Are Basel's Capital Surcharges for Global Systemically Important Banks Too Small?*

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The Basel Committee promulgates bank regulatory standards, including capital surcharges for global systemically important banks (G-SIBs). Our analysis suggests that the Basel III capital surcharge framework underestimates the probability of bank failure, wrongly disregards short-term funding, and excludes too many banks; our baseline estimate suggests surcharges should increase 3.00 to 8.25 percentage points and that even higher surcharges should apply to G-SIBs that rely on short-term funding. Our findings, which do not account for Basel III beyond the capital surcharges, may differ from the findings of a comprehensive analysis of Basel III.

JEL Codes: G01, G18, G21.

1. Introduction

The Basel Committee on Banking Supervision (BCBS, the Basel Committee, or Basel) has developed a methodology for identifying global systemically important banks (G-SIBs) and assessing a higher

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loss absorbency (HLA) requirement (BCBS 2013b).[1] To accomplish higher loss absorbency, the Basel III standards require G-SIBs to hold more common equity tier 1 (CET1) capital. According to the Basel Committee, adding common equity reduces the probability of failure for these banks (BCBS 2013b). G-SIB capital surcharges are one of many policies—including stricter supervision, stress testing, liquidity requirements, additional leverage ratios, and recovery and resolution requirements—applied to G-SIBs to directly target "too big to fail" concerns surrounding the largest banks. As part of this process, the Financial Stability Board (FSB) annually releases a list of banks that the Basel Committee has identified as G-SIBs; the FSB published an updated G-SIB list (table 1) on November 21, 2017 (FSB 2017).[2] The list provides a G-SIB score for each bank. The Basel III framework uses the G-SIB score as a measure of systemic losses should the bank fail (we provide more detail about this measure in section 3). The list also provides the capital surcharges that, according to the Basel Committee, equalize the expected social impact of a G-SIB failure to the expected social losses of the failure of a bank that is not a G-SIB.

One goal of G-SIB capital surcharges is to make government bailouts of G-SIBs less likely by having G-SIBs self-insure themselves against severe financial crises. Traditionally, central banks would stand ready to lend to solvent banks on good collateral, or the government would implement some other assistance (e.g., the Troubled Asset Relief Program) to mitigate the catastrophic losses

[1] According to the Basel Committee, "The BCBS is the primary global standard-setter for the prudential regulation of banks and provides a forum for cooperation on banking supervisory matters. Its mandate is to strengthen the regulation, supervision, and practices of banks worldwide with the purpose of enhancing financial stability" (BCBS 2013a). "The Committee seeks to achieve its aims by setting minimum standards for the regulation and supervision of banks; by sharing supervisory issues, approaches and techniques to promote common understanding and to improve cross-border cooperation; and by exchanging information on developments in the banking sector and financial markets to help identify current or emerging risks for the global financial system" (BCBS 2015).

[2] The Financial Stability Board (FSB) succeeded the Financial Stability Forum (FSF), which was established by the G-7 finance ministers and central bank governors in 1999. To strengthen its mandate and increase membership, the G-20 replaced the FSF with the FSB in April 2009. For analysis of previously published G-SIB scores, see Glasserman and Loudis (2015) and Allahrakha and Loudis (2016).

Table 1. Basel G-SIB Capital Surcharges

Bucket	Capital Surcharge (CET1)	G-SIB Score Range (Basis Points)	2017 List of G-SIBs (In Alphabetical Order)
5	+3.5%	530–629	(Empty)
4	+2.5%	430–529	JPMorgan Chase
3	+2.0%	330–429	Bank of America Citigroup Deutsche Bank HSBC
2	+1.5%	230–329	Bank of China Barclays BNP Paribas China Construction Bank Goldman Sachs Industrial and Commercial Bank of China Limited Mitsubishi UFJ FG Wells Fargo
1	+1.0%	130–229	Agricultural Bank of China Bank of New York Mellon Credit Suisse Groupe Crédit Agricole ING Bank Mizuho FG Morgan Stanley Nordea Royal Bank of Canada Royal Bank of Scotland Santander Société Générale Standard Chartered State Street Sumitomo Mitsui FG UBS Unicredit Group

Source: Financial Stability Board (2017).
Notes: A G-SIB is a global systemically important bank. CET1 is common equity tier 1 capital.

stemming from severe financial crises. However, to avoid *all* public bailouts, banks must self-insure against all losses, even catastrophic losses. Such self-insurance might result in restrictive credit conditions during times without financial crisis, but this policy would reassure taxpayers that public funds would not be used to assist G-SIBs. A complete assessment of the effect of higher bank capital requirements on social welfare would need to investigate both the reduction of the probability of financial crises and the potential reduction of bank lending and economic growth.

In the following analysis, we assume that the purpose of the surcharges is to self-insure G-SIBs through financial crises and to avoid extraordinary public assistance; in addition, we set aside the other elements of Basel III reforms, beyond the capital surcharges. We find that the current G-SIB capital surcharges are too small based on the experience of the 2008–09 financial crisis. Our baseline estimate of G-SIB capital surcharges would (i) raise capital requirements between 5.50 and 8.25 percentage points for banks currently subject to G-SIB capital surcharges, (ii) create an additional surcharge of 3.00 percent for very large and systemically important banks that are not currently subject to any G-SIB capital surcharge, and (iii) include a short-term funding metric that further boosts capital surcharges 1.75 to 5.75 percentage points for banks that fund assets with a high proportion of short-term funding.[3] Based on FSB (2017), a back-of-the-envelope calculation implies that the banking system would have needed at least €425 billion more CET1 capital to survive a financial crisis similar to that of 2008 to 2009 without bailouts.[4]

[3]These capital surcharges are in the spirit of French et al. (2010), who recommend increased capital requirements based on size, asset liquidity, and short-term funding. The quoted range of increases is based on estimated continuous capital surcharge functions.

[4]This aggregate capital shortfall is the sum of individual CET1 capital shortfalls for banks in the BCBS sample (that have data reported in Bureau Van Djik 2017). The calculation is based on their current equity holdings, most of which are above regulatory minimums. For each bank, we calculate the level of CET1 capital required under our baseline estimate as risk-weighted assets times the sum of the G-SIB capital surcharge, the high short-term funding boost (if the bank's short-term funding is more than 10 percent of its risk-weighted assets), the capital conservation buffer, and the minimum capital ratio (BCBS 2010). If banks perceive current equity cushions above regulatory minimums as necessary to maintain, then the aggregate capital shortfall would be larger. In addition, since we estimate surcharges using data from the 2008–09 financial crisis, this

The average G-SIB would need additional capital equal to 1.52 percent of its risk-weighted assets. Including the short-term funding surcharge increases the amount of capital needed by €200 billion; the top five G-SIBs generate over 60 percent of this increase, and the top ten G-SIBs generate about 90 percent.

Basel III is a comprehensive set of "reforms to strengthen global capital and liquidity rules with the goal of promoting a more resilient banking sector." The Basel III framework includes numerous banking reforms, such as the countercyclical capital buffer, the supplemental leverage ratio, the liquidity coverage ratio (LCR), the net stable funding ratio (NSFR), the total loss-absorbing capacity proposal, and resolution plans (for detailed descriptions of these reforms, see BCBS 2010; Duffie 2016; and Baker, Cumming, and Jagtiani 2017). Because our approach omits aspects of Basel III other than capital surcharges, our estimates may be biased upward. Offsetting this upward bias is the fact that returns on assets at the largest banks may have been significantly supported by government action during and after the financial crisis; such enhancements would cause us to underestimate the need for G-SIB capital if the goal was to minimize public assistance during a crisis. The net effect of these caveats for our estimates is difficult to determine.

As an alternative to our baseline estimate, we estimate capital surcharges based on the 95 percent confidence interval around our baseline estimates. The upper bound may appeal to observers who doubt the effectiveness of additional Basel III reforms and post-crisis national regulations or who believe that G-SIBs' returns to assets during the financial crisis were significantly enhanced by public interventions; therefore, we refer to these estimates as pessimistic. These observers desire the highest capital levels that would have likely prevented almost all G-SIB defaults during the 2008–09 financial crisis. In contrast, the lower bound may appeal to observers who believe that the lessons from the 2008–09 financial crisis, the other reforms of Basel III, and the actions of national bank regulators and government will likely lower the losses associated with a financial crisis relative to recent history. Indeed, Basel III includes many substantial

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aggregate capital shortfall presumes that governments take similar actions to shore up the financial system during a future crisis. If governments intervene in a less forceful manner, then the aggregate capital shortfall would be even larger.

changes to bank regulation and supervision, as enumerated above. We refer to these estimates as optimistic. Because the optimistic capital surcharges are still higher than the current surcharges, our estimates suggest that Basel III capital surcharges may be too small unless other reforms (those of Basel III or other regulatory bodies) have induced significant changes in banking systems.

1.1 The Expected Impact Theory

The Basel Committee's approach to capital surcharges is based on the expected impact theory (BCBS 2013b; Board of Governors of the Federal Reserve System 2015), which uses three key features to derive capital surcharges: (i) an estimation of probability of default, $F(\cdot)$; (ii) a method of measuring social losses given default, $H(\cdot)$; and (iii) a choice of a reference bank, r. The estimation of probability of default relates the level of capital held by a bank to the probability of its default.[5] The social losses given default of a bank are the costs incurred by that bank's failure to the financial system and the wider economy. The expected impact of a bank's failure is the product of the probability of its default and the social losses given its default. The reference bank defines the extent of social losses that would be borne by the public without a "bailout." In the expected impact theory, a bank is either a G-SIB, whose social losses given default are higher than that of the reference bank, or a "normal" bank, whose social losses given default are lower. Thus, the reference bank is the

[5] Jordà et al. (2017) empirically explore the relationship between bank capital ratios and probability of financial crises: "A high capital ratio is a direct measure of a well-funded loss-absorbing buffer. However, more bank capital could reflect more risk-taking on the asset side of the balance sheet. Indeed, we find in fact that there is no statistical evidence of a relationship between higher capital ratios and lower risk of systemic financial crisis. If anything, higher capital is associated with higher risk of systemic financial crisis." Their findings do not support increasing capital to reduce the probability of default of G-SIBs. However, they do find that if a banking system is better capitalized before a financial crisis, a recession resulting from the financial crisis is not as bad: "We have also presented evidence that, conditional on being in a crisis, higher initial capital ratios are associated with significantly shallower recessions. From a social cost standpoint, in terms of GDP losses, the long record of macroeconomic experience shows that economies with better capital banking systems appear to weather financial storms more successfully than those with lower capital ratios." This study suggests that G-SIBs should hold higher capital in order to reduce their social losses given default (instead of their probability of default, as in the expected impact theory).

most systemically important bank that public authorities are willing to let fail; in other words, no public assistance would be provided to the reference bank should it default. In the expected impact theory, the purpose of the G-SIB capital surcharges is to reduce the probability of default of a G-SIB until its expected impact is equal to the expected impact of the reference bank:

$$\frac{F(f - k_r - k_{GSIB})}{F(f - k_r)} = \frac{H(r)}{H(GSIB)} \leq 1,$$

where k_r is the capital held by the reference bank, k_{GSIB} is the capital surcharge, and f is a proxy for the failure point at which a bank can no longer operate.[6]

By definition, it is impossible to observe the default of a G-SIB. Indeed, during the 2008–09 financial crisis, governments took aggressive actions—mergers, asset purchases, guarantee programs, and equity injections—to prevent G-SIB defaults. Because historical defaults are difficult to observe, we use a "distance to default" approach, in which extremely low returns on risk-weighted assets (RORWAs) indicate failure (as in BCBS 2013b and Board of Governors 2015).[7] The RORWA that yields failure is $k + RORWA' \leq f$ or $RORWA' \leq f - k$. Hence a distribution of RORWA describes the distribution of $f - k$. We estimate a Gumbel distribution—a special case of the generalized extreme value distribution—for RORWA (Gumbel 1958):

$$F(RORWA) = e^{-t(RORWA)},$$

$$\text{where } t(RORWA) = e\frac{-(RORWA \ - \mu)}{\sigma}.$$

We discuss our choice of the Gumbel distribution at length in the appendix.[8] Substituting in the Gumbel distribution and letting the

[6]Detailed derivations of the equations in this paper can be found in Passmore and von Hafften (2017).

