identification challenge. The impact on debt and equity prices of a downward shift in the assumed fractional loss of asset values at default can be approximately offset by some common multiplicative upward shift in assumed pre-crisis and post-crisis bailout probabilities. Estimating the fractional 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-crisis bailout probability π_{pre} and a post-crisis 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 be homogeneous with respect to bailout and to have a post-crisis bailout probability $\pi_{\text{post}} = 0.2$, we estimate a pre-crisis bailout probability π_{pre} of 0.60. Alternatively, for a post-crisis bailout probability π_{post} of 0.3, our estimate of π_{pre} is 0.65. Complete schedules of these estimated pairs of pre-crisis and post-crisis bailout probabilities are plotted and tabulated later in this 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-crisis D-SIB bailout probability of 0.20, the data imply a pre-crisis D-SIB bailout probability of 0.4, much lower than the associated G-SIB pre-crisis estimated bailout probability of 0.6.

Given our estimated post-crisis 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. We compute the ratio of the fitted market value of all future government subsidies to the observed market capitalization of the bank. For example, with a data-consistent post-crisis bailout

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

probability of 0.2 and pre-crisis bailout probability of 0.6, we find an average 32% reduction in the market value of equity due to the reduction in bailout-subsidized debt financing costs.

The remainder of the paper is structured as follows. Section 1 reviews the related literature. Section 2 presents our model of firm value and default decision in the presence of government subsidies. Section 3 describes the data and presents descriptive statistics. Section 4 calibrates the model to the data without considering bailouts and explains how ignoring the possibility of government intervention may bias defaut risk and credit risk premia estimates. Section 5 presents estimates of pre-Lehman bailout probabilities for various assumed post-Lehman probabilities and offers comparative statistics. Section 6 discusses a potential alternative to our main hypothesis and then concludes.

1. 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 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 provided by 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

[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.

equity to the accounting value of equity. In principle, a post-crisis reduction in TBTF subsidies should lower the market-to-book ratio. Indeed, the authors show that the equity-to-book ratio 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-crisis 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-crisis 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] In this sense, 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-crisis 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-crisis sovereign ratings uplifts automatically implies smaller estimated TBTF debt subsidies.[9]

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

[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. 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.

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.

2. Valuation of Bank Equity and Debt with Bailout Subsidies

Consider a bank with assets in place of V_t satisfying

$$dV_t \quad = \quad V_t(r-k)\,dt + V_t\sigma\,dZ_t, \tag{1}$$

where Z is a standard Brownian motion under some risk-neutral probability measure,[10] r is the risk-free rate, σ is the asset volatility and k is the total cash revenue rate. 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. (Appendix A considers an extension with three layers of debt.) 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. It is also easy to solve the model with a fixed rate of default insurance premium. Allowing for the possibility of imperfect competition in the deposit market, we do not require that $d = r$.

The remaining class of debt consists of bonds of constant total principle P, with maturities that are exponentially distributed. 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

[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.

deducible at the corporate tax rate κ. This is the model of Leland (1994a), except for the fact that we have two classes of debt, deposits and bonds, and also that we allow for a government bailout at default, to be explained shortly.

The bank's current shareholders choose a 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), 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 boundary V^*.

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[11] and occurs with a given risk-neutral probability π. That is, the conditional probability of bailout at any time $t < \tau$ is 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, becomes the new equity owner, and continues to service the debt as originally contracted.

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 capital injection is, for simplicity, modeled as a purchase of some quantity $\widehat{V} - V^*$ of additional assets. The quantity of additional assets could be a multiple of assets in place at default or, alternatively, large enough to bring the market value of the bonds up to some stipulated value B. In the latter case, B could be the par value P, or the market value associated with a chosen yield spread over the risk-free rate. The net government bailout subsidy is thus $\widehat{V} - V^* - H(\widehat{V})$, where $H(x)$ is the initial market value of a version of the bank with assets in place of x and with the original liabilities parameterized by (D, d, P, c).

In the event of no bailout at a default time, the bank is permanently liquidated. At liquidation,

[11]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 $\mathcal{F}_t = \sigma(\{z_s : s \leq t\} \cup \{B_1, \ldots, B_n\})$, where $B_1, B_2, \ldots$ 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 deposits are paid off in full, using if necessary the government's deposit guarantee, and the bond creditors receive the remaining liquidation value of the assets, pro rata by principal amount. That is, per unit of the face value of their debt claims, the depositors receive one and the bond holders receive $(\alpha V^* - D)^+/P$. The government pays $(D - \alpha V^*)^+$. This simple model is time-homogeneous with Markov state variable V_t. 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 parameter restrictions, bond recoveries above par are possible in practice.

The vector of primitive model parameters is

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

We now turn to the valuation of various relevant contingent claims and a calculation of the optimal default boundary V^* and the bailout recapitalized asset level $\widehat{V}$. At first taking 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 guarantees, and bailout capital injections, net of distress costs, at all future bailouts. We then equate this value of net available cash flows to the market value of the positions held by all 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 an contingent equity claimant at all future bailouts. From this equation, taking V^* as given, we can explicitly deduce the market value of equity and the recapitalized asset level $\widehat{V}$. Using a "smooth pasting" condition for the market value of equity at the default boundary V^*, we can then deduce an equation pinning down V^*. Finally, this equation for V^* is solved.

The market value at any time $t < \tau$ of receiving one unit of account at time τ is

$$U(V_t) \quad = \quad E^{\mathbb{Q}}\left(e^{-r(\tau-t)}\middle|V_t\right) = \left(\frac{V_t}{V^*}\right)^{-\gamma}, \tag{2}$$

where

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

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

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

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

$$y_1(x) \quad = \quad U(x)\left[(1-\pi)\,(1-\alpha)V^* + \pi\, y_1(\widehat{V})\right]. \tag{3}$$

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

$$y_2(x) \quad = \quad \kappa\frac{cP+dD}{r}\,(1-U(x)) + \pi\, U(x) y_2(\widehat{V}). \tag{4}$$

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

$$y_3(x) \quad = \quad U(x)\,\pi\left[\widehat{V} - V^* + y_3(\widehat{V})\right]. \tag{5}$$

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

$$y_4(x) \quad = \quad U(x)\left[(1-\pi)(D-\alpha V^*)^+ + \pi y_4(\widehat{V})\right]. \tag{6}$$

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

$$Y(x) \quad = \quad y_0(x) - y_1(x) + y_2(x) + y_3(x) + y_4(x).$$

The market value of the claims of current depositors is

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

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

$$v_2(x) \quad = \quad \zeta(1 - U_m(x)) + U_m(x)\left\{\pi B + (1-\pi)\left[(\alpha V^* - D)^+ \wedge \zeta\right]\right\}, \tag{8}$$

where "$\wedge$" denotes the minimum operator and

$$\zeta \quad = \quad P\frac{c+m}{r+m} \tag{9}$$

is the total market value of bonds that are default free but otherwise equivalent to those issued by the bank. We therefore assume that $B \leq \zeta$. In addition,

$$U_m(x) \quad = \quad E^{\mathbb{Q}}\left(e^{-(r+m)(\tau-t)} \,\middle|\, V_t = x\right) = \left(\frac{x}{V^*}\right)^{-\eta} \tag{10}$$

where

$$\eta \quad = \quad \frac{r - k - \sigma^2/2 + \sqrt{(r-k-\sigma^2/2)^2 + 2(m+r)\sigma^2}}{\sigma^2}.$$

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

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

Recall that $H(x)$ is the equity value of the bank with assets in place of x.

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

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

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

$$H(x) \quad = \quad x + a + bU_m(x) + gU(x), \quad x \geq V^*, \tag{13}$$

where a, b and g are specified in Appendix B as functions of the primitive model parameters, V^* and $\widehat{V}$.

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

$$\widehat{V} \quad = \quad V^* \left(\frac{\zeta - B}{\zeta - \pi B - (1 - \pi) \left[(\alpha V^* - D)^+ \wedge \zeta \right]} \right)^{-\frac{1}{\eta}}. \tag{14}$$

As a result, a, b and g in Equation (13) are fully specified as functions of the primitive model parameters and V^*.

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

$$H'(V^*) \quad = \quad 0. \tag{15}$$

In light of Equations (2), (10) and (13), the smooth-pasting condition (15) reduces to

$$0 \quad = \quad V^* - \eta b(V^*) - \gamma g(V^*). \tag{16}$$

We use the notation $b(V^*)$ and $g(V^*)$ instead of b and g to highlight the dependency of b and g on V^*, as shown in Equations (B.1) and (B.3). Expression (16) provides an equation for the default boundary V^* that we can then solve.

Other recent 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). A number of papers have incorporated government subsidies into a Leland-type model. In Albul, Jaffee, and Tchistyi (2010), all debt is perpetual. A government guarantee benefits only the debt holders and does not subsidize equity. Chen, Glasserman, Nouri, and Pelger (2017), on the other hand, allow for debt rollover and show that in this case, part of the government subsidy is captured by shareholders. Shareholders maximize their benefit by raising the default boundary, thus increasing the value of the subsidy and increasing the propensity for debt-induced collapse. The model framework in Chen, Glasserman, Nouri, and Pelger (2017) is based on Chen and Kou (2009). Outside of the Leland-type framework, Gandhi, Lustig, and Plazzi (2016) develop a bailout-augmented asset pricing model with rare disasters at the country level.

3. Data and Descriptive Statistics

The focus of our analysis is on systematically important banks. The Financial Stability Board (FSB), in consultation with Basel Committee on Banking Supervision (BCBS) and national authorities, identifies global systemically important banks (G-SIBs). Our analysis is based on the list published in November 2017, which uses end-2016 data and the updated assessment methodology published by the BCBS in July 2013 (Financial Stability Board (2017), Bank of International Settlement (2013)). 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.