[7]We use return on risk-weighted assets instead of return on assets because the relevant regulatory failure standard for banks in this paper is in terms of risk-weighted assets.

[8]The expected impact theory, which translates the estimated RORWA probability distribution into capital surcharges, requires certain characteristics of the

capital conservation buffer, CC, be the difference between the reference bank capital and the failure point, we solve for an explicit formula of the capital surcharge[9]:

$$k_{GSIB} = \sigma \ln \left[1 - e^{\frac{-CC-\mu}{\sigma}} \ln \left(\frac{H(r)}{H(GSIB)} \right) \right].$$

A larger capital surcharge results from higher G-SIB scores, lower reference bank scores, or RORWA distributions with lower location (μ) and larger scale (σ). In addition, capital surcharges are concave with respect to the G-SIB score.[10] The concavity reflects the fact that only "double exponential" distributions satisfy desired statistical properties for models of the tails of probability distributions (de Haan and Ferreira 2006). As a result, expanding the buffer between the capital the G-SIB holds and the failure point diminishes the probability of failure at an increasing rate for a given increment of the G-SIB score.

This paper proceeds as follows: Section 2 estimates the probability of default (μ, σ in the previous equation) and analyzes short-term funding as a crucial element missing from the G-SIB assessment methodology. Section 3 describes the method of measuring social

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probability distribution's functional form. The Gumbel distribution is one such distribution. Although other distributions can be used, the Gumbel distribution easily and tractably results in capital surcharges. The Gumbel distribution allows us to derive a continuous and straightforward solution for the G-SIB surcharge based on the expected impact theory. As mentioned in the text, we discuss this choice at length in the appendix.

[9] We discuss the capital conservation buffer in more detail in appendix 2 of Passmore and von Hafften (2017). When we estimate capital surcharges, we will equate the capital conservation buffer to 2.5 percent of risk-weighted assets (as is done in the Basel III framework). In other words, we assume the reference bank holds the minimum amount of capital needed to avoid restricted dividend payments and stock repurchases but holds no discretionary capital cushions beyond regulatory requirements.

[10] The concavity of our estimated G-SIB capital surcharges with respect to the G-SIB score contrasts with Basel III capital surcharges. For occupied buckets (buckets 1–4), Basel III capital surcharges linearly increase (as seen in figure 4). In addition, the capital surcharge increase between the highest occupied bucket (bucket 4) and (yet) unoccupied bucket (bucket 5) is larger than the capital surcharge increases between occupied buckets. The rationale behind this convexity with respect to the G-SIB score is to create a disincentive for the largest G-SIBs to increase their systemic footprint (and thus their G-SIB score). Such "ex post" adjustments could also be made to our system to create similar disincentives.

losses given default used in Basel III ($H(\cdot)$ in the previous equation). Section 4 examines the choice of reference bank (r in the previous equation). Section 5 compares current Basel III capital surcharges with estimated capital surcharges. Section 6 concludes.

2. Probability of Default

By estimating the probability of default, we seek to relate the level of capital held by a bank to the likelihood of its failure. As set forth in the introduction, we use extremely low RORWA as an indication of failure and assume the Gumbel distribution functional form. In general, a higher mean of RORWA and a lower variance of RORWA yields lower capital surcharges; higher average returns generate lower capital surcharges because banks are less likely to experience losses that deplete their capital stock.[11] More formally, the derivative of the capital surcharge formula with respect to μ yields the following:

$$\frac{\partial k_{GSIB}}{\partial \mu} = \left[\left[e^{\frac{-CC-\mu}{\sigma}} \ln\left(\frac{H(r)}{H(GSIB)}\right)\right]^{-1} - 1\right]^{-1}.$$

Because $e^{\frac{-CC-\mu}{\sigma}} > 0$ and $\ln\left(\frac{H(r)}{H(GSIB)}\right) < 0$, the derivative is negative. The derivative of the capital surcharge formula with respect to σ is the following:

$$\frac{\partial k_{GSIB}}{\partial \sigma} = \ln\left[1 - e^{\frac{-CC-\mu}{\sigma}} \ln\left(\frac{H(r)}{H(GSIB)}\right)\right] + \frac{-CC-\mu}{\sigma\left[\left[e^{\frac{-CC-\mu}{\sigma}} \ln\left(\frac{H(r)}{H(GSIB)}\right)\right]^{-1} - 1\right]}.$$

If we assume that banking is profitable (i.e., $\mu > 0$), the derivative is positive. Thus, capital surcharges are higher when RORWA is more uncertain.

[11] While the parameter μ is not strictly the mean of the Gumbel distribution, μ is the location parameter, which strongly indicates the center of the distribution (the mean is $\mu + \sigma\gamma$, where γ is the Euler-Mascheroni constant).

We use Moody's Analytics BankFocus (Bureau van Dijk) data to estimate μ and σ.[12] Our sample is composed of annual observations of commercial banks and bank holding companies (BHCs) larger than \$50 billion in total assets from 2000 to 2016 and from countries with European Union or Basel Committee membership.[13] The sample mean of RORWA is 0.99 percent, and the sample standard deviation is 1.81 percent.

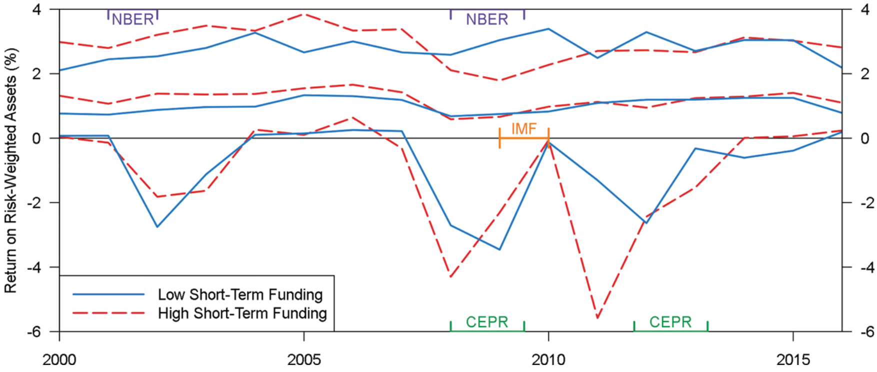
Capital surcharges can be empirically calibrated either unconditional or conditional on financial system stress. According to the BCBS, the G-SIB capital surcharge was developed in response to the 2008–09 financial crisis "to reduce the likelihood and severity of problems that emanate from the failure of global systemically important financial institutions" (BCBS 2013b). This policy goal suggests that the empirical calibration of capital surcharges should focus on banks during times of financial distress.[14] Below, we outline a method for calibrating capital surcharges. At the end of this section, we discuss research on the effect of short-term funding on the profitability of large banks. Much of this research argues that

[12]Our analysis data set is a combination of Bankscope and Orbis Bank Focus databases from Moody's Analytics BankFocus (Bureau van Dijk). Both databases contain detailed information about banks across the globe. Our analysis data set uses Bankscope between 2000 and 2015 and Orbis Bank Focus for 2016. Bankscope was discontinued at the end of 2016 but contains better coverage over 2007, 2008, and 2009.

[13]Quoted in 2016 dollars, the total asset cutoff is deflated by world gross domestic product using International Monetary Fund (2017). RORWA is limited to between +/− 30 percent. We use observations with the highest level of consolidation; when institutions have multiple entries for a given year, we use the most consolidated report available. To avoid double counting, we drop firms with owners that also appear in the sample based on Bankscope's information about domestic and global ultimate owners.

[14]Tarullo (2009) makes the case for adopting robust policies in non-crisis times: "First, no matter what its general economic policy principles, a government faced with the possibility of a cascading financial crisis that could bring down its national economy tends to err on the side of intervention. Second, once a government has obviously extended the reach of its safety net, moral hazard problems are compounded, as market actors may expect similarly situated firms to be rescued in the future. Both these observations underscore the importance of adopting robust policies in non-crisis times that will diminish the chances that, in some future period of financial distress, a government will believe it must intervene to prevent the failure of a large financial institution."

Figure 1. Time Series of Return on Risk-Weighted Assets



Source: Annual bank balance sheet data are available from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: Purple ticks indicate U.S. recessions from 2001:Q1 to 2001:Q4 and 2007:Q4 to 2009:Q2 (National Bureau of Economic Research 2010). Green ticks indicate euro-area recessions from 2007:Q4 to 2009:Q2 and 2011:Q3 to 2013:Q1 (Centre for Economic Policy Research 2017). Orange ticks indicate a global recession from 2009:Q1 to 2009:Q4 (International Monetary Fund 2009).

the profitability of high short-term funders is similar to (or possibly better than) low short-term funders during normal times, but high short-term funders fare far worse during a crisis. Our findings support these dynamics. Thus, we estimate the RORWA distribution split by high short-term funding.

Figure 1 shows annual median RORWA as well as the 5th and 95th percentiles; banks are divided in half by the median value of short-term wholesale funding (STWF) for each year.[15] As shown in the figure, median RORWA for the banking industry drops substantially from 2007 to 2008. In addition, 5 percent or more of the banking industry has negative returns from 2008 to 2013. Figure 1

[15]We discuss research on the effect of short-term funding below. As a metric of short-term funding, we use "other deposits and short-term borrowing" divided by risk-weighted assets. "Other deposits and short-term borrowing" includes senior debt maturing in less than one year, money market instruments, certificates of deposit, commercial paper, corporate deposits, and margin deposits (Moody's Analytics BankFocus).

suggests that banks with high levels of STWF are particularly prone to significant declines in profits during a financial crisis.[16]

In table 2, we regress RORWA on lagged RORWA with year fixed effects. The crisis is particularly concentrated in 2008, but bank losses were also significantly large in 2009 and 2011. Given the presence of the lagged dependent variable, we estimate the regression using a panel generalized method of moments approach (Croissant and Millo 2008). The Sargan test suggests that the instruments are valid, and the autocorrelation test suggests that the residuals of order 2 are not autocorrelated. Based on this regression, we identify the crisis RORWA distribution as 2008, 2009, and 2011.