We also identify U.S. banks that are sufficiently systemic, beyond the U.S. G-SIBs, to require a stress test under Comprehensive Capital Analysis and Review (CCAR) and for Dodd-Frank Act stress tests.[12] 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. We refer to these firms as U.S. 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 be matched unambiguously across the Markit CDS, Compustat and CRSP databases. Markit 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. Assuming no upfront and zero dealer margins, the at-market CDS rate is, in theory, that for which the net market value of the contract is zero. 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.

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

The CDS data used in the main part of the paper are for a contractual definition of default known as "no restructuring." The contractual definition allows for bankruptcy and 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.

We only use CDS quotes for which Markit rates the quality of the quote 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 expenses.[13] 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—where "large bank" means G-SIB or D-SIB—we use the Compustat Banks database and 10-Q/10-K filings to fill in missing data.[14]

For large banks, we calculate the daily time series of notional-weighted bond maturity using the maturity information provided in the 10-K filings. For all other firms, we take the simple view that the maturity of short- and long-term debt equals one and five years, respectively, and then use the reported notional amounts for short- 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. Interest rate data are downloaded from the website of the Federal Reserve Bank of San Francisco, and are based on the calibration technique described in Gurkaynak, Sack, and Wright (2007).

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

[13] The total interest expense item XINTQ in Compustat includes the interest payments on short- 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.

[14] We have verified that the information contained in large banks' 10-K filings 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 it offers in terms of measuring short-term debt—the 10-K definition of short-term debt is inconsistent across banks and time.

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

Figure C.1 in the appendix 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 key accounting variables, separately for G-SIBs, D-SIBs and other firms. We consider two sub-periods—the "pre-Lehman" period from January 1, 2002 to September 15, 2008 and the "post-Lehman" period from September 16, 2008 to December 31, 2017. We observe that large banks tend to be larger and more highly levered than other firms. Yet the cost of default protection tends to be lower for large banks than for other firms, particularly prior to the crisis.

4. Measuring Credit Risk Premia Without Considering Government Bailouts

We first calibrate the model to the data without considering government bailouts, by taking π to be zero. For a given bank i and date t, we observe the market value of equity, H_t^i; the amount of

Table 2: **Accounting measures** This table reports averages statistics for book assets (BVA), book debt (BVD), short-term debt (STD), long-term debt (LTD), deposit (Dpst), market capitalization (MC), cash dividends (CD) and interest expense (IE), in billion U.S. dollars. Book leverage (Lev) is the ratio of book debt to book assets. We also report average five-year CDS rates in basis points, Moody's ratings (Rtg) and notional-weighted bond maturity (Mat) 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	0.38	38	Aa	2.58	8
Post	1,578	481	251	230	682	131	3.60	7.27	0.34	127	A	2.99	7
							D-SIBs						
Pre	120	36	12	24	45	29	0.71	1.14	0.34	72	A	3.66	12
Post	210	42	9	33	78	39	0.84	1.02	0.24	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

deposits, D_t^i; the amount of short- plus long-term debt, P_t^i; and the notional-weighted bond maturity, $1/m_t^i$. We also observe the risk-free interest rate r_t and deposit rate d_t. We set the coupon rate c_t^i equal to r_t plus the cash bond spread for bank i on date t. The cash bond spread is computed as the firm's at-market credit default swap (CDS) rate minus the CDS-bond basis.[15] The parameters α and κ are set exogenously, with details provided in Appendix D. For the special case of non-banks, we take D to be zero, which reduces the model in Section 2 to the standard Leland model.

The model parameters to be estimated are the asset volatility σ_t^i and payout rate k_t^i. We assume that asset volatility is constant throughout certain time periods p, meaning $\sigma_t^i = \sigma_{p(t)}^i$, and that $k_t^i = \rho_{p(t)}^i r_t$. The periods we consider are the "pre-Lehman period" from January 1, 2002 to September 15, 2008 and the "post-Lehman period" from September 16, 2006 to December 31, 2017. We impose the over-identifying restrictions that the period-p average payout rate is equal to the period-p average ratio of the sum of cash dividends and interest expenses to assets in place, and that the asset volatility σ_p^i is equal to the period-p standard deviation of log asset growth. We adjust our choices for σ_p^i and ρ_p^i until these restrictions are satisfied. This procedure yields a daily time series of assets in place that is internally consistent with the assumed levels of asset volatility and payout rates. Details are provided in Appendix D.

[15] If at time t bank i has investment-grade (IG) status, we subtract the Markit IG CDX basis. If the bank has high-yield (HY) status, we subtract the Markit HY CDX basis. We linearly interpolate the CDS term structure and use the CDS rate consistent with horizon $1/m_t^i$.

For a given value of σ_p^i and ρ_p^i, the default threshold $V_t^{*,i}$ is given as the solution to the smooth-pasting condition (16). A closed-form solution for $V_t^{*,i}$ is provided in Appendix E. Assets in place V_t^i are such that the model-implied market equity $H(V_t^i)$ in Equation (12) matches the observed market equity. Given V_t^i and $V_t^{*,i}$, we compute the firm's distance to default as

$$\text{DtD}_t^i = \frac{\log(V_t^i) - \log(V_t^{*,i})}{\sigma_{p(t)}^i}. \tag{17}$$

Table C.1 in the appendix shows that DtD tends to be lower for large banks than for other firms, and that it tends to be particularly low for G-SIBs. This pattern is confirmed in Figure C.2. Recall that in practice large banks may benefit from government bailouts, and that by ruling out the possibility of government intervention at default and setting $\pi_p^i = 0$ we may have introduced downward biased into our distance to default estimates.

We uncover further evidence of a downward bias in zero-π-based estimates of the financial health of large banks when comparing the fitted relationship between distance and default and CDS rates for banks and non-banks. Specifically, we estimate the panel-data regression

$$\begin{aligned} \log(\text{CDS}_t^i) &= \alpha + \beta\, \text{DtD}_t^i + \sum_{\text{sec } s} \delta^s\, D^s(i) + \sum_{\text{mos } m} \delta_m\, D_m(t) + \sum_{\text{mos } m} \delta_m^G\, D_m(t)\, D^G(i) \\ &\quad + \sum_{\text{mos } m} \delta_m^D\, D_m(t)\, D^D(i) + \epsilon_t^i, \end{aligned} \tag{18}$$

where ϵ_t^i is a random disturbance term, $D^s(i)$ is one if firm i is in sector s and zero otherwise, $D_m(t)$ is one if date t is in month m and zero otherwise, and $D^G(i)$ ($D^D(i)$) is one if firm i is a G-SIB (D-SIB) and zero otherwise.

Equation (18), which is based on work by Berndt, Douglas, Duffie, and Ferguson (2018), establishes a link between the price of default insurance as measured by the CDS rate and the riskiness of the firm as measured by its distance to default. The coefficients δ^s capture sector fixed effects, the coefficients δ_m capture month fixed effects, and the coefficients δ_m^G and δ_m^D capture G-SIB-specific and D-SIB-specific month fixed effects.

The regression results are summarized in the left panel of Table 3. The root mean squared error (RMSE) for this fitted relationship is 0.69. An assumption of normally distributed disturbances implies a one-standard-deviation confidence band for a given CDS rate of between $\exp(-0.69) = 50\%$ and

$\exp(0.69) = 199\%$, as a multiple of the observed rate. 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 63%—of variation in log rates.

Table 3: **Panel regression results for $\pi_t^i = 0$** The left panel of the table reports the results for the panel data regression (18), when $\pi_t^i = 0$ for all firms i and dates t. CDS rates are measured in basis points. The benchmark sector is Basic Materials and the benchmark month is December 2017. Driscoll-Kraay standard errors that are robust to heteroskedasticity, autocorrelation and cross-sectional dependence are reported in parentheses. The data include 783 firms, over 2002–2017. The right panel shows the difference between the average G-SIB dummy coefficient over post-Lehman months, $\overline{\delta}_{\text{post}}^G$, and the average G-SIB dummy coefficient over pre-Lehman months, $\overline{\delta}_{\text{pre}}^G$, and the standard error estimate for this difference in means. Similar results are shown for D-SIBs as well. The pre-Lehman period is from January 1, 2002 to September 15, 2008 and the post-Lehman period is from September 16, 2008 to December 31, 2017.

	Estimate	Std err		Estimate	Std err
Constant	6.735	0.044	$\overline{\delta}_{\text{post}}^G - \overline{\delta}_{\text{pre}}^G$	0.757	0.049
DtD	-0.294	0.002	$\overline{\delta}_{\text{post}}^D - \overline{\delta}_{\text{pre}}^D$	0.365	0.064
Consumer Goods	0.068	0.006			
Consumer Services	0.055	0.007			
Energy	-0.069	0.010			
Financials	0.059	0.014			
Healthcare	-0.076	0.013			
Industrials	-0.150	0.007			
Technology	0.119	0.011			
Telecommunications Services	0.254	0.013			
Utilities	-0.285	0.010			
R^2	0.628				
RMSE	0.689				

The right panel of the table reveals that the increase in CDS rates, at a given DtD, from the pre- to post-Lehman period was significantly higher for large banks than for other firms. In addition, the increase in average dummy coefficients is greater for G-SIBs than D-SIBs. This effect is visualized in Figure 1. The left axis of the left panel shows the fitted CDS rate for G-SIBs at a distance to default of two, and the right axis shows the ratio of the G-SIB to non-bank multiplier, $\exp(\delta_m^G)$. The latter is the relative time fixed effect multiplier for G-SIBs versus nonbanks. The figure shows that the fitted CDS rate for G-SIBs experienced a large increase in the post-Lehman period, and that this pattern is reflected in the relative time fixed effect multipliers. In the right panel of Figure 1, we find similar pattern for D-SIBs.