We estimate the Gumbel cumulative distribution function (CDF) on the bottom 5 percent tail for the crisis and non-crisis periods.[17] Using ordinary least squares, we estimate the Gumbel distribution location parameter, μ, and scale parameter, σ:

$$RORWA = \mu + \sigma(-\ln[-\ln F(RORWA)]).$$

To formally test for the significance of shifts in the Gumbel distribution in the crisis period, we interact the slope coefficient with fixed effects for crisis and high STWF:

$$\begin{aligned} RORWA = {} & \mu_1 + \mu_2 Crisis + \mu_3 High\ STWF \\ & + (\sigma_1 + \sigma_2 Crisis + \sigma_3 High\ STWF \\ & + \sigma_4 Crisis\ High\ STWF)(-\ln[-\ln F(RORWA)]), \end{aligned}$$

where *Crisis* is one for observations from 2008, 2009, and 2011 and zero otherwise, and *High STWF* is one for observations with STWF higher than the annual median and zero otherwise.

[16] Ticks indicate U.S. recessions from 2001:Q1 to 2001:Q4 and 2007:Q4 to 2009:Q2 (National Bureau of Economic Research 2010), euro-area recessions from 2007:Q4 to 2009:Q2 and 2011:Q3 to 2013:Q1 (Centre for Economic Policy Research 2017), and a global economic recession from 2009:Q1 to 2009:Q4 (IMF 2009).

[17] Board of Governors (2015) also estimates probability of default using the bottom 5 percent tail. Details about extreme value distributions can be found in de Haan and Ferreira (2006).

Table 2. Crisis Identification Regression

	Dependent Variable: ***RORWA***	
Lag *RORWA*	0.24***	(0.04)
2002	−0.12	(0.14)
2003	0.05	(0.12)
2004	0.09	(0.15)
2005	0.23	(0.16)
2006	0.34**	(0.15)
2007	−0.03	(0.17)
2008	−1.05***	(0.26)
2009	−0.68*	(0.39)
2010	−0.03	(0.37)
2011	−0.65*	(0.37)
2012	−0.35	(0.38)
2013	0.06	(0.41)
2014	−0.01	(0.40)
2015	0.02	(0.39)
2016	−0.09	(0.40)
Observations Used (Total):	1,600 (2,393)	
Sargan Test (Chi-Square (2)):	0.27 (p-value = 0.88)	
Autocorrelation Test (1) (Normal):	–3.60 (p-value = 0.00)	
Autocorrelation Test (2) (Normal):	–0.93 (p-value = 0.36)	

Source: Annual bank balance sheet data are available from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: The panel model is estimated using the generalized method of moments approach. The two-step model is estimated in first differences, and time dummies are included. The normal instruments are the second, third, and fourth lagged differences of return on risk-weighted assets (RORWA). *, **, and *** denote $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively.

Table 3 shows the estimated CDF coefficients. Because the scale parameter is significantly smaller for the non-crisis period relative to the crisis period, negative realizations of RORWA are more likely during a crisis (i.e., the RORWA distribution shifts to the left during a crisis). As a result, capital buffers based on crisis periods would be larger than capital buffers not based on crisis periods.

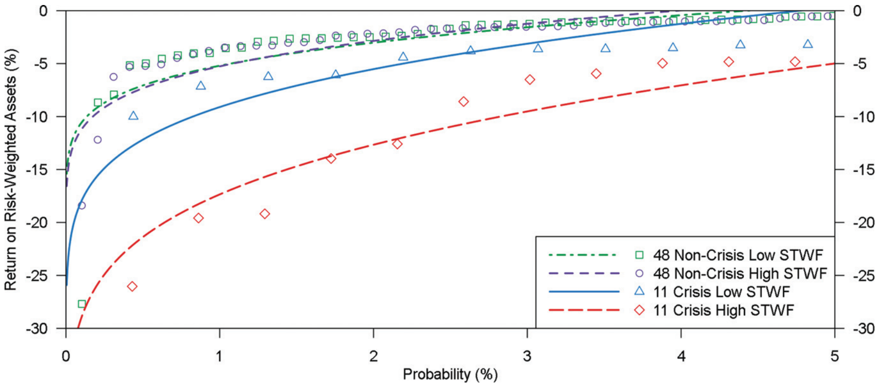
Table 3. Ordinary Least Squares Estimates of Return on Risk-Weighted Assets Parameters

	Dependent Variable: ***RORWA***
–ln(–ln(Pr{RORWA}))	13.32***
	(1.55)
–ln(–ln(Pr{RORWA})) ∗ High STWF	1.44
	(2.10)
–ln(–ln(Pr{RORWA})) ∗ Crisis	8.64***
	(3.01)
–ln(–ln(Pr{RORWA})) ∗ Crisis ∗ High STWF	5.36***
	(0.79)
High STWF	2.14
	(2.87)
Crisis	9.28**
	(4.01)
Constant	15.14***
	(2.11)
Observations	118
Adjusted R^2	0.77
Residual Std. Error (df = 111)	2.25

Source: Annual bank balance sheet data are available from Moody's Analytics Bank-Focus (Bureau van Dijk).
Notes: *Crisis* = 1 for 2008, 2009, and 2011. *High STWF* = 1 for "other deposits and short-term borrowing" divided by risk-weighted assets over the median by year. The models are estimated on the bottom five percentiles of the sample. *, **, and *** denote $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively.

The estimated parameters appear to fit the 5 percent tails well, shown in figure 2 (the color version of this and other figures can be found at http://www.ijcb.org). The y value of each point is the given observation's RORWA, and the x value is the portion of the sample with a RORWA less than or equal to that observation's RORWA. The green squares and purple circles indicate non-crisis observations with low and high STWF, respectively. The blue triangles and red diamonds indicate crisis observations with low and high STWF, respectively. The lines show the estimated tails of the RORWA distribution (the non-crisis low STWF tail is

Figure 2. OLS Estimates of RORWA Distribution



Source: Annual bank balance sheet data are available from Moody's Analytics BankFocus (Bureau van Dijk).

Notes: Based on table 2, crisis observations are from 2008, 2009, and 2011; non-crisis observations are from 2000–07, 2010, and 2012–16. The annual median values of "other deposits and short-term borrowing" over risk-weighted assets divide observations with high and low short-term wholesale funding (STWF). The samples are split at the median level of STWF. The y value of each point is the given observation's return on risk-weighted assets (RORWA), and the x value is the portion of the sample with a RORWA less than or equal to that observation's RORWA. Table 3 shows the tail estimation for each sample.

alternating-long-and-short-dashed green, the non-crisis high STWF is short-dashed purple, the crisis low STWF is solid blue, and the crisis high STWF is long-dashed red). Consistent with the significantly negative crisis fixed effect in table 3, the crisis tails are significantly lower than the non-crisis tails, and the crisis high STWF tail is significantly lower than the crisis low STWF tail. Our baseline estimate of empirical capital surcharges uses the regression coefficients of both crisis tails; the pessimistic and optimistic estimates use the upper and lower bounds of the 95 percent confidence intervals around these estimates, respectively.

Our estimation of the 5 percent lower tail for RORWA highlights a significant increase in the probability of default during a crisis. As an example, we consider the increased probability of default associated with the loss of the capital conservation buffer. The Basel III framework defines two ratios of CET1 capital to risk-weighted assets: the minimum ratio and the conservation buffer.[18] Generally, if a bank has a 7 percent or higher ratio of CET1 to risk-weighted assets, the bank is viewed as sound. If the bank's ratio falls to between 4.5 and 7 percent, regulators take actions to restrict dividends and stock repurchases. At a capital ratio below 4.5 percent, regulators are expected to take substantial actions (BCBS 2010).[19] Thus, the Basel III framework suggests that a negative 2.5 percent RORWA is a significant loss for a bank that meets minimum capital standards; if a bank holds negligible capital beyond minimum requirements, it would face significant regulatory scrutiny after such a loss. By our estimation, banks (at the regulatory minimums for capital holdings) with low short-term funding are 1.4 times more likely to fall below this threshold during a crisis than in non-crisis periods. For banks with high short-term funding, this ratio rises to 2.9 times. However, for banks that hold large capital buffers, a larger (and less likely) shock to capital would be needed for the bank to fall under such regulatory scrutiny. Indeed, these voluntary capital buffers may reflect a desire by some banks to be more certain that they will not fall under regulatory scrutiny, and it is too soon to tell whether such buffers will be used simply to "fill" the G-SIB surcharges or whether the buffers will be carried by banks in addition to the G-SIB surcharges.

2.1 Short-Term Funding

Our model of default incorporates short-term funding and suggests that higher short-term funding is associated with substantially lower RORWA during a financial crisis. As shown in figure 1, during the period before the 2008–09 financial crisis, banks that financed a high

[18]The BCBS framework also includes the countercyclical capital buffer, which "aims to ensure that banking sector capital requirements take account of the macro-financial environment in which banks operate. It will be deployed by national jurisdictions when excess aggregate credit growth is judged to be associated with a build-up of system-wide risk to ensure the banking system has a buffer of capital to protect it against future potential losses" (BCBS 2010). See Drehmann, Borio, and Tsatsaronis (2011) and Dewatripont and Tirole (2012) for some analysis.

[19]As noted by many observers, regulatory bank capital is often substantially larger than market valuations, and market actions may impose failure on the G-SIB long before this ratio is reached. For recent commentary and analysis along these lines, see Bulow and Klemperer (2013), Haldane (2011), and Sarin and Summers (2016).

proportion of assets with short-term funding had a higher median RORWA than banks that used lower levels of short-term funding. Consistent with the estimate of the RORWA distribution, profitability declines sharply for large banks with higher proportions of short-term funding in 2008 and 2009. However, in the post-crisis period, short-term funders are more in line with other large banks. This sharp decline and recovery may reflect the complicated interactions between short-term funding and profitability.

In table 3, we estimate the probability of default parameters conditional on short-term funding by splitting the sample by the median value of short-term funding and interacting the fixed effect with the scale estimate.[20] The estimated parameters based on banks with low short-term funding do not significantly differ from non-crisis estimates. In contrast, the estimated parameters of high short-term funders during the crisis period produce significantly fatter tails.

The existing BCBS G-SIB methodology omits uninsured short-term funding (e.g., money market mutual funds, commercial paper, repurchase agreements, and securities lending) when estimating probability of default and when measuring social losses given default.[21] In general, large banks, which are already substantial contributors of systemic risk, use higher proportions of short-term funding than smaller banks (Damar, Meh, and Terajima 2013; Laeven, Ratnovski, and Tong 2014). Consistent with recent research describing the relationship among short-term funding, defaults, and financial stability, we find that higher proportions of short-term funding increase the probability of default for G-SIBs.[22] Thus, in the spirit of the capital requirement recommendations of French et al. (2010) and

[20]The median value of short-term funding is 8.6 percent in the crisis period and 8.2 percent in the non-crisis period.

[21]The neglect of short-term funding in Basel III is ironic because the bulk of the value from government intervention may lie in reducing the risk of runs by short-term funders (see Veronesi and Zingales 2010). As outlined in Board of Governors (2015), the U.S. implementation of the BCBS G-SIB methodology includes short-term funding as an indicator in the G-SIB score. Scores are calculated both by the BCBS method (see section 3) and by replacing the substitutability category with a measure of reliance on short-term funding. For each bank, the larger of the resulting capital surcharges is used.

[22]McAndrews et al. (2014) show that more short-term funding increases social losses resulting from a bank failure; thus, short-term funding is not exclusively related to the probability of default. Specifically, banks may be forced to engage

Tarullo (2015), higher short-term funding suggests higher capital surcharges.

However, the relationship between RORWA and short-term funding is complex. In normal times (i.e., when access to short-term funding markets is uninhibited), the higher use of short-term funding likely generates higher returns for banks because they can borrow over maturities shorter than those over which they lend. In addition, because funders conduct little due diligence when banks have safe credit ratings or when their collateral is low risk (e.g., government guaranteed), short-term funding may be even less expensive (Diamond 1991; Gorton and Ordoñez 2014).[23] Finally, banks have an incentive to shorten debt holders' contract maturity to pressure their other funders to provide better terms, leading to a "maturity rat race," which lowers banks' funding costs but can leave banks with significant rollover risks (Brunnermeier and Oehmke 2013).

In crisis periods, banks that heavily rely on uninsured short-term liabilities are vulnerable to runs (Gorton and Metrick 2012; Martin, Skeie, and von Thadden 2014). During a crisis, providers of short-term funding can deprive banks of funding or can raise capital collateral demands for continued funding (Gorton and Metrick 2012; Gorton and Ordoñez 2014). Moreover, investors can become skittish about lending to banks over longer maturities. As a result, the maturity of liabilities at a bank during financial turmoil can shorten quickly.

These crisis dynamics of short-term wholesale funding substantially contributed to bank distress and default during the 2008–09 financial crisis. A detailed case study of the Lehman Brothers failure shows that once investors perceived it as undercapitalized, Lehman had to substantially shorten the maturity of its liabilities; as a result, Lehman's failure was fast and furious (Gorton, Metrick, and Xie 2014). Generally, banks that relied substantially on STWF experienced more difficulties during the crisis (Demirguc-Kunt and

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in asset "fire sales" to meet repayment demands. Both runs and fire sales further increase the social losses of failure because they force the rapid resolution or closure of banks as the government responds to investors (Shliefer and Vishny 2011).

[23]More broadly, short-term funding may counteract costly asymmetric information about the asset side of bank balance sheets between investors and managers (Calomiris and Kahn 1991; Diamond and Rajan 2001).

Huizinga 2010). These banks also contracted lending more severely than banks that relied on insured deposits (Ivashina and Scharfstein 2010; Dewally and Shao 2014).

Our estimates for the Gumbel distributions account for the effect of short-term funding on the probability of default function. We show that the function "shifts out" for banks that are heavy users of short-term funding during the crisis period. During a crisis or a prolonged period of low profitability, a bank that relies on short-term funding may need more capital to offset its expected impact compared with a bank using less short-term funding. This shift in the probability of default function reflects the steeper decline in RORWA experienced by banks with more short-term funding.

Two existing Basel III reforms focus on short-term funding: the LCR and the NSFR. The LCR requires G-SIBs to hold more high-quality assets relative to their runnable liabilities, and the NSFR requires G-SIBs to lengthen the maturity of liabilities. Both actions would likely reduce the outward shift in the probability of default function. However, there is skepticism that these restrictions have actually reduced vulnerabilities of banks. Martin, Skeie, and von Thadden (2014) show that even with substantial self-insurance, banks that are unprofitable or that use high levels of short-term funding may be vulnerable to runs. Krishnamuthy, Bai, and Weymuller (2016) show that the runoff estimates used in the LCR are too small to capture runoffs during a crisis (because LCR runoff estimates vary over time), the LCR maturity horizon is too short compared with the length of a crisis, and the LCR indicator is not a reliable measure of bank or banking system risk-taking. Finally, as noted by Diamond and Rajan (2001), Duffie (2016), and Gorton and Muir (2016), limiting short-term funding may enhance—rather than diminish—social losses during a crisis; banks may choose to reduce their illiquid investments rather than their higher quality, liquid assets (because safe assets have become "too valuable") when trying to meet these liquidity requirements after a shock.[24] Overall,

[24]As summarized by Duffie (2016), the LCR might not offset the losses given default created by a bank run because "the goal of LCR is that the balance sheet of the financial institution can withstand such a run, perhaps however in a form that significantly limits the ability of the bank to continue providing much new credit to the general economy."

the impacts of the LCR and NSFR on distance to default and loss given default during a crisis are unclear.[25]

In summation, our estimates suggest that banks with higher levels of short-term funding are more likely to default during a financial crisis. In the expected impact framework, a higher probability of default results in a higher capital surcharge. Thus, our estimated capital surcharges include a high short-term funding boost, which we calibrate using the interaction term for short-term funding during the crisis. The boost in the pessimistic and optimistic estimates uses lower and upper bounds of the 95 percent confidence intervals of the interaction term.

Our approach has shortcomings. It does not account for the additional capital that national authorities may require beyond the G-SIB capital surcharges (e.g., capital requirements for domestic systemically important banks, or D-SIBs) and that banks may carry at their own discretion (so-called capital cushions). Moreover, other post-crisis reforms may lessen the need for higher capital surcharges—for example, better resolution procedures may reduce the need for capital. However, our approach does implicitly incorporate the multitude of extraordinary governmental actions taken to mitigate the losses of banks during the 2008–09 financial crisis. Without these government actions, we would likely estimate a probability of default function that suggests even higher capital surcharges.

3. Social Losses Given Default

Measures of social losses given default seek to capture the negative social externalities associated with bank failures on the financial system and the wider economy. Both the lack of a definition of default for "too big to fail" banks and the lack of data directly measuring

[25]Our estimation technique suggests a way to calibrate the tradeoff between capital surcharge boosts for high short-term funding and stricter liquidity requirements (like the LCR and NSFR). If the LCR and NSFR reduce banks' use of short-term funding, our model suggests the probability of their default would lower, implying a smaller capital surcharge boost for high short-term funding. Building such a system is beyond the scope of this paper, but our model suggests that G-SIB capital surcharges should increase as short-term funding increases, and thus higher levels of the LCR and the NSFR might be explicitly linked to lower G-SIB capital surcharges.

social costs of failure handicap this analysis. The Basel III G-SIB score framework is best interpreted as bank supervisors' judgment on which balance sheet measures are correlated with systemic importance. Additionally, due to the lack of data, the Basel III G-SIB assessment methodology ranks banks by the social costs of their defaults relative to the reference bank.

As outlined in BCBS (2013b), G-SIB capital surcharges are based on the G-SIB score. The G-SIB score is a weighted average of twelve indicators associated with the five dimensions (or "categories") of systemic risk identified by Basel III: (i) size, (ii) interconnectedness, (iii) substitutability/financial institution infrastructure, (iv) complexity, and (v) cross-jurisdictional activity.[26]

(i) *Size:* The size of a bank is a straightforward measure of its systemic importance. To replace a large failed bank, other institutions must finance more assets and provide more services. Also, the resolution of large failed banks requires more effort. Basel III measures size with a single indicator, referred to as total exposures. Total exposures include on-balance-sheet assets and some off-balance-sheet credit exposures.

(ii) *Interconnectedness:* The failure of a bank has repercussions for its clients and its service providers. If a bank is highly connected to the financial system, its failure could distress other financial firms.[27] Basel III measures interconnectedness with three indicators: intrafinancial assets, intrafinancial liabilities, and outstanding securities. Intrafinancial assets and liabilities have counterparties within the financial system. Securities

[26]Reporting templates also include a range of ancillary indicators, which may be additional indicators of systemic importance. A complete description of data collected by Basel can be found in BCBS (2017a). Recent academic research that develops metrics for measuring social losses given default primarily focuses on market valuation, tail risk, or both (Acharya et al. 2010; Huang, Zhou, and Zhu 2011; Kritzman et al. 2011; Billio et al. 2012; Das 2015; Levy-Cariente et al. 2015; Adrian and Brunnermeier 2016). Market-based models are not used in the Basel III assessment methodology. For analysis of market-based models, see Zhang et al. (2015).

[27]For some analysis of the systemic risk implications of interbank lending, see Rochet and Tirole (1996).

outstanding include all outstanding securities issued by the institution to any affiliated or unaffiliated institutions.

(iii) *Substitutability/Financial Institution Infrastructure:* Some banks play a significant role in the infrastructure of the financial system, although they may not be particularly large in terms of total exposures (or highly connected to other financial firms). For example, if a major provider of payment systems fails, social losses could stem directly from the disruption of payments services. Beyond payments activity, two other indicators measure substitutability: assets under custody and underwritten transactions in debt and equity markets.[28] Banks hold assets under custody for safekeeping but do not manage them as investments on behalf of the owners. Underwritten transactions in debt and equity markets are market-making activities that, if impaired, could impose substantial losses on other parties.

(iv) *Complexity:* If a bank is more complex in terms of business model, structure, or operations, its resolution after failure may be more difficult. Basel III complexity indicators are meant to capture illiquidity of assets, which are difficult to evaluate during significant financial stress. The complexity indicators include over-the-counter (OTC) derivatives, trading and available-for-sale (AFS) securities, and level 3 assets. Traded outside of a formal exchange, OTC derivatives include a wide variety of non-standardized contracts. Trading and AFS securities, which include any equity or debt security that is not intended to be held to maturity, may be subject to fire-sale valuations during periods of stress. Level 3 assets lack observable price measures (e.g., a market price).

(v) *Cross-Jurisdictional Activity:* Banks with more cross-jurisdictional activity risk spreading distress to the financial

[28] The substitutability category is capped at 500 basis points; after the first three years of data collection, the BCBS determined that the substitutability category contributed disproportionately to the overall G-SIB score. Instead of a cap, Benoit, Hurlin, and Pérignon (2016) present an alternative G-SIB score methodology that prevents individual indicators or categories from unduly influencing the aggregate score.

systems of other countries.[29] In addition, the resolution of international banks may be more costly and more time intensive because regulators in different countries must coordinate. The cross-jurisdictional indicators are cross-jurisdictional claims and liabilities.

The twelve indicators are expressed as approximate global market shares.[30] For example, an indicator of 500 represents roughly a 5 percent global market share.[31] Basel III estimates the global market size of indicators using proxies, each of which is the sum of an indicator for all banks in the Basel III sample. The Basel III sample of banks includes the largest seventy-five BHCs (as determined by total exposures) and any other BHC that was designated as a G-SIB in the previous year. In 2017, the BCBS sample included seventy-six banks. These denominators are published annually; end-2016 denominators are shown in table 5.