Rather than interpreting the findings in Figure 1 as evidence of a structural break in the post-

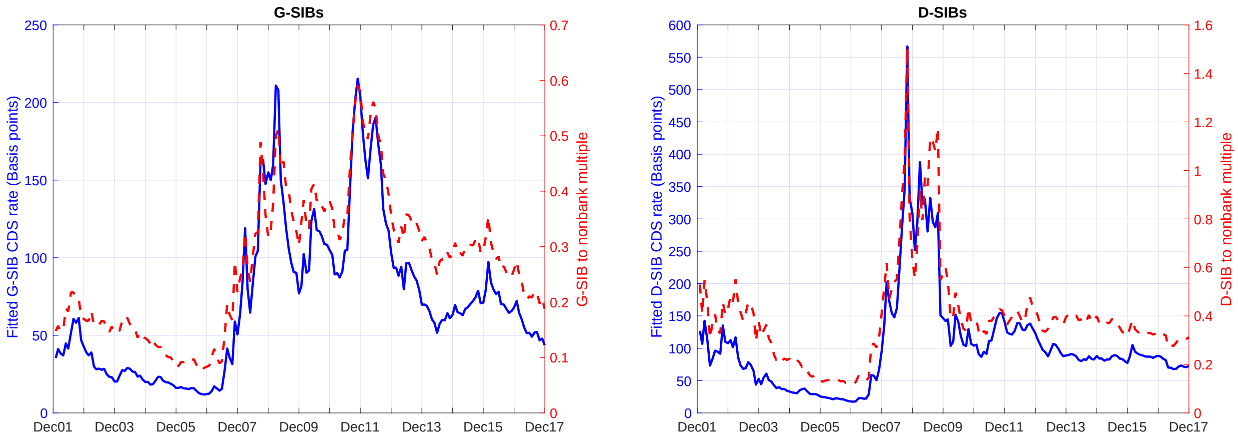

Figure 1: **Fitted CDS rate and relative month multiplier without bailout effects** The left panel shows the fitted CDS rate for G-SIBs at a distance to default of two, and the G-SIB to nonbank relative month multiplier, $\exp(\delta_m^G)$. The right panel shows a similar plot for D-SIBs. We calibrate the model in Section 2 to the data without considering government bailouts.

Lehman pricing of default risk for large banks, we postulate that the higher post-Lehman big-bank to non-bank multipliers are due to mismeasuring distance to default when potential government bailouts are ignored. Indeed, in the next section we show that the fitted distance to default is higher for higher bailout probabilities. Thus, as the assumed value for pre-crisis bailout probabilities for large banks increases, the big-bank to non-bank multiplier in Figure 1 should flatten out.

5. Estimating Bailout Probabilities

In this section, we estimate pre-Lehman bailout probabilities π^G_{pre} for G-SIBs and π^D_{pre} for D-SIBs, for various assumed values of post-Lehman bailout probabilities. Our identifying assumption relates to the panel-data regression (18), after scaling CDS^i_t on the left-hand side by $(1-\pi^i_t)$ to acknowledge the fact that CDS rates are compensation for expected default losses and that expected losses at the time of default, measured as a fraction of notional, scale with $1-\pi^i_t$:

$$\begin{aligned}\log(\text{CDS}^i_t) - \log(1-\pi^i_t)s \;&=\; \alpha + \beta\,\text{DtD}^i_t + \sum_{\text{sec } s} \delta^s\, D^s(i) + \sum_{\text{mos } m} \delta_m\, D_m(t) + \sum_{\text{mos } m} \delta^G_m\, D_m(t)\, D^G(i) \\ &\quad + \sum_{\text{mos } m} \delta^D_m\, D_m(t)\, D^D(i) + \epsilon^i_t, \qquad (19)\end{aligned}$$

We determine π^G_{pre} and π^D_{pre} such that

$$\overline{\delta}^G_{\text{post}} - \overline{\delta}^G_{\text{pre}} = \overline{\delta}^D_{\text{post}} - \overline{\delta}^D_{\text{pre}} = 0. \tag{20}$$

Equation (20) imposes the constraint that the proportional temporal variation in the pricing of default risk, for a given level of risk, are the same for large banks than for non-banks.

To calibrate our model for non-zero bailout probabilities, in the main part of the paper we assume that the government constraints its actions such that $U_m(\widehat{V}) = u$, meaning

$$\widehat{V} = V^* u^{-1/\eta}, \tag{21}$$

for some $u \in (0, 1)$. This assumption implies a particular functional form for B:

$$B = \frac{(1-u)\zeta + u(1-\pi)\left[(\alpha V^* - D)^+ \wedge \zeta\right]}{1 - \pi u}. \tag{22}$$

Equation (22) states that $B = \zeta$ for $\pi = 1$ and $B = (1-u)\zeta + u\left[(\alpha V^* - D)^+ \wedge \zeta\right]$ for $\pi = 0$. It is straightforward to show that B is increasing in $\pi \in [0, 1]$. The parameter u is set exogenously, with details provided in Appendix D. In Appendix F we report results for the alternative assumption that the government's capital injection is such that it brings the market value of the bonds up to some the par value, i.e., $B = P$.

In Appendix E, we provide the closed-form solution for V^*. We show—both theoretically in the appendix and visually in Figure E.1—that V^* is a strictly decreasing function of π. Dropping superscript i from the notation in (17), the sensitivity of the distance to default to the bailout probability is given by

$$\frac{\partial \text{DtD}_t}{\partial \pi_p} = \frac{1}{\sigma_p} \frac{\partial\left(\log(V_t) - \log(V_t^*)\right)}{\partial \pi_p} = \frac{1}{\sigma_p V_t^*} \frac{\partial V_t^*}{\partial \pi_p} \left(\frac{\partial V_t / V_t}{\partial V_t^* / V_t^*} - 1 \right).$$

Since $\partial V_t^* / \partial \pi_p < 0$, the distance to default increases with the bailout probability as long as the elasticity of assets in place with regard to the default threshold is less that one, meaning as long as

$$\frac{\partial V_t / V_t}{\partial V_t^* / V_t^*} < 1. \tag{23}$$

Our computations in Appendix G show that the inequality in (23) is indeed satisfied, meaning that DtD is an increasing function of π, as shown in Figure 2. This suggests that for higher pre-Lehman big-bank bailout probabilities, the big-bank to non-bank multiplier in Figure 1 should flatten out.[16]

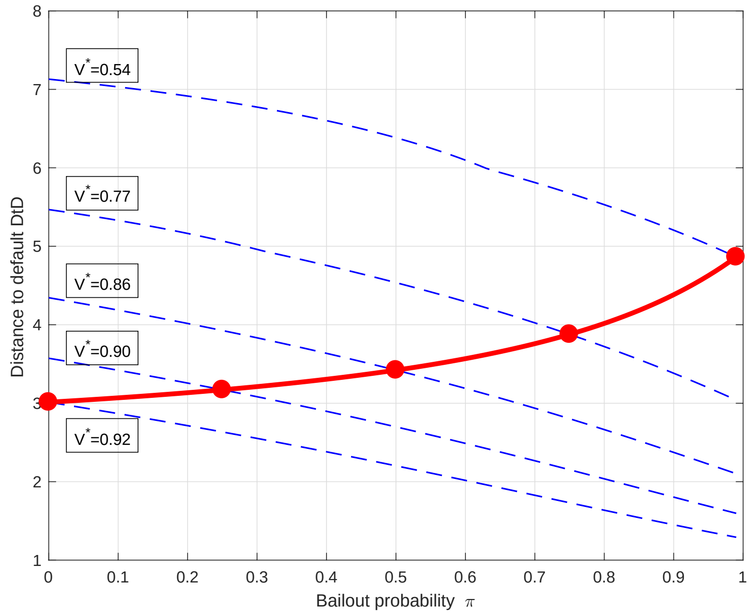

Figure 2: **Distance to default as a function of bailout probability** The figure shows the fitted distance to default for Citigroup at the end of December 2017 (red solid line), for various values of the bailout probability π. The figure also shows DtD as a function of π for certain fixed values of V^* (dashed blue lines), by solving Equation (13). We set σ equal to the sample standard deviation of log book asset growth in the post-Lehman period, and $k = \rho r$ where ρ is such that the average ratio of cash dividends plus interest expense to book assets is equal to ρ time the average risk-free rate.

Figure 3 shows our estimates for $\overline{\delta}^G_{\text{post}} - \overline{\delta}^G_{\text{pre}}$ and $\overline{\delta}^D_{\text{post}} - \overline{\delta}^D_{\text{pre}}$, as a function of various pre-Lehman bailout probabilities π^G_{pre} and π^D_{pre}. The post-Lehman bailout probabilities for large banks are set to 0.2. We find that the identifying constraints (20) are satisfied for $\pi^G_{pre} = 0.60$ and $\pi^D_{pre} = 0.40$. Alternatively, when the post-Lehman bailout probability is set to zero, the identifying constraints are satisfied for $\pi^G_{pre} = 0.51$ and $\pi^D_{pre} = 0.25$.

Figure 4 shows—using the solid blue line—the fitted CDS rate for G-SIBs at a distance to default of two. We find that the cost of debt financing for G-SIBs, at a fixed level of risk, tends to be higher in the post-Lehman period. We show that this increase is largely due to an increase in loss given default of creditors of large BHCs. Indeed, if the post-Lehman CDS rate would have been fitted while keeping

[16] In Appendix G and Figure 2, we keep all model parameters other than π the same. Note, however, that when we calibrate the model to the data for different values of π, the internally-consistent parameters for σ and k change. We have confirmed that the positive relationship between π and DTD remains nevertheless intact.

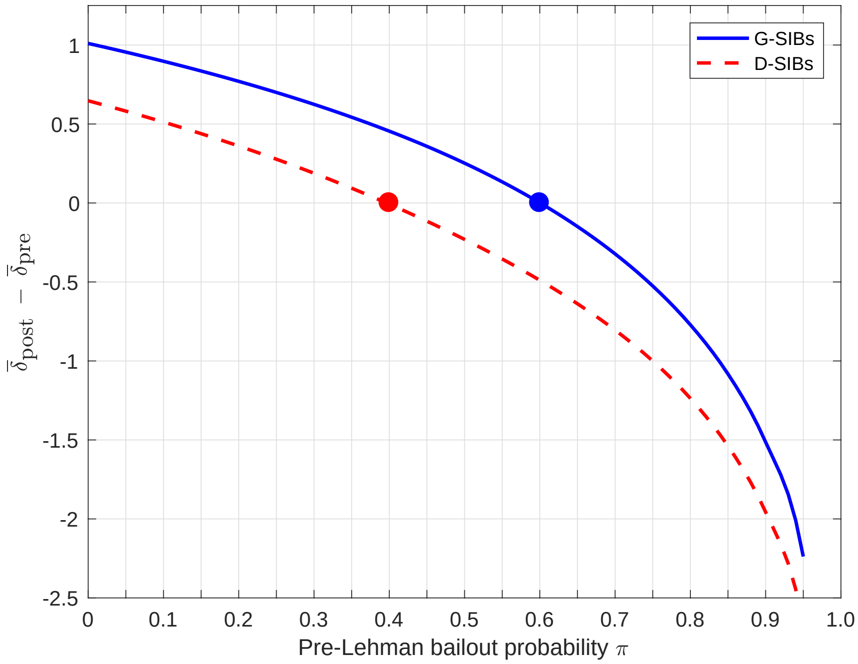

Figure 3: **Change in big-bank coefficients** This figure shows the estimates for $\bar{\delta}^G_{\text{post}} - \bar{\delta}^G_{\text{pre}}$ and $\bar{\delta}^D_{\text{post}} - \bar{\delta}^D_{\text{pre}}$ in the panel regression (19), as a function of the pre-Lehman bailout probability π^G_{pre}. The post-Lehman bail-out probabilities for large banks are set to 0.2. We assume $U_m(\widehat{V}) = 0.1$.

π^G_t on the right-hand side of Equation (19) at its pre-Lehman level, the fitted CDS rate shown in the dashed red line would have reverted to near-pre-crisis levels towards the end of our sample period.

Table 4 shows—for the fitted bailout probabilities—the decomposition of the total net cash flows of the average pre-Lehman G-SIB (D-SIB) into its components. A higher assumed post-Lehman bailout probability results in a higher pre-Lehman π. For the pre-Lehman period, when the bailout probability is higher, the fitted assets in place are lower, the implied default threshold is lower and the market value of debt is higher. Independent of the assumed post-Lehman bailout probability, the market value of the government subsidy, y_3, is about 86% of the value of market equity. About 59% are due to the subsidy at the next bailout, $U(x)\pi(\widehat{V} - V^*)$, and 27% are due to subsidies at subsequent bailouts, $U(x)\pi y_3(\widehat{V})$. Table C.2 reports similar results for D-SIBs.

While Tables 4 and C.2 report components as fraction of market equity, Tables C.3 and C.4 report them as fractions of total net cash flow.

Figure 5 shows the daily time series of the average ratio of the fitted market value of all future government subsidies to the observed market value of equity, across all G-SIBs. We assume $\pi_{post} = 0.20$,

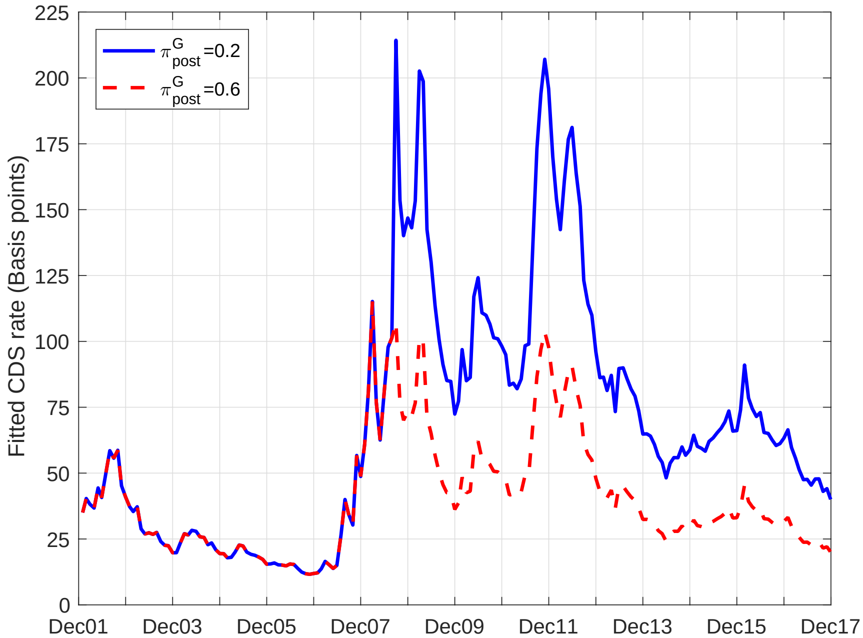

Figure 4: **Fitted CDS rate** This figure shows the fitted CDS rate for G-SIBs at a distance to default of two (solid blue line), and the fitted rate when π_t^G on the left-hand side of Equation (19) is kept constant at π^G_{pre} (dashed red line). The model in Section 2 is calibrated to the data assuming a post-Lehman bail-out probability for large banks of 0.2 and $U_m(\widehat{V}) = 0.1$.

Table 4: **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 $Y = y_0 - y_1 + y_2 + y_3 + y_4 = v_1 + v_2 + v_3 + H$. 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. We assume $U_m(\widehat{V}) = 0.1$.

π_{post}	π_{pre}	$y_0 = V_0$	y_1	y_2	y_3	y_4	v_1	v_2	v_3	H	P	V^*	$\widehat{V}$
						Pre-Lehman bailout probability is fitted							
0.30	0.65	5.167	-0.639	1.501	0.932	0.261	2.656	3.015	0.550	1.000	3.104	4.083	5.621
0.20	0.60	5.339	-0.739	1.430	0.861	0.273	2.656	2.971	0.537	1.000	3.104	4.265	5.858
0.10	0.55	5.504	-0.841	1.360	0.797	0.282	2.656	2.924	0.523	1.000	3.104	4.431	6.090
0.00	0.51	5.632	-0.925	1.305	0.749	0.287	2.656	2.884	0.508	1.000	3.104	4.558	6.275
						Pre-Lehman bailout probability is set to zero							
0.00	0.00	6.955	-1.924	0.748	0.000	0.276	2.656	2.400	0.000	1.000	3.104	5.795	8.178

which implies the fitted value $\pi^G_{pre} = 0.60$. The figure shows that the subsidy-to-equity ratio tends to be higher in the pre-Lehman period and lower in the post-Lehman period, especially from mid-2013 onwards.

Figure 5: **Subsidy to equity ratio** This figure shows the daily time series of the average ratio of the fitted subsidy to the observed market equity for G-SIBs. We assume $U_m(\widehat{V}) = 0.1$.

6. Discussion and Concluding Remarks

A potential alternative to our main hypothesis could perhaps be based on the idea that, before the crisis, creditors were not aware that big banks could fail. Once Lehman failed and other banks had close calls, creditors became aware of this risk, causing wholesale bank credit spreads to remain elevated. This alternative story is related to beliefs, learning, and perhaps behavioural rather than rational beliefs. This story does not rely on changes in the likelihood of bailout, but rather changes in the likelihood of insolvency.

If this alternative story applies, then the fact that big-bank credit spreads remain very high relative to pre-crisis levels would imply that the crisis-induced increase in the perception of bank failure risk would need to have persisted for a decade after the crisis. However, we are not aware of any evidence that crisis-induced jumps in wholesale big-bank credit spreads persisted well beyond the ends of historical banking crises.

For example, Gorton and Tallman (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-crisis 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. 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 (1) 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 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 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

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

where $y_1(\,\cdot\,)$ is the solution for the value of distress costs in the basic model for a bank with parameters $c, P, B, m, D, d, r, \sigma, k, \alpha$ and κ. This equation implies an explicit solution for $y_{1b}(\widehat{V})$.

The market value of all future tax shields is

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

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

$$y_{3b}(x) \quad = \quad U(x)[\pi\,(\widehat{V} - V^* + y_{3b}(\widehat{V})) + \psi y_3(V^*)]. \qquad \text{(A.1)}$$

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

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

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

$$Y_b(x) = y_0(x) - y_{1b}(x) + y_{2b}(x) + y_{3b}(x) + y_{4b}(x). \qquad \text{(A.3)}$$

The total value of the claims of all current depositors is

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

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

The market value of all claims by current senior bondholders is

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

We have the consistency condition

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

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

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

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

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

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

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

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

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

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 (A.5) and (A.8) to solve for the two boundaries V^* and

$\widehat{V}$.

B. Model Derivations

The expressions for a, b and g in Equation (13) are given by

$$\begin{aligned} a &= \kappa\frac{cP+dD}{r}-\frac{dD}{r}-\zeta \\ b &= \zeta-\pi B-(1-\pi)\left[(\alpha V^*-D)^+\wedge\zeta\right] \end{aligned} \tag{B.1}$$

$$\begin{aligned} g &= -(1-\pi)(1-\alpha)V^*-\pi\, y_1(\widehat{V})-\kappa\frac{cP+dD}{r}+\pi y_2(\widehat{V}) \\ &\quad +\pi\left[\widehat{V}-V^*+y_3(\widehat{V})\right]+(1-\pi)(D-\alpha V^*)^+ +\pi y_4(\widehat{V})+D\frac{d}{r} \\ &\quad -\pi v_1(\widehat{V})-(1-\pi)D-\pi\left[H(\widehat{V})+v_3(\widehat{V})\right]. \end{aligned} \tag{B.2}$$

Equations (3) through (11) imply linear equations for $y_i(\widehat{V})$ and $v_i(\widehat{V})$, for each i, with explicit solutions:

$$y_1(\widehat{V})=\frac{U(\widehat{V})(1-\pi)\,(1-\alpha)V^*}{1-\pi U(\widehat{V})} \qquad y_2(\widehat{V})=\frac{\kappa\frac{cP+dD}{r}(1-U(\widehat{V}))}{1-\pi U(\widehat{V})}$$

$$y_3(\widehat{V})=\frac{\pi\, U(\widehat{V})\,(\widehat{V}-V^*)}{1-\pi U(\widehat{V})} \qquad y_4(\widehat{V})=\frac{(1-\pi)\,U(\widehat{V})(D-\alpha V^*)^+}{1-\pi U(\widehat{V})}$$

$$v_1(\widehat{V})=\frac{D\frac{d}{r}(1-U(\widehat{V}))+(1-\pi)DU(\widehat{V})}{1-\pi U(\widehat{V})} \qquad v_3(\widehat{V})=\frac{\pi\, U(\widehat{V})H(\widehat{V})}{1-\pi U(\widehat{V})}.$$