To aggregate the twelve indicators into a single score, indicators are weighted equally in a systemic risk category, and categories are weighted equally in the final score (see table 4).[32] For example, the "interconnectedness" category includes the intrafinancial system assets, intrafinancial system liabilities, and securities outstanding (denoted A, B, and C, respectively). The "interconnectedness" category sub-score for bank i is the equally weighted average of the three market share indicators:

$$\text{Interconnectedness sub-score}_i = \frac{1}{3}\left(\frac{A_i}{A_1 + A_2 + \cdots} + \frac{B_i}{B_1 + B_2 + \cdots} + \frac{C_i}{C_1 + C_2 + \cdots}\right).$$

[29] See Kollmann (2013) for some analysis of the real effect of financial crisis propagating between countries through global banks.

[30] Appendix 3 of Passmore and von Hafften (2017) discusses management incentives created by the market share approach.

[31] Because the activity of all banks in the world is not fully captured, the market share is overestimated.

[32] In appendix 1 of Passmore and von Hafften (2017), we explore weighting schemes with logical foundations, including a market-based weighting scheme and a stable equilibrium weighting scheme. While the relative rankings of some G-SIBs change, these weighting schemes at most move G-SIBs up or down one capital surcharge bucket.

Table 4. G-SIB Score Example of JPMorgan Chase & Co.

Category	Indicator	Indicator Weight (%)	From Disclosures (billions EUR)	Denominator (billions EUR)	Indicator Score (in bps)	Category Score (in bps)
Size	Total exposures	1/5 = 20%	3,073	75,900	405	405
Interconnectedness	Intrafinancial system assets	1/15 = 6.$\bar{6}$%	308	7,834	393	
	Intrafinancial system liabilities	1/15 = 6.$\bar{6}$%	365	8,847	413	411
	Securities outstanding	1/15 = 6.$\bar{6}$%	568	13,337	426	
Substitutability/ Financial Institution Infrastructure	Payments activity	1/15 = 6.$\bar{6}$%	258,988	2,156,973	1,201	
	Assets under custody	1/15 = 6.$\bar{6}$%	19,163	139,936	1,369	1,104
	Underwritten transactions in debt and equity markets	1/15 = 6.$\bar{6}$%	444	5,999	741	(500)
Complexity	Notional amount of OTC derivatives	1/15 = 6.$\bar{6}$%	42,268	530,406	797	
	Trading and AFS securities	1/15 = 6.$\bar{6}$%	249	3,441	724	654
	Level 3 assets	1/15 = 6.$\bar{6}$%	22	501	440	
Cross-Jurisdictional Activity	Cross-jurisdictional claims	1/10 = 10%	613	18,677	329	367
	Cross-jurisdictional liabilities	1/10 = 10%	662	16,375	404	

Source: G-SIB denominators are available from BCBS (2017b), and G-SIB disclosures from BCBS (2017a).
Notes: OTC derivatives are over-the-counter derivatives. AFS securities are available-for-sale securities. The G-SIB score for JPMorgan Chase & Co. in 2017 is 467 bps.

The G-SIB score is the simple average of the category sub-scores. Because each category sub-score receives a 20 percent weight in the G-SIB score, the interconnectedness indicator weights are 6.7 percent ($= .2 * .33\bar{3}$).

As an example, in table 4 we present the G-SIB score calculation for JPMorgan Chase & Co, which is the highest-scoring BHC in FSB (2017). The balance sheet and denominator data are from the end of 2016. For each indicator, a market share is calculated, which reflects the proportion of the denominator held by JPMorgan. For example, JPMorgan holds 405 basis points (bps) of all total exposures. The category sub-score is the equally weighted average of the market share indicators associated with that category. The interconnectedness sub-score for JPMorgan is 411 bps, the average of 393, 413, and 426 bps. Finally, the G-SIB score is 467 bps, the equally weighted average of the five category sub-scores (405 bps for size, 411 bps for interconnectedness, 500 bps for substitutability, 654 bps for complexity, and 367 bps for cross-jurisdictional activity).[33]

In general, the total losses associated with a firm's default can be broken down into private losses covered by shareholders, private losses left uncovered, and social losses. Our model establishes a confidence interval around the given G-SIB index by correlating social losses and uncovered private losses.[34] Although uncovered private losses are not direct estimates of social losses given default, they may be proxies for the relative size of social losses given default for each G-SIB. We use market-based estimates of uncovered private losses to provide a useful comparison with the G-SIB score, which solely reflects the views of bank regulators.

To assess error in regulatory assessment of systemic risk, we use the SRISK measure developed by Acharya et al. (2010) as an independent market-based measure of uncovered private losses imposed on shareholders from a systemic crisis in the financial system. This measure considers "a firm systemically risky if it is likely to face a capital shortage when the financial sector itself is weak" (NYU Stern

[33]G-SIB disclosure data are available from BCBS (2017a). G-SIB disclosure data are missing for two banks in the BCBS sample: Bank of Communications and China Guangfa Bank.

[34]Other measures of losses, such as CoVaR (Adrian and Brunnermeier 2016), could also be used, but these measures are only proxies for social losses.

Volatility Institute 2018). First, the long-run marginal expected shortfall is estimated, which is the loss in capital for each firm if the market suffers significant declines for six months. Then, the amount of capital needed to survive the crisis is estimated. SRISK is the percentage of the financial system capital shortfall each given firm experiences.[35]

We estimate a Cobb-Douglas equation relating the G-SIB score and SRISK with ordinary least squares:

$$\ln(\mathit{GSIB\ Score}) = \ln(\alpha) + \beta \ln(\mathit{SRISK}) + \varepsilon,$$

where $\varepsilon \sim N(0, \sigma_\varepsilon)$. Table 5 shows the model estimation with and without fixed effects for U.S. and EU banks. The alpha and beta coefficients imply a positive, concave down relationship. From figure 3, which shows the scatterplot, we see significant variation around the fitted line. Given the regression residuals, a confidence interval for a G-SIB score, x, can be estimated:

$$e^{\ln(x) \pm CV_\alpha s_\varepsilon} = [xe^{-CV_\alpha s_\varepsilon}, xe^{CV_\alpha s_\varepsilon}],$$

where s_ε is the residual standard error and CV_α is the standard normal critical value associated with a $(1-\alpha)$ level of confidence. In the next section, we use this model to evaluate the reference bank score.

How well does the G-SIB score measure social losses given default? As previously discussed, this question is challenging to answer due to a lack of data that directly measure social externalities of G-SIB defaults. Because of this shortcoming, our estimated G-SIB capital surcharges (in section 5) use the Basel III G-SIB score as the measure of social losses given default.

[35] SRISK uses the GMES data set of exchange-traded top holders, for which iShares MSCI ACWI ETF is the reference index. Recommended capital requirements of 8 percent for Asian and American banks and 5.5 percent for European banks are used (NYU Stern Volatility Institute 2018). Data are merged on the reporting month of the public G-SIB disclosure. SRISK is unavailable for unlisted banks; eleven banks in the BCBS sample are unlisted: ABN AMRO, ANZ, BPCE, Caixa Economica Federal, China Guangfa Bank, Credit Mutuel, DZ Bank, KEB Hana Bank, Kookmin, Norinchukin, and Rabobank.

Table 5. Social Losses and Uncovered Private Losses Given Default

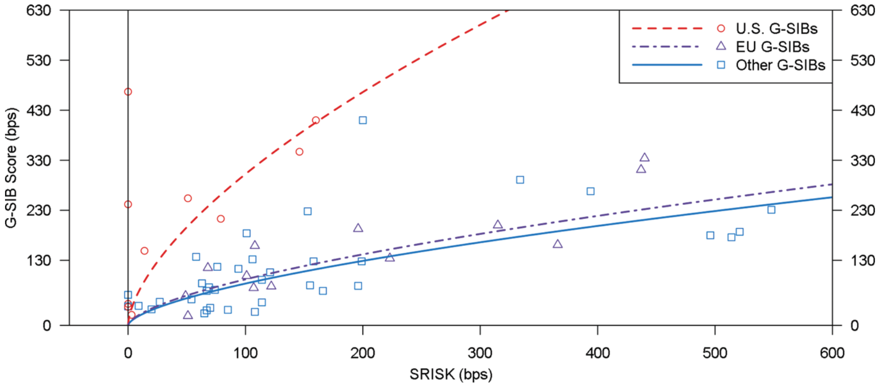
	Dependent Variable: ln(G-SIB Score)	
	(1)	(2)
ln(SRISK)	0.50***	0.63***
	(0.08)	(0.07)
U.S. Fixed Effect		1.29***
		(0.24)
EU Fixed Effect		0.10
		(0.17)
Constant	2.32***	1.55***
	(0.39)	(0.35)
Observations	55	55
Adjusted R^2	0.41	0.61
Residual Std. Error	0.63 (df = 53)	0.51 (df = 51)

Source: G-SIB denominators are available from BCBS (2017b), G-SIB disclosures from BCBS (2017a), and SRISK from the Volatility Laboratory of the NYU Stern Volatility Institute (2018).
Note: *, **, and *** denote $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively.

4. Reference Bank

Currently set at a G-SIB score of 130 bps, the choice of reference bank makes a distinction between G-SIBs and "normal" banks (or non-G-SIBs). Supposedly, G-SIBs are banks that governments would bail out in the event of failure, and non-G-SIBs are banks that governments would let fail. The expected impact of the failure of a non-G-SIB does not warrant increasing its common equity holdings to reduce the probability of its default. Choosing the reference bank—and, therefore, choosing the demarcation line between G-SIBs and non-G-SIBs—substantially affects all G-SIB capital surcharges. A larger reference bank indicates that public authorities have a higher tolerance for the social losses created by G-SIB failures, and G-SIBs require less capital as a result. Because the expected impact theory equates the expected impact of each G-SIB given default to the expected impact of the reference bank given default, the choice of

Figure 3. Social Losses and Uncovered Private Losses Given Default



Source: G-SIB disclosures are available from BCBS (2017a), G-SIB denominators from BCBS (2017b), and SRISK from the Volatility Laboratory of the NYU Stern Volatility Institute (2018).
Note: The lines are based on ordinary least squares regressions of logged G-SIB scores on logged values of SRISK (shown in table 5); the regressions include a dummy that equals one for banks from the United States and a dummy that equals one for banks from the EU.

the reference bank's social losses given default is crucial both for determining which banks are subject to the capital surcharge and for determining the size of all capital surcharges.

The partial derivative of the capital surcharge function shows the effect of the reference bank score:

$$\frac{\partial k_{GSIB}}{\partial H(r)} = \frac{-\sigma}{H(r)\left[e^{\frac{CC+\mu}{\sigma}} - \ln\left(\frac{H(r)}{H(GSIB)}\right)\right]}.$$

Because $\frac{H(r)}{H(GSIB)} < 1, e^{\frac{CC+\mu}{\sigma}} > 0$, and $\sigma > 0$, a decrease in the reference bank score increases capital surcharges.