Substituting $\widehat{V}=h(V^*)$ given in (14) into Equation (B.2), we obtain

$$\begin{aligned} g &= -(1-\pi)(1-\alpha)V^*-\pi\, y_1(h(V^*))-\kappa\frac{cP+dD}{r}+\pi y_2(h(V^*)) \\ &\quad +\pi\left[h(V^*)-V^*+y_3(h(V^*))\right]+(1-\pi)(D-\alpha V^*)^+ +\pi y_4(h(V^*))+D\frac{d}{r} \\ &\quad -\pi v_1(h(V^*))-(1-\pi)D-\pi\left[H(h(V^*))+v_3(h(V^*))\right]. \end{aligned} \tag{B.3}$$

C. Additional Tables and Figures

Table C.1: **Median distance to default** This table shows the median distance to default for G-SIBs, D-SIBs and other firms, assuming that there are no government bailouts. This tables also shows the median distance to default for G-SIBs and D-SIBs, under a government bailout probability ranging from 0.1 to 0.9. 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.

π	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
					G-SIBs					
Pre	1.24	1.30	1.38	1.48	1.61	1.77	1.97	2.22	2.54	2.96
Post	1.02	1.06	1.10	1.17	1.26	1.39	1.55	1.76	2.01	2.40
					D-SIBs					
Pre	2.20	2.35	2.52	2.72	2.93	3.11	3.27	3.39	3.52	3.88
Post	2.26	2.38	2.49	2.61	2.74	2.86	2.94	3.03	3.17	3.42
					Other firms					
Pre	4.55									
Post	4.84									

Table C.2: **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}	y_0	y_1	y_2	y_3	y_4	v_1	v_2	v_3	H	P	V^*	$\widehat{V}$
						Pre-Lehman bailout probability is fitted							
0.30	0.47	3.104	-0.213	0.920	0.230	0.197	1.881	1.202	0.153	1.000	1.227	2.080	2.979
0.20	0.40	3.153	-0.247	0.891	0.191	0.215	1.881	1.190	0.131	1.000	1.227	2.151	3.060
0.10	0.32	3.206	-0.288	0.856	0.153	0.238	1.881	1.175	0.109	1.000	1.227	2.222	3.153
0.00	0.25	3.260	-0.333	0.819	0.119	0.262	1.881	1.158	0.087	1.000	1.227	2.286	3.247
						Pre-Lehman bailout probability is set to zero							
0.00	0.00	3.446	-0.502	0.685	0.000	0.345	1.881	1.093	0.000	1.000	1.227	2.477	3.580

Table C.3: **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}	$y_0 = V_0$	y_1	y_2	y_3	y_4	v_1	v_2	v_3	H	P	V^*	$\widehat{V}$
						Pre-Lehman bailout probability is fitted							
0.30	0.65	0.716	-0.089	0.208	0.129	0.036	0.368	0.418	0.076	0.138	0.430	0.565	0.778
0.20	0.60	0.745	-0.103	0.200	0.120	0.038	0.371	0.415	0.075	0.140	0.433	0.595	0.818
0.10	0.55	0.775	-0.118	0.192	0.112	0.040	0.374	0.412	0.074	0.141	0.437	0.624	0.857
0.00	0.51	0.799	-0.131	0.185	0.106	0.041	0.377	0.409	0.072	0.142	0.440	0.647	0.890
						Pre-Lehman bailout probability is set to zero							
0.00	0.00	1.148	-0.318	0.124	0.000	0.046	0.439	0.396	0.000	0.165	0.513	0.957	1.350

Table C.4: **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}	y_0	y_1	y_2	y_3	y_4	v_1	v_2	v_3	H	P	V^*	$\widehat{V}$
						Pre-Lehman bailout probability is fitted							
0.30	0.47	0.732	-0.050	0.217	0.054	0.046	0.444	0.284	0.036	0.236	0.289	0.491	0.703
0.20	0.40	0.750	-0.059	0.212	0.045	0.051	0.448	0.283	0.031	0.238	0.292	0.512	0.728
0.10	0.32	0.770	-0.069	0.205	0.037	0.057	0.452	0.282	0.026	0.240	0.295	0.533	0.757
0.00	0.25	0.790	-0.081	0.198	0.029	0.063	0.456	0.281	0.021	0.242	0.297	0.554	0.787
						Pre-Lehman bailout probability is set to zero							
0.00	0.00	0.867	-0.126	0.172	0.000	0.087	0.473	0.275	0.000	0.252	0.309	0.623	0.901

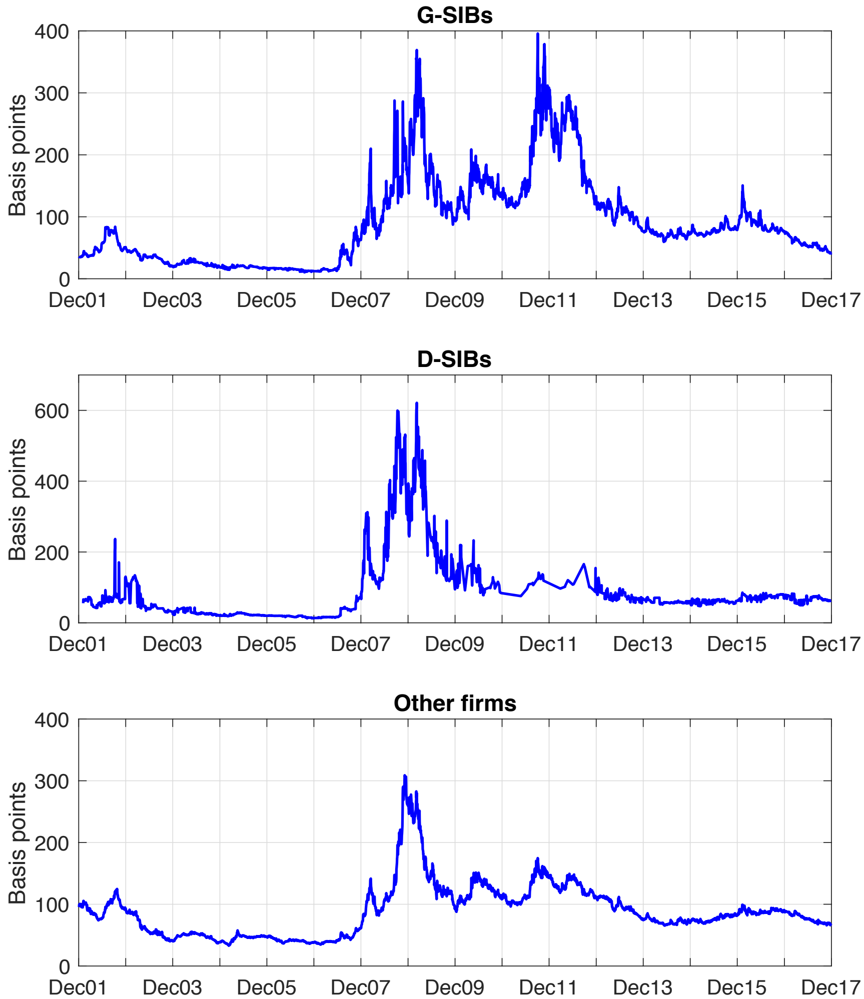

Figure C.1: **Median five-year CDS rates** The figure shows the daily times series of median five-year CDS rates. For G-SIBs and D-SIBs, only those days on which CDS rates are available for four or more firms are shown. For other firms, only days on which CDS rates are available for 50 or more firms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

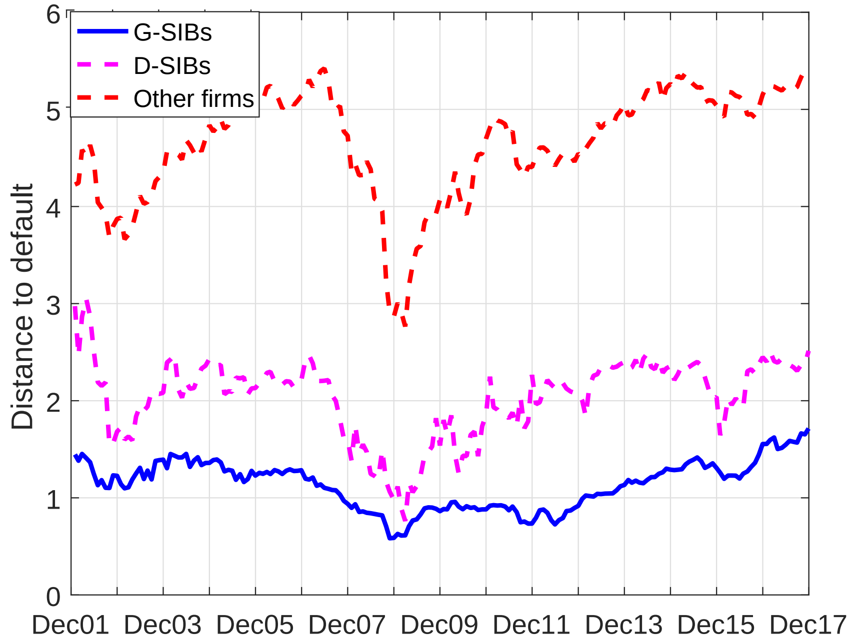

Figure C.2: **Distance to default**. The figure shows the time-series of median distance to default for G-SIBs, D-SIBs and other firms, assuming that there are no government bailouts. The median distance to default is computed across all firms in each subgroup monthly. The sample period is from January 1, 2002 to December 31, 2017.

D. Model Calibration

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

Table D.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 (13) matches observed market equity
σ	Asset volatility	$\sigma_p = \frac{1}{\sqrt{h}} \text{StdDev}\left(\log(V_{t+h}) - \log(V_t^i) \middle| t \in p\right)$
k	Payout rate	$k_p = \text{Mean}\left((\text{CD}_t + \text{IE}_t)/V_t \middle| t \in p\right)$

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

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

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

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

   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 (16). Closed-form solutions are provided in Appendix E.

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

4. Re-compute k_p^i in Equation (D.1) and σ_p^i in Equation (D.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.

E. Solving for the Default Threshold when $U_m(\widehat{V}) = u$

In this section, we derive a closed-form solution for V^* and show that, all else the same, V^* is decreasing in π. Starting with Equation (B.2), we can multiply both sides with $1 - \pi U(\widehat{V})$ to get

$$\begin{aligned} g\left[1 - \pi U(\widehat{V})\right] &= (1-\pi)\left[-\kappa \frac{cP + dD}{r} - (1-\alpha)V^* + (D - \alpha V^*)^+ + D\frac{d}{r} - D\right] \\ &\quad + \pi\left[\widehat{V} - V^* - H(\widehat{V})\right]. \end{aligned} \tag{E.1}$$

Because of Equation (13),

$$\begin{aligned} \widehat{V} - V^* - H(\widehat{V}) &= \widehat{V} - V^* - \left(\widehat{V} + a + bU_m(\widehat{V}) + gU(\widehat{V})\right) \\ &= -V^* - a - b(V^*)U_m(\widehat{V}) - gU(\widehat{V}). \end{aligned}$$

Substituting this equation into (E.1) yields

$$\begin{aligned} g(V^*, \widehat{V}) &= (1-\pi)\left[-\kappa \frac{cP + dD}{r} + (\alpha V^* - D) + (D - \alpha V^*)^+ + D\frac{d}{r}\right] \\ &\quad - \pi\left[a + b(V^*)U_m(\widehat{V})\right] - V^*. \end{aligned} \tag{E.2}$$

Further substituting Equation (E.2) into the the smooth-pasting condition (16) yields

$$\begin{aligned} V^* &= \eta b(V^*) + \gamma(1-\pi)\left[D\frac{d}{r} - \kappa\frac{Pc + Dd}{r} + (\alpha V^* - D) + (D - \alpha V^*)^+\right] \\ &\quad - \gamma\pi\left[a + b(V^*)U_m(\widehat{V})\right] - \gamma V^*, \end{aligned}$$

which can be re-written as

$$\begin{aligned} (1+\gamma)V^* &= \left[\eta - \gamma\pi U_m(\widehat{V})\right] b(V^*) \\ &\quad + \gamma(1-\pi)\left[D\frac{d}{r} - \kappa\frac{Pc + Dd}{r} + (\alpha V^* - D) + (D - \alpha V^*)^+\right] - \gamma\pi a. \end{aligned} \tag{E.3}$$

So far, we have not made use of the assumption $U_m(\widehat{V}) = u$. Making this assumption implies the functional form for B given in Equation (22). Substituting Equation (22) into Equation (B.1), we obtain

$$b = \frac{1-\pi}{1-\pi u}\left(\zeta - \omega(V^*)\right), \tag{E.4}$$

where $\omega(V^*) = (\alpha V^* - D)^+ \wedge \zeta$. Since $U_m = u$, Equation (E.3) becomes

$$\begin{aligned}(1+\gamma)V^* &= [\eta - \gamma\pi u]\frac{(1-\pi)}{1-\pi u}\left(\zeta - \omega(V^*)\right) \\ &\quad + \gamma(1-\pi)\left[D\frac{d}{r} - \kappa\frac{Pc+Dd}{r} + (\alpha V^* - D) + (D - \alpha V^*)^+\right] - \gamma\pi a.\end{aligned} \tag{E.5}$$

When $\alpha\mathbf{V}^* < \mathbf{D}$, Equation (E.5) can be re-written as

$$(1+\gamma)V^* = \eta\zeta\frac{1-\pi}{1-\pi u} + \gamma\pi\zeta\frac{1-u}{1-\pi u} + \gamma\left[D\frac{d}{r} - \kappa\frac{Pc+Dd}{r}\right]. \tag{E.6}$$

Taking derivatives with respect to π yields

$$(1+\gamma)V^{*\prime} = -\eta\zeta\left\{\frac{1-u}{(1-\pi u)^2}\right\} + \gamma\zeta\frac{1-u}{(1-\pi u)^2} < 0.$$

When $\alpha\mathbf{V}^* \in [\mathbf{D}, \zeta + \mathbf{D}]$, Equation (E.5) can be re-stated as

$$\begin{aligned}\left[(1-\pi u)(1+\gamma) + (\eta-\gamma)(1-\pi)\alpha\right]V^* &= \{\eta(1-\pi) + \gamma\pi\}(\zeta + D) - \gamma\pi u\zeta \\ &\quad + \gamma\left[D\frac{d}{r} - \kappa\frac{Pc+Dd}{r} - D\right] - \pi u\gamma\left[D\frac{d}{r} - \kappa\frac{Pc+Dd}{r}\right].\end{aligned} \tag{E.7}$$

Taking derivatives with respect to π on both sides yields

$$\left[(1-\pi u)(1+\gamma) + (\eta-\gamma)(1-\pi)\alpha\right]V^{*\prime} = -(\eta-\gamma)\left(\zeta + D - \alpha V^*\right) + u\left\{(1+\gamma)V^* + \gamma a\right\}.$$

It is straightforward to show that

$$(1+\gamma)V^* + \gamma a = \frac{(\eta-\gamma)(1-\pi)}{1-\pi u}\left(\zeta + D - \alpha V^*\right). \tag{E.8}$$

Thus,

$$[(1-\pi u)(1+\gamma)+(\eta-\gamma)(1-\pi)\alpha]\, V^{*\prime} \;\; = \;\; -(\eta-\gamma)\frac{1-u}{1-\pi u} < 0.$$

When $\alpha\mathbf{V}^* > \zeta + \mathbf{D}$, Equation (E.5) can be re-stated as

$$[1+\gamma-\gamma\alpha+\gamma\alpha\pi]\, V^* \;\; = \;\; \gamma\left[D\frac{d}{r}-\kappa\frac{Pc+Dd}{r}-D\right]+\gamma\pi\,(\zeta+D)\,. \tag{E.9}$$

Taking derivatives with regard to π yields

$$\gamma\alpha V^* + [1+\gamma-\gamma\alpha+\gamma\alpha\pi]\, V^{*\prime} \;\; = \;\; \gamma\,(\zeta+D)\,,$$

which implies

$$[1+\gamma(1-\alpha)+\gamma\alpha\pi]\, V^{*\prime} \;\; = \;\; -\gamma\,(\alpha V^* - (\zeta+D)) < 0.$$

In summary, everything else the same, V^* is a decreasing function of π. This is visualized in Figure E.1.

F. Default Threshold and Estimation Results when $B = P$

In this section, we report estimation results for the case where the government's capital injection is such that it brings the market value of the bonds up to some the par value, i.e., $B = P$. Before presenting the results, we show that when B is constant, V^* is the solution of a quadratic equation.

Scenario 1: $\alpha\mathbf{V}^* < \mathbf{D}$ For the case where $\alpha V^* - D < 0$, Equation (B.1) states

$$b(V^*) \;\; = \;\; \frac{P(c+m)}{r+m} - \pi B,$$

which allows us to rewrite Equation (E.3) as

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

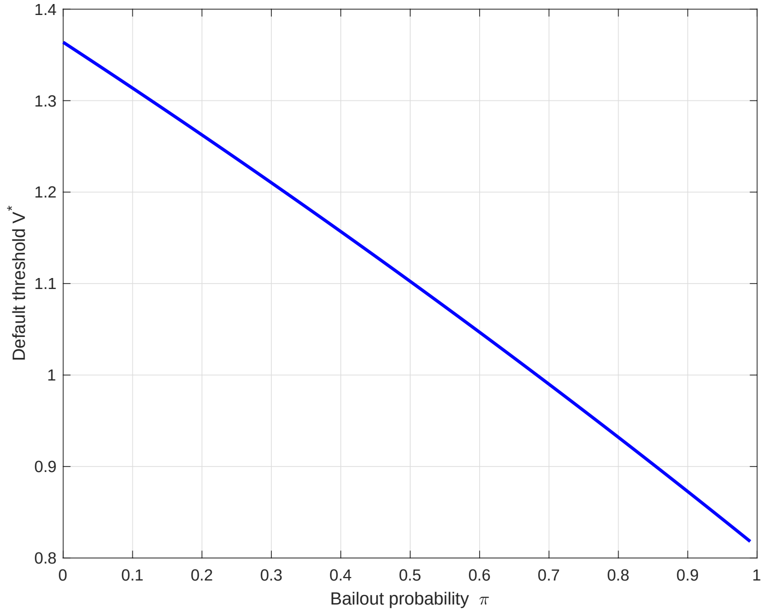

Figure E.1: **Default threshould as a function of bailout probability**. The figure shows the fitted default threshold for Citigroup on December 29, 2017, for various values of the bailout probability π. We set σ equal to the sample standard deviation of log book asset growth in the post-Lehman period, and $k = \rho r$ where ρ is such that the average ratio of cash dividends plus interest expense to book assets is equal to ρ time the average risk-free rate.