How does one choose the reference bank score? Is 130 bps a good choice? Our three capital surcharge estimates (baseline, optimistic, and pessimistic) use three different reference bank scores. Our baseline estimate of surcharges adopts the average regulatory assessment that G-SIBs are banks with scores higher than 130 bps. However, the correlated loss model based on SRISK suggests that the G-SIB score is an uncertain measure of social losses given default. Thus, we lower the reference bank score to account for this error. For the baseline estimate, we limited the chance that a G-SIB is classified as a non-G-SIB to 5 percent using the correlated loss model. The resulting reference bank score is 56 bps, which approximately corresponds to €550 billion in total exposures.[36]

The optimistic capital surcharge estimate employs the Basel III choice of the reference bank score of 130 bps (approximately €1 trillion in total exposures). This choice reflects the belief that regulators are correct and that only those banks with G-SIB scores of 130 bps or higher warrant bailouts.

The pessimistic estimate adopts the minimum of G-SIB scores in the current Basel III sample as the reference bank score, which is 19 bps (approximately €325 billion in total exposures). For the pessimistic estimate, we consider the history of government support for banks during the 2008–09 financial crisis. Broadly speaking, all of the banks in the Basel III sample seem at least as systemically important as the banks that received bailouts in the 2008–09 financial crisis. Two important caveats apply to this rationale.

The first caveat is that data about the systemic importance of banks in the pre-crisis and crisis periods are limited. Namely, the G-SIB score does not exist prior to 2012.[37] Thus, our above rationale for choosing the minimum G-SIB score can be restated: All of the banks in the Basel III sample are *larger* than the *smallest* banks that received bailouts in the 2008–09 financial crisis. Size, of course, may be a poor indicator of the probability of bailout, and, for this reason, the G-SIB index captures more than just size. We provide a substantial analysis of the relationship of size (measured by total exposures) and the G-SIB score in appendix 1 of Passmore and von Hafften (2017), where we show that size accounts for about

[36]A reference bank score of 56 bps is based on the correlated loss model with U.S. and EU fixed effects. Without these fixed effects, the reference bank score would be 46 bps, which is approximately €500 billion in total exposures.

[37]Some metrics related to systemic importance, such as SRISK, can be created using historical data over these periods. However, as we discuss in the previous section and in Passmore and von Hafften (2017), these metrics measure systemic importance differently than the G-SIB score.

34 percent of the variation in G-SIB scores.[38] White and Yorulmazer (2014) describe select large financial institutions that received government support between 2007 and 2012. A number of these institutions held significantly less than €250 billion in total assets. Arguably, the size of these banks may indicate the lower bound of bank size required to induce government intervention in the 2008–09 financial crisis.

The second caveat is that, during the 2008–09 financial crisis, governments supported banks for reasons other than the social costs of a bank's failure to the global economy and financial system. Factors—from importance in domestic economies and financial systems to political and historical significance—may have led to government bailouts of banks. Regardless, the smallest banks considered for the G-SIB sample are well within the range of banks that received public support during the 2008–09 financial crisis, and we argue that a pessimistic observer might be skeptical that these banks would be allowed to fail during a financial crisis.[39]

5. Capital Surcharges

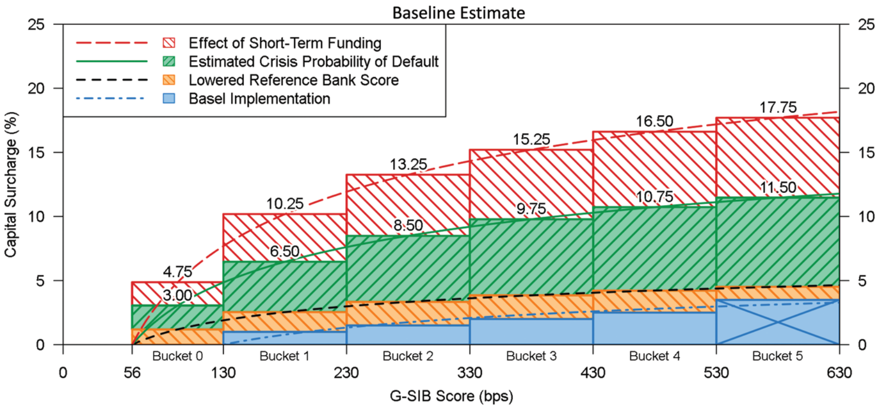
To produce an HLA requirement based on the G-SIB score, the BCBS adopts a bucketing approach (BCBS 2013b). Figure 4 shows the current buckets as solid blue boxes. Each bucket encompasses a 100 basis point range of G-SIB scores, and higher G-SIB scores are associated with larger capital surcharges. If we assume a bank's score is not near a threshold between buckets, the bucketing approach permits minor changes in indicators and denominators without major capital requirement changes.

The buckets and capital surcharges of the Basel III system are shown in table 1. Starting at 130 bps, the G-SIB scores are bucketed

[38] Size is the most important factor in G-SIB score variation. International activity and capital markets activity account for 24 percent and 21 percent, respectively, of the variation in the G-SIB scores. Our results highlight that size is the most important factor, but that other factors are also important and that, together, they can be more important than size.

[39] The lowest-scoring bank in the Basel III sample is CaixaBank, with a G-SIB score of 19 bps and €328.2 billion in total exposures. The smallest bank in the Basel III sample is State Street, with a G-SIB score of 149 bps and €244.3 billion in total exposures.

Figure 4. Estimated Global Systemically Important Bank Capital Surcharges



Source: Basel III capital buckets are available from BCBS (2013b), G-SIB denominators from BCBS (2017b), G-SIB disclosures from BCBS (2017a), and annual bank balance sheet data from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: See BCBS (2013b) for details about the G-SIB score. For Basel capital surcharges, the reference bank G-SIB score is 130 basis points; for the best estimate, the reference bank G-SIB score is 56 basis points, which is the lower bound of the one-sided 95 percent confidence interval of the correlated loss model centered at 130 basis points. Probability of default and the effect of short-term funding are estimated using the lower tail of the return on risk-weighted assets distribution from 2008, 2009, and 2011. Bucket 5 is crossed out to indicate that it is empty (Financial Stability Board 2017). Continuous capital surcharges are based on a capital conservation buffer of 2.5 percent from BCBS (2010).

every 100 bps.[40] The G-SIB score of 130 is the reference bank score; only banks that score 130 bps or higher are considered G-SIBs and are thus subject to capital surcharges. Currently, populated buckets are bucket 1 (130 to 229 bps), bucket 2 (230 to 329 bps), bucket 3 (330 to 429 bps), and bucket 4 (430 to 529 bps). The current requirement is 1 percent of CET1 capital for bucket 1 and an additional

[40]BCBS (2013b) provides no justification for fixed-width 100 basis point buckets. For the most part, our estimated G-SIB capital surcharges adopt Basel III buckets; an analysis of "optimal" bucket sizes would be desirable but is outside the scope of this paper.

0.5 percent for each higher bucket.[41] There is an additional empty bucket, called bucket 5, with an increase of 1 percentage point from bucket 4 instead of just 0.5 percentage point. Figure 4 shows bucket 5 crossed out. The purpose of this bucket is to provide an incentive for G-SIBs to avoid becoming more systemically important.[42] If bucket 5 becomes populated, bucket 6 will be introduced with scores between 630 and 729 bps and a 4.5 percent capital surcharge.

5.1 Estimated Capital Surcharges

Figure 4 illustrates the baseline estimate of G-SIB capital surcharges consistent with our empirical analysis of capital needed to avoid public assistance to G-SIBs during a severe financial crisis. However, the costs of higher capital standards are debated in the literature (see Myerson 2014 and Dagher et al. 2016). If capital is expensive, then higher capital requirements should be weighed against potentially higher loan rates. In this paper, we do not incorporate "economy wide" or "over time" costs that may stem from higher capital requirements for banks.[43]

[41] For the definition of risk-weighted assets and CET1 capital, see BCBS (2010). The G-SIB capital surcharge is subject to a three-year phase-in period. Beginning in January 2016, the applicable surcharge increases each year by one-fourth of the total surcharge; thus, the total buffer was completely phased in by January 2019.

[42] The primary purpose of the G-SIB capital surcharges is to decrease the possibility of default. Additionally, the surcharges aim to provide G-SIBs with an incentive to reduce their systemic footprints. For example, JPMorgan Chase took significant actions to reduce its surcharge (Dimon 2014).

[43] In addition to capital surcharges (so-called pillar 1), the G-SIBs are subject to stricter supervision and stress testing (pillar 2), greater market discipline (pillar 3), and resolution and recovery requirements. These other aspects of the G-SIB framework may affect the impact of a G-SIB upon failure. A comprehensive analysis of the effectiveness of the entire G-SIB framework needs to take into account all aspects of the framework. In contrast to capital surcharges, analysis of the other aspects of the G-SIB framework is hampered by difficulties in quantifying their levels and in defining the implementation period. Examining differences in market perceptions of G-SIB and non-G-SIB fragility might measure the effectiveness of the entire G-SIB framework. We looked at credit default swap (CDS) spreads and expected default frequencies (EDFs) for banks in the G-SIB assessment sample (Moody's 2018). In general, almost all banks follow the same pattern: very low CDS spreads and EDFs before the crisis, historically high levels during the crisis, and low levels after the crisis (but not as low as before the crisis). Although these time-series dynamics may reflect the impact

Because our analysis does not suggest that the G-SIB score itself is inadequate, we measure social losses given default using the Basel III G-SIB score.[44] To calibrate capital surcharges for discrete buckets from continuous functions and vice versa, we use the capital surcharge at the midpoint G-SIB score. Estimated by minimizing the sum of squared errors, the alternating-long-and-short-dashed blue line is a continuous approximation of the Basel III system.[45]

- *Reference Bank:* The short-dashed black line is the continuous capital surcharge function using a reference bank score of 56 bps, which is the lower bound of the one-sided 95 percent confidence interval from the correlated loss model centered at 130 bps. The shaded right-hatched yellow boxes show increases in capital surcharges, including 1.50 percentage points for bucket 1 and 1.75 percentage points for bucket 4. A lower reference bank score creates bucket 0, which ranges between the new

of Basel III, they may also reflect many other factors, such as an improving economic environment and a better profit outlook for banking. By adopting a difference-in-differences approach, we directly test the treatment effect of being a G-SIB on the change in CDS spreads and EDFs from the pre-crisis period to the post–Basel III period. This approach assumes that banks are comparable across time and the treatment is randomly assigned; both assumptions are questionable. We find the effect of this treatment to be statistically insignificant. Because the implementation of Basel III has occurred over a number of years, we test a variety of post–Basel III periods, including starting in 2010, 2013, and 2015; the treatment remains insignificant for all definitions of the post–Basel III period. In addition, the difference-in-differences approach generally supported our visual analysis (i.e., CDS spreads and EDFs rose from the pre-crisis period to the post-crisis period). Nevertheless, identifying the treatment effect purely from Basel III remains a challenge, and a more detailed analysis would be needed.

[44] We analyze the G-SIB score in more detail in Passmore and von Hafften (2017). Because estimated surcharges use the G-SIB score, the ranking of G-SIBs by their relative social losses given default does not change. Using Orbis Bank Focus data from 2016, we calculate that the five banks in the BCBS sample with the highest proportion of short-term funding to risk-weighted assets are Sumitomo Mitsui Trust Holdings, Nordea, Groupe Crédit Agricole, Rabobank, and Commonwealth.

[45] Note that apart from raising the capital surcharges, the system based on our baseline estimate leaves the Basel III capital surcharge system largely enacted (with the exception of adding bucket 0). Other adjustments, such as changing the thresholds or increasing the number of buckets, could also change G-SIB capital holdings.

and old reference bank scores with a capital surcharge of 1.25 percent.

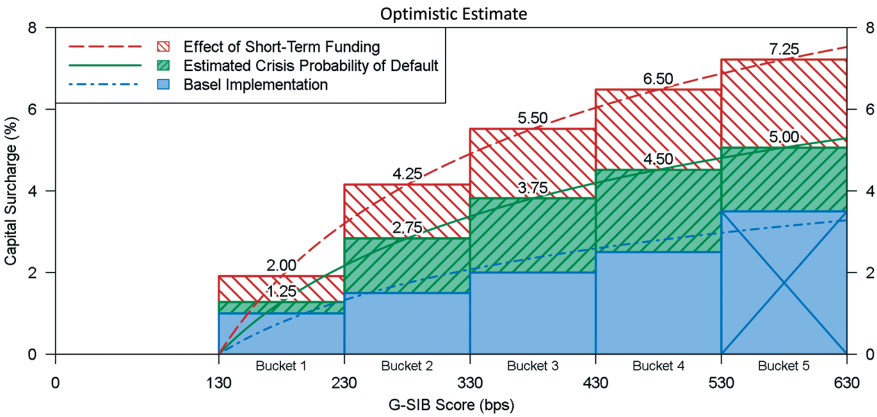
- *Probability of Default:* The solid green line is the continuous capital surcharge function estimated on RORWAs from the crisis period (shown in table 3). The shaded left-hatched green boxes indicate the surcharge increases, including 1.75 percentage points for bucket 0, 4.00 percentage points for bucket 1, and 6.50 percentage points for bucket 4.
- *Short-Term Funding:* The long-dashed red line is the continuous capital surcharge function estimated on RORWA data for banks reliant on short-term funding in the crisis period (shown in table 3). The unshaded right-hatched pink boxes show the high short-term funding boost to capital surcharges, including 1.75 percentage points for bucket 0, 3.75 percentage points for bucket 1, and 5.75 percentage points for bucket 4.

Figure 5 illustrates an alternative formulation of empirical capital surcharges, which we characterized as an optimistic view about the effectiveness of other Basel III reforms (and of regulatory oversight in general). With the belief that the regulatory assessment of social losses is correct, the reference bank score is set at 130 bps. Thus, unlike the baseline estimate, surcharges do not increase from a lower reference bank score. In addition, instead of setting the crisis regression coefficients (from table 3) as the probability of default derived from our best estimates, we use the lower bounds of 95 percent confidence intervals of the estimates. Although lower than the baseline estimate, these optimistic capital surcharges are still higher than the Basel III capital surcharges.

Figure 6 shows a third formulation of capital surcharges that is consistent with a pessimistic view about the effectiveness of regulatory oversight and other Basel III reforms. From this perspective, capital is the strictly preferred method of decreasing the expected impact of distress and default. As described earlier, the reference bank score is set at 19 bps, which is the minimum G-SIB score in the sample. The probability-of-default parameters are the upper 95 percent confidence interval bound. This approach yields historically high levels of capitalization.

Table 6 compares the three estimated capital surcharge systems with the Basel III system. For estimated capital surcharge buckets,

Figure 5. Estimated Global Systemically Important Bank Capital Surcharges



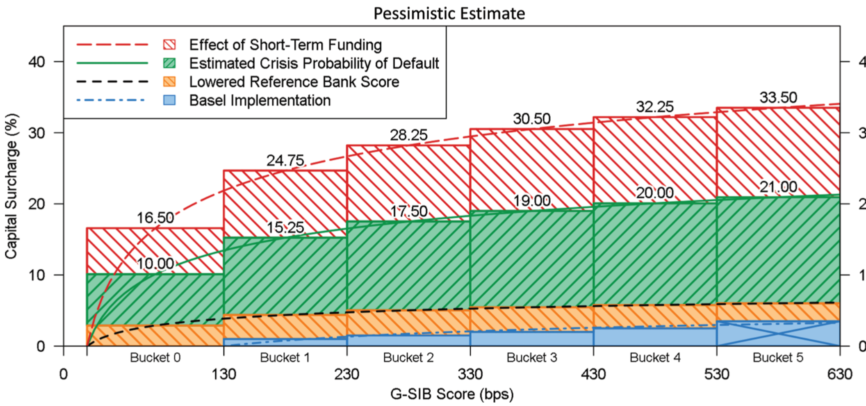
Source: Basel III capital buckets are available from BCBS (2013b), G-SIB denominators from BCBS (2017b), G-SIB disclosures from BCBS (2017a), and annual bank balance sheet data from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: See BCBS (2013b) for details about the G-SIB score. For Basel capital surcharges and the optimistic estimate, the reference bank G-SIB score is 130 basis points. Probability of default and the effect of short-term funding are estimated using the lower tail of the return on risk-weighted assets distribution from 2008, 2009, and 2011; the optimistic estimate uses the lower bounds of the 95 percent confidence intervals of estimated parameters. Bucket 5 is crossed out to indicate that it is empty (Financial Stability Board 2017). Continuous capital surcharges are based on a capital conservation buffer of 2.5 percent from BCBS (2010).

two numbers are quoted: The lower capital surcharge is for banks not reliant on short-term funding; the higher capital surcharge is for banks reliant on short-term funding. Based on the median level of short-term funding, the cutoff between low and high short-term funding is approximately 10 percent of risk-weighted assets. All three estimated capital surcharge systems suggest that Basel III capital surcharges are too small.

How do our estimates of capital compare with some recent literature on bank capitalization?[46] Using an alternative approach,

[46]For capital comparison using total assets instead of risk-weighted assets, the following approximation can be used. Based on 2010–16 Bankscope data, risk-weighted assets are, on average, 75 percent of total assets. Thus, as a proportion

Figure 6. Estimated Global Systemically Important Bank Capital Surcharges



Source: Basel III capital buckets are available from BCBS (2013b), G-SIB denominators from BCBS (2017b), G-SIB disclosures from BCBS (2017a), and annual bank balance sheet data from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: See BCBS (2013b) for details about the G-SIB score. For Basel capital surcharges, the reference bank G-SIB score is 130 basis points; for the pessimistic estimate, the reference bank G-SIB score is 19 basis points, which is the minimum G-SIB score in the Basel sample of banks in 2017. Probability of default and the effect of short-term funding are estimated using the lower tail of the return on risk-weighted assets distribution from 2008, 2009, and 2011; the pessimistic estimate uses the upper bounds of the 95 percent confidence intervals of estimated parameters. Bucket 5 is crossed out to indicate that it is empty (Financial Stability Board 2017). Continuous capital surcharges are based on a capital conservation buffer of 2.5 percent from BCBS (2010).

Dagher et al. (2016) estimate equity to risk-weighted assets of between 15 and 23 percent to avoid failures similar to the 2008–09 financial crisis. As Basel III sets a capital floor and a capital conservation buffer of 7 percent total, their estimates suggest surcharges should be between 8 and 15 percent. Similarly, Myerson

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of total assets, our baseline estimate would (i) raise capital requirements 4.00 to 6.25 percentage points for banks in buckets 1–5, (ii) create bucket 0 with a capital surcharge of 2.25 percent, and (iii) include a short-term funding metric that further boosts capital surcharges 1.25 to 4.25 percentage points for banks reliant on short-term funding. Our pessimistic and optimistic estimates, in terms of total assets, would be deflated similarly.

Table 6. Comparison between Basel and Estimated G-SIB Capital Surcharges

	G-SIB Score Range	Basel III	Baseline	Optimistic	Pessimistic
Bucket 5	530–629	3.50	11.50/17.75	5.00/7.25	21.00/33.50
Bucket 4	430–529	2.50	10.75/16.50	4.50/6.50	20.00/32.25
Bucket 3	330–429	2.00	9.75/15.25	3.75/5.50	19.00/30.50
Bucket 2	230–329	1.50	8.50/13.25	2.75/4.25	17.50/28.25
Bucket 1	130–229	1.00	6.50/10.25	1.25/2.00	15.25/24.75
Bucket 0	56–129	None	3.00/4.75	None	10.00/16.50
Bucket 0	19–55	None	None	None	10.00/16.50

Source: Basel III capital buckets are available from BCBS (2013b), G-SIB denominators from BCBS (2017b), G-SIB disclosures from BCBS (2017a), and annual bank balance sheet data from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: Units for G-SIB scores and capital surcharges are basis points and percent, respectively. See BCBS (2013b) for details about the G-SIB score. For the Basel III implementation and the optimistic estimate, the reference bank G-SIB score is 130 basis points. For the baseline estimate, the reference bank G-SIB score is 56 basis points, which is the lower bound of the one-sided 95 percent confidence interval of the correlated loss model centered at 130 basis points. For the pessimistic estimate, the reference bank G-SIB score is 19 basis points, which is the minimum G-SIB score in the Basel sample of banks in 2017. Probability of default and the effect of short-term funding are estimated using the lower tail of the return on risk-weighted assets distribution from 2008, 2009, and 2011; the baseline, optimistic, and pessimistic estimates use the mean estimate, the lower bounds of the 95 percent confidence intervals, and the upper bounds of the 95 percent confidence intervals, respectively. For each estimated bucket, the smaller capital surcharge applies to banks that fund 10 percent or less of their risk-weighted assets with short-term funding, and the larger capital surcharge applies to banks that fund more than 10 percent of their risk-weighted assets with short-term funding. Bucket 5 is empty (Financial Stability Board 2017). Estimated capital surcharges assume the capital conservation buffer of 2.5 percent from BCBS (2010).