The consistency condition (14) states

$$U_m(\widehat{V}) \quad = \quad \frac{B-\zeta}{\pi B - \zeta}.$$

Thus,

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

The assumption $\alpha V^* - D < 0$ translates into an associated restriction on the model parameters:

$$\left[\eta - \gamma\pi\frac{B-\zeta}{\pi B-\zeta}\right]\left(P\frac{c+m}{r+m} - \pi B\right) + \gamma(1-\pi)\left[D\frac{d}{r} - \kappa\frac{Pc+Dd}{r}\right] - \gamma\pi a \quad \leq \quad \frac{D}{\alpha}(1+\gamma).$$

Scenario 2: $\alpha\mathbf{V}^* \geq \mathbf{D}$ For the case where $\alpha V^* - D \geq 0$, Equation (B.1) becomes

$$b(V^*) \quad = \quad P\frac{c+m}{r+m} - \pi B - (1-\pi)(\alpha V^* - D).$$

From Equation (E.3), we know that

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

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

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

We can now substitute the consistency condition (14), which states

$$
U_m(\widehat{V}) = \frac{B-\zeta}{\pi B + (1-\pi)(\alpha V^* - D) - \zeta},
$$

into Equation (F.1) to get a quadratic equation for V^*.

In summary, V^* is given as the solution of a quadratic equation.

Figure F.1 shows our estimates for $\overline{\delta}^G_{\text{post}} - \overline{\delta}^G_{\text{pre}}$ and $\overline{\delta}^D_{\text{post}} - \overline{\delta}^D_{\text{pre}}$, as a function of various pre-Lehman bailout probabilities π^G_{pre} and π^D_{pre}. The post-Lehman bailout probabilities for large banks are set to 0.2. We find that the identifying constraints (20) are satisfied for $\pi^G_{pre} = 0.65$ and $\pi^D_{pre} = 0.45$. Alternatively, when the post-Lehman bailout probability is set to zero, the identifying constraints are satisfied for $\pi^G_{pre} = 0.55$ and $\pi^D_{pre} = 0.35$.

These fitted bailout probabilities are reported in the second column of Table 4 for G-SIBs and Table C.2 for D-SIBs. The remaining columns of Table 4 (Table C.2) show—for the fitted bailout probabilities—the decomposition of the total net cash flows of the average pre-Lehman G-SIB (D-SIB) into its components. A higher assumed post-Lehman bailout probability results in a higher pre-Lehman π. For the pre-Lehman period, when the bailout probability is higher, the fitted assets in place are lower, the implied default threshold is lower and the market value of debt is higher. Independent of the

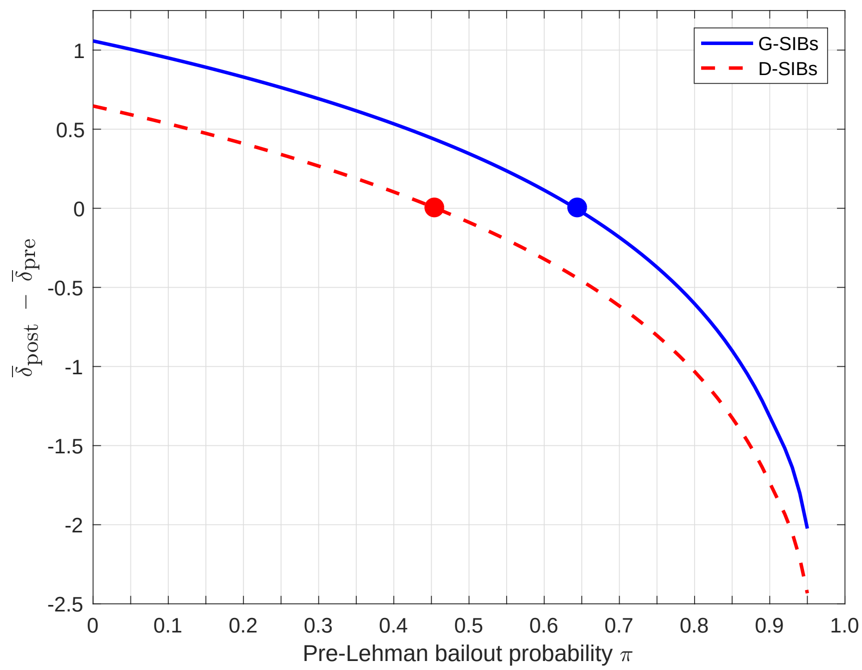

Figure F.1: **Change in big-bank coefficients** This figure shows the estimates for $\bar{\delta}^G_{\text{post}} - \bar{\delta}^G_{\text{pre}}$ and $\bar{\delta}^D_{\text{post}} - \bar{\delta}^D_{\text{pre}}$ in the panel regression (19), as a function of the pre-Lehman bailout probability π^G_{pre}. The post-Lehman bailout probabilities for large banks are set to 0.2. We assume $B = P$.

assumed post-Lehman bailout probability, the market value of the government subsidy, y_3, is about 120% of the value of market equity. About 0.97 of this is due to the subsidy at the next bailout, $U(x)\pi(\widehat{V} - V^*)$, and 0.27 is due to subsidies at subsequent bailouts, $U(x)\pi y_3(\widehat{V})$.

While Table F.1 reports components as fraction of market equity, Table F.2 reports them as fractions of total net cash flow.

Figure F.2 shows the daily time series of the average ratio of the fitted market value of all future government subsidies to the observed market value of equity, across all G-SIBs. We assume $\pi_{post} = 0.20$, which implies the fitted value $\pi^G_{pre} = 0.65$. The figure shows that the subsidy-to-equity ratio tends to be higher in the pre-Lehman period and lower in the post-Lehman period, especially from mid-2013 onwards.

Table F.1: **Firm value components of G-SIBs, scaled by market equity** The top panel 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 $Y = y_0 - y_1 + y_2 + y_3 + y_4 = v_1 + v_2 + v_3 + H$. 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. The bottom panel reports similar results for D-SIBs. We assume $B = P$.

π_{post}	π_{pre}	$y_0 = V_0$	y_1	y_2	y_3	y_4	v_1	v_2	v_3	H	P	V^*	$\widehat{V}$
G-SIBs													
Pre-Lehman bailout probability is fitted													
0.20	0.65	5.275	-0.503	1.634	1.240	0.208	2.653	2.971	1.230	1.000	3.104	4.045	6.877
0.00	0.55	5.565	-0.685	1.497	1.232	0.237	2.653	2.894	1.297	1.000	3.104	4.374	7.719
Pre-Lehman bailout probability is set to zero													
0.00	0.00	6.953	-1.921	0.749	0.000	0.275	2.653	2.400	0.000	1.000	3.104	5.795	12.192
D-SIBs													
Pre-Lehman bailout probability is fitted													
0.20	0.45	3.141	-0.202	0.933	0.333	0.176	1.879	1.191	0.311	1.000	1.227	2.100	3.839
0.00	0.35	3.202	-0.252	0.889	0.285	0.207	1.879	1.174	0.277	1.000	1.227	2.192	4.103
Pre-Lehman bailout probability is set to zero													
0.00	0	3.446	-0.501	0.684	0.000	0.345	1.879	1.093	0.000	1.000	1.227	2.477	5.213

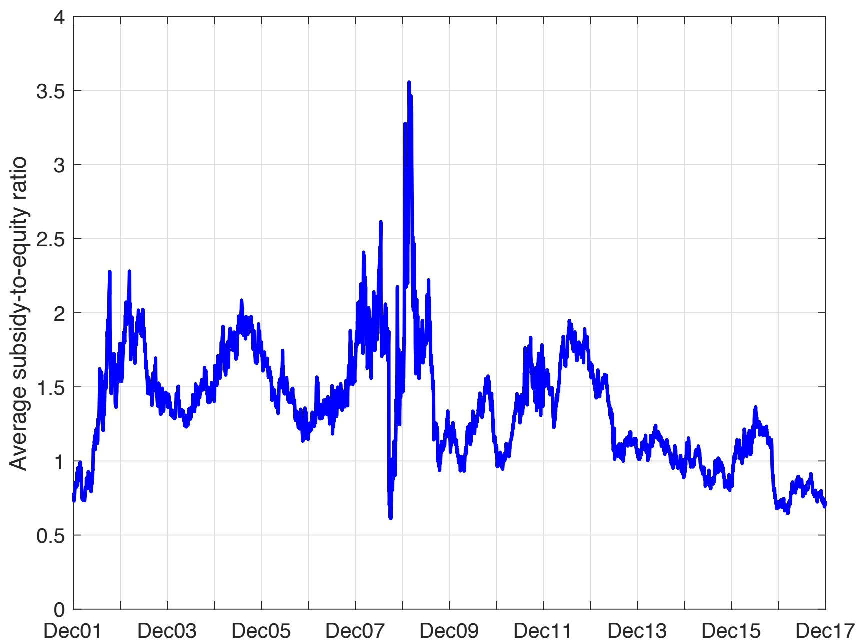

Figure F.2: **Subsidy to equity ratio** This figure shows the daily time series of the average ratio of the fitted subsidy to the observed market equity for G-SIBs. We assume $B = P$.

Table F.2: **Firm value components, scaled by total net cash flow** The top panel 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. The bottom panel reports similar results for D-SIBs. We assume $B = P$.

π_{post}	π_{pre}	y_0	y_1	y_2	y_3	y_4	v_1	v_2	v_3	H	P	V^*	$\widehat{V}$
							G-SIBs						
							Pre-Lehman bailout probability is fitted						
0.20	0.65	0.672	-0.064	0.208	0.158	0.027	0.338	0.378	0.157	0.127	0.395	0.515	0.875
0.00	0.55	0.709	-0.087	0.191	0.157	0.030	0.338	0.369	0.165	0.127	0.396	0.557	0.984
							Pre-Lehman bailout probability is set to zero						
0.00	0.00	1.148	-0.317	0.124	0.000	0.045	0.438	0.396	0.000	0.165	0.513	0.957	2.013
							D-SIBs						
							Pre-Lehman bailout probability is fitted						
0.20	0.45	0.717	-0.046	0.213	0.076	0.040	0.429	0.272	0.071	0.228	0.280	0.479	0.876
0.00	0.35	0.739	-0.058	0.205	0.066	0.048	0.434	0.271	0.064	0.231	0.283	0.506	0.947
							Pre-Lehman bailout probability is set to zero						
0.00	0	0.867	-0.126	0.172	0.000	0.087	0.473	0.275	0.000	0.252	0.309	0.623	1.312

G. Elasticity of Assets in Place with regard to Default Threshold when $U_m(\widehat{V}) = u$

For a given observed value of market equity, assets in place x are given as the solution to Equation (13):

$$\widetilde{H} \quad = \quad x + a + bU_m(x) + gU(x), \tag{G.1}$$

where $x \geq V^*$. We are interested in how x depends on V^*. Note that $\pi = \pi(V^*)$, $b = b(V^*)$ and $g = g(V^*)$ all depend on V^*. We differentiate (G.1) with respect to V^* to obtain

$$0 \quad = \quad x' + b'U_m + bU'_m + g'U + gU'. \tag{G.2}$$

Here,

$$U'_m = -\eta U_m \frac{1}{x}\left(x' - \frac{x}{V^*}\right), \qquad U' = -\gamma U \frac{1}{x}\left(x' - \frac{x}{V^*}\right).$$

Substituting U_m' and U' into Equation (G.2), we obtain

$$x' = -\frac{x}{V^*}\frac{b'U_mV^* + g'UV^* + b\eta U_m + g\gamma U}{x - b\eta U_m - g\gamma U}$$

and

$$\frac{\partial x/x}{\partial V^*/V^*} = \frac{-(b'U_m + g'U)V^* - b\eta U_m - g\gamma u}{x - b\eta U_m - g\gamma U}.$$

Since $\partial H(x)/\partial x > 0$ for $x > V^*$, we have

$$0 < x - b\eta U_m - g\gamma U.$$

Thus, the elasticity $\frac{\partial x/x}{\partial V^*/V^*}$ is less than one as long as

$$-\left(b'U_m + g'U\right) < \frac{x}{V^*}. \tag{G.3}$$

In what follows, we use the assumption that $U_m(\widehat{V}) = u$. Equation (E.4) states

$$b = \frac{1-\pi}{1-\pi u}\left[\zeta - \left((\alpha V^* - D)^+ \wedge \zeta\right)\right]. \tag{G.4}$$

With $U_m(\widehat{V}) = u$, Equation (E.2) is

$$g = \left[-\kappa\frac{cP + dD}{r} + (\alpha V^* - D) + (D - \alpha V^*)^+ + D\frac{d}{r}\right] - \pi\left[(\alpha V^* - D) + (D - \alpha V^*)^+ - \zeta\right]$$
$$- \pi bu - V^*.$$

When $\alpha\mathbf{V}^* < \mathbf{D}$, we have

$$b = \frac{1-\pi}{1-\pi u}\zeta,$$
$$b' = -\pi'\frac{1-u}{(1-\pi u)^2}\zeta$$

and

$$
\begin{aligned}
g &= \left[-\kappa\frac{cP+dD}{r}+D\frac{d}{r}\right]+\pi\zeta-\pi bu-V^{*} \\
g' &= \pi'\zeta-(\pi' b+b'\pi)u-1.
\end{aligned}
$$

Taking derivatives in Equation (E.6) with respect to V^{*}, and solving for π', yields

$$
\pi' = -\frac{(1+\gamma)(1-\pi u)^2}{(\eta-\gamma)(1-u)\zeta}<0.
$$

Plugging this expression for π' into those for b' and g', we obtain

$$
\begin{aligned}
-(b'U_m+g'U) &= \pi'\frac{1-u}{(1-\pi u)^2}\zeta U_m-\left\{\pi'\zeta-\pi'\zeta\left[\frac{1-\pi}{1-\pi u}-\frac{1-u}{(1-\pi u)^2}\pi\right]u-1\right\}U \\
&= -\frac{1+\gamma}{\eta-\gamma}U_m+\frac{1+\eta}{\eta-\gamma}U.
\end{aligned}
$$

In what follows, we prove that

$$
-\frac{1+\gamma}{\eta-\gamma}U_m+\frac{1+\eta}{\eta-\gamma}U < \frac{x}{V^{*}}, \tag{G.5}
$$

for $x>V^{*}$, which implies that the inequality (G.3) holds. To keep notation simple, we use v to denote $\frac{x}{V^{*}}$. For $v=1$, it is straightforward to show that (G.5) holds with equality. When $v>1$, we rewrite (G.5) as

$$
-\frac{1+\gamma}{\eta-\gamma}+\frac{1+\eta}{\eta-\gamma}v^{\eta-\gamma} < v^{\eta+1}. \tag{G.6}
$$

The derivative of the left-hand side of (G.6) with regard to v is $(1+\eta)v^{\eta-\gamma-1}$, the derivative of the right-hand side is $(1+\eta)v^{\eta}$. Since $v>1$, the derivative of the left-hand side of (G.6) is smaller than that on the right-hand side. Since (G.6) holds with equality for $v=1$, it holds as inequality for $v>1$.

When $\alpha\mathbf{V}^* \in [\mathbf{D}, \zeta + \mathbf{D}]$, we have

$$\begin{aligned} b &= \frac{(1-\pi)}{1-\pi u}\left[\zeta - \alpha V^* + D\right] \\ b' &= -\frac{1-\pi}{1-\pi u}\alpha - \frac{\pi'(1-u)}{(1-\pi u)^2}\left[\zeta - \alpha V^* + D\right] \end{aligned}$$

and

$$\begin{aligned} g &= \left[-\kappa\frac{cP+dD}{r} + (\alpha V^* - D) + D\frac{d}{r}\right] - \pi\left[\alpha V^* - D - \zeta\right] - \pi b u - V^* \\ g' &= \alpha - \pi'\left[\alpha V^* - D - \zeta\right] - \pi\alpha - (\pi' b + b'\pi)u - 1. \end{aligned}$$

Taking derivatives in Equation (E.6) with respect to V^* and solving for π' yields

$$\pi' = \frac{(1-\pi u)(1+\gamma) + (\eta-\gamma)(1-\pi)\alpha}{(1+\gamma)uV^* - (D+\zeta-\alpha V^*)(\eta-\gamma) + a\gamma u}.$$

Solving Equation (E.8) for V^* and substituting the expression for V^* into the previous equation allows us to rewrite π' as

$$\pi' = -\frac{\left[(1-\pi u)(1+\gamma) + (\eta-\gamma)(1-\pi)\alpha\right](1-\pi u)}{(\eta-\gamma)(1-u)(\zeta + D - \alpha V^*)}.$$

Plugging this expression for π' into those for b' and g', we obtain $g' = -(1+\eta)/(\eta-\gamma)$ and $b' = (1+\gamma)/(\eta-\gamma)$. Thus,

$$\begin{aligned} -(b'U_m + g'U) &= -\frac{1+\gamma}{\eta-\gamma}U_m + \frac{1+\eta}{\eta-\gamma}U \\ &< \frac{x}{V^*}. \end{aligned}$$

The last inequality follows as for the case where $\alpha\mathbf{V}^* < \mathbf{D}$.

When $\alpha\mathbf{V}^* > \zeta + \mathbf{D}$, we have $B = \zeta$, $b = 0$ and

$$g = \left[-\kappa\frac{cP+dD}{r} + (\alpha V^* - D) + D\frac{d}{r}\right] - \pi\left[(\alpha V^* - D) - \zeta\right] - V^*.$$

Taking derivatives with respect to V^* yields $b' = 0$ and

$$g' = \alpha - \pi' \left[(\alpha V^* - D) - \zeta\right] - \pi\alpha - 1.$$

Taking derivatives in Equation (E.9) with respect to V^*, and solving for π', yields

$$\pi' = \frac{1}{\gamma}\frac{1 + \gamma - \gamma\alpha + \gamma\alpha\pi}{\zeta + D - \alpha V^*}.$$

Thus,

$$\begin{aligned} -(b'U_m + g'U) &= -\{\alpha + \pi' \left[\zeta + D - \alpha V^*\right] - \pi\alpha - 1\}U \\ &= -\frac{U}{\gamma} < 0, \end{aligned}$$

meaning the inequality (G.3) holds.

Figure G.1 shows the fitted elasticity of assets in place with regard to the default threshold for Citigroup on December 29, 2017.

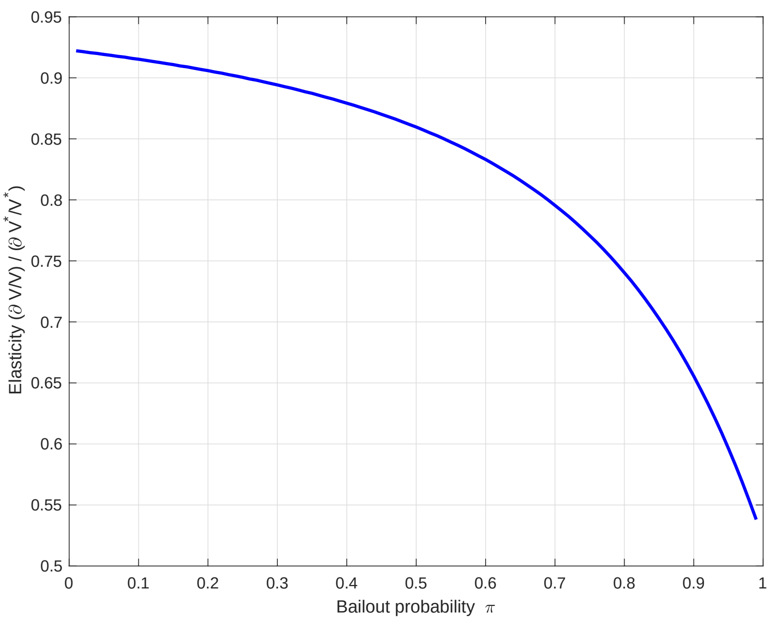

Figure G.1: **Elasticity of assets in place with regard to the default threshold**. The figure shows the fitted elasticity of assets in place with regard to the default threshold for Citigroup on December 29, 2017, for various values of the bailout probability π. We set σ equal to the sample standard deviation of log book asset growth in the post-Lehman period, and $k = \rho r$ where ρ is such that the average ratio of cash dividends plus interest expense to book assets is equal to ρ time the average risk-free rate.