(2014) suggests reasonable ratios of total capital to risk-weighted assets of at least 20 percent. The Minneapolis Plan (Federal Reserve Bank of Minneapolis 2016) proposes initial minimum capital requirements of 23.5 percent of risk-weighted assets, which could increase to as high as 38 percent. Miles, Yang, and Marcheggiano (2012) and Firestone, Lorenc, and Ranish (2017) find that optimal bank capital levels range between 16 and 20 percent and 13 and 26 percent, respectively. Moreover, Bulow and Klemperer (2013) suggest that even a 14 percentage point increase in capital requirements is grossly inadequate because of embedded deficiencies in regulatory accounting. Finally, Goel (2016) builds a stochastic general equilibrium model with a banking industry, and his results suggest that there may be room for much higher capital requirements than envisioned under the Basel III minimum standard. In addition, he finds that optimal regulations are characterized by tighter requirements for large banks relative to small banks. Overall, our conclusion that capital surcharges may be too small seems consistent with other recent studies of bank capital.[47]

6. Conclusion

Overall, our baseline estimate suggests that, although its method of measuring systemic importance may be valid, Basel III G-SIB capital surcharges may be too small based on the experience of the 2008–09 financial crisis. Our baseline estimate of G-SIB capital surcharges would (i) raise capital requirements 5.50 to 8.25 percentage points for banks currently subject to surcharges, (ii) create an additional lower bucket with a surcharge of 3.00 percent for very large and systemically important banks that are not currently subject to any surcharge, and (iii) include a short-term funding metric that further boosts surcharges 1.75 to 5.75 percentage points for banks that fund assets with a high proportion of short-term funding. Observers who are pessimistic about the Basel III reforms might desire even higher surcharges. Although optimistic observers would suggest surcharges lower than our baseline, our calculation of optimistic capital surcharges suggests that current Basel III G-SIB capital surcharges are still too low. However, other Basel III reforms may lessen the social losses associated with G-SIB failures even more than we have allowed for in this analysis. Until these reforms are tested by a financial crisis, it is difficult to incorporate them directly into a study of capital adequacy.

[47] In contrast, Brooke et al. (2015) find that appropriate capital levels range from 10 to 14 percent for banks in the United Kingdom. They attribute the discrepancy between their estimate and other studies to incorporating the effect of resolution requirements.

Appendix. G-SIB Capital Surcharge Based on the Generalized Extreme Value Distribution

In the paper, we model the lower tail of return on risk-weighted assets (RORWA) with a Gumbel distribution. The Gumbel distribution is one of three cases of the generalized extreme value (GEV) distribution. In this appendix, we estimate capital surcharges by modeling RORWAs with the GEV distribution. In general, capital surcharges estimated with the GEV distribution are slightly lower than capital surcharges estimated with the Gumbel distribution; however, the GEV capital surcharges are substantially higher than Basel III capital surcharges.

The primary benefit of the Gumbel distribution over the GEV distribution is simplicity. Simplicity is desirable because it leads to a more transparent analytical framework on which to base bank regulation. The Gumbel distribution yields a differentiable, well-defined, non-piecewise capital surcharge function. In addition, estimation of the Gumbel distribution is more straightforward because the Gumbel distribution has two parameters and the GEV distribution has three parameters.

Table 7 shows a variety of capital surcharges. The first column of capital surcharges shows those associated with the Basel III and the second is estimated capital surcharges based on the Gumbel distribution developed in the body of the paper. The third and fourth columns show capital surcharges estimated using the GEV distribution for the RORWA tail. The third column shows capital surcharges associated with the best fit of the RORWA tail. The fourth column shows those estimated by constraining the support of the GEV distribution to all negative realizations of RORWA. The capital surcharge system shown in the fourth column is attractive because it imposes a logical range for losses and maintains some flexibility in the shape of the RORWA tail. However, we present the approach based on the Gumbel distribution in the body of the paper because it is simpler and more standard.

The maximum (or minimum) of a sample of independent identically distributed random values converges to the GEV distribution via the Fisher-Tippett-Gnedenko theorem.[48] This theorem is

[48]See de Haan and Ferreira (2006) for the Fisher-Tippett-Gnedenko theorem and an extensive discussion of extreme value distributions.

Table 7. G-SIB Capital Surcharge Robustness

	G-SIB Score Range	Basel III	Baseline (Gumbel)	Best Fit (GEV)	Negative Support Only (GEV)
μ			20.94/30.11	–1.23/–0.12	–0.20/–0.17
$\hat{\sigma}$			19.38/31.37	0.22/0.68	0.48/0.52
$\hat{\xi}$			0.00/0.00	–2.81/–2.81	–2.36/–3.01
Bucket 5	530–629	3.50	10.25/19.00	6.25/15.75	7.50/16.50
Bucket 4	430–529	2.50	9.50/17.75	5.50/13.75	6.50/14.25
Bucket 3	330–429	2.00	8.75/16.25	4.75/11.50	5.75/11.75
Bucket 2	230–329	1.50	7.50/14.25	3.50/8.75	4.50/9.00
Bucket 1	130–229	1.00	5.75/10.75	2.25/5.50	3.00/5.75
Bucket 0	56–129	None	2.75/5.25	0.75/2.00	1.25/2.00

Source: Basel III capital buckets are available from BCBS (2013b), G-SIB denominators from BCBS (2017b), G-SIB disclosures from BCBS (2017a), and annual bank balance sheet data from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: Units for G-SIB scores and capital surcharges are basis points and percent, respectively. See BCBS (2013b) for details about the G-SIB score. For the Basel III implementation, the reference bank G-SIB score is 130 basis points. For the baseline (Gumbel), best fit (GEV), and negative support only (GEV) estimates, the reference bank G-SIB score is 56 basis points, which is the lower bound of the one-sided 95 percent confidence interval of the correlated loss model centered at 130 basis points. Probability of default and the effect of short-term funding are estimated using the lower tail of the return on risk-weighted assets distribution from 2008, 2009, and 2011. For each estimated bucket, the smaller capital surcharge applies to banks that fund 10 percent or less of their risk-weighted assets with short-term funding, and the larger capital surcharge applies to banks that fund more than 10 percent of their risk-weighted assets with short-term funding. Bucket 5 is empty (Financial Stability Board 2017). Estimated capital surcharges assume the capital conservation buffer of 2.5 percent from BCBS (2010). For the purpose of this table, we have dropped an additional observation from our RORWA sample. In particular, we dropped Abanca Corporacion Bancaria SA in 2012. The RORWA of this bank was –27.6 percent, and is unique in that it is an extreme outlier in the non-crisis period. The best-fit method of estimating ξ results in undefined capital surcharges if this observation is included. This highlights the fragility of the GEV estimates, which may be highly influenced by outliers.

approximately analogous to the central limit theorem, which states the sample average of independent and identically distributed random values converge to the normal distribution. The cumulative density function of the GEV distribution follows:

$$F(RORWA) = e^{-t(RORWA)}$$

$$\text{where } t(RORWA) = \begin{cases} \left(1 + \xi\left(\frac{RORWA-\mu}{\sigma}\right)\right)^{-\frac{1}{\xi}}, & \text{if } \xi \neq 0, \\ e^{\frac{-(RORWA-\mu)}{\sigma}}, & \text{if } \xi = 0. \end{cases}$$

The value of the shape parameter, ξ, links the GEV distribution to its three cases: the Fréchet distribution ($\xi > 0$), the Gumbel distribution ($\xi = 0$), and the reversed Weibull distribution ($\xi < 0$). It also indicates heaviness of the tail of the underlying distribution; the extreme value from a distribution with a heavy tail converges to a Fréchet distribution, a medium tail to a Gumbel distribution, and a light tail to a reversed Weibull distribution (Moscadelli 2004). For underlying distributions with sufficiently heavy tails (i.e., $\xi \geq 1$ and $\xi \geq \frac{1}{2}$), the mean and variance of the GEV distribution become infinite. When estimating capital surcharges below, we only consider GEV distributions with a finite mean and variance (i.e., $\xi < \frac{1}{2}$).[49] The support of the GEV distribution also depends on the parameters:

$$RORWA \in \left[\mu - \frac{\sigma}{\mu}, +\infty\right), \text{ when } \xi > 0,$$
$$RORWA \in (-\infty, +\infty), \text{ when } \xi = 0,$$
$$RORWA \in \left(-\infty, \mu - \frac{\sigma}{\xi}\right], \text{ when } \xi < 0.$$

In the expected impact theory, a bank's expected impact is the product of its probability of default and its loss given default. The

[49] We estimate negative values of ξ, so the limitation to distributions with finite means and variances does not affect our results. If distributions with finite higher moments are considered, the choice of ξ is further limited on the upper end because the kth moment of the GEV distribution is undefined if $\xi \geq \frac{1}{k}$. If all moments are assumed finite, then ξ must be non-positive.

expected impact theory equates the expected impact of G-SIB to the expected impact of a reference bank:

$$\frac{F(-CC - k_{GSIB})}{F(-CC)} = \frac{H(r)}{H(GSIB)}.$$

To estimate capital surcharges, the expected impact theory requires that the probability of default distribution is defined at the shock that would wipe out the reference bank capital ($RORWA = -CC$) and the shock that would wipe out the G-SIB capital surcharge ($RORWA = -CC - k_{GSIB}$). Undefined capital surcharges arise because some parameters may result in GEV distributions that are undefined for these shocks. If ξ is negative, the GEV distribution support is constrained by an upper bound; thus, the shock that would wipe out the reference bank's capital is the relevant constraint, and capital surcharges are undefined if $\mu \neq CC$ and $\xi < \frac{\sigma}{CC+\mu}$. If ξ is positive, the GEV distribution support is constrained by a lower bound, making the shock that would wipe out the G-SIB's capital the relevant constraint; because the GEV distribution support covers all values of $RORWA = -CC - k_{GSIB}$, all capital surcharges are defined. Based on the expected impact theory and the support of the GEV distribution, we can broaden the explicit formula for capital surcharges based on the GEV distribution:

$$k_{GSIB} = \begin{cases} g(GSIB), & \text{if } \mu = CC \text{ and } \xi \neq 0, \\ g(GSIB), & \text{if } \mu \neq CC \text{ and } \\ & \quad \xi \in \left[\frac{\sigma}{CC+\mu}, \infty\right) \backslash \{0\}, \\ \sigma \ln\left[1 - e^{\frac{-CC-\mu}{\sigma}} \ln\left(\frac{H(r)}{h(GSIB)}\right)\right], & \text{if } \xi = 0, \\ \text{undefined}, & \text{otherwise,} \end{cases}$$

where $g(GSIB)$

$$= -CC - \mu - \frac{\sigma}{\xi}\left[\left[\left(1 + \xi\left(\frac{-CC-\mu}{\sigma}\right)\right)^{-\frac{1}{\xi}} - \ln\left[\frac{H(r)}{H(GSIB)}\right]\right]^{-\xi} - 1\right].$$

For a given $\xi \neq 0$, μ and σ can be estimated with ordinary least squares:

$$RORWA = \mu + \sigma h(RORWA),$$

where $h(RORWA) = \xi^{-1}((-\ln F(RORWA))^{-\xi} - 1)$. As in the paper, to formally test for the significance of shifts in the distribution, we interact the slope coefficient with fixed effects for crisis and high short-term wholesale funding (STWF):

$$\begin{aligned} RORWA = {} & \mu_1 + \mu_2 Crisis + \mu_3 High\ STWF \\ & + (\sigma_1 + \sigma_2 Crisis + \sigma_3 High\ STWF \\ & + \sigma_4 Crisis\ High\ STWF) h(RORWA), \end{aligned}$$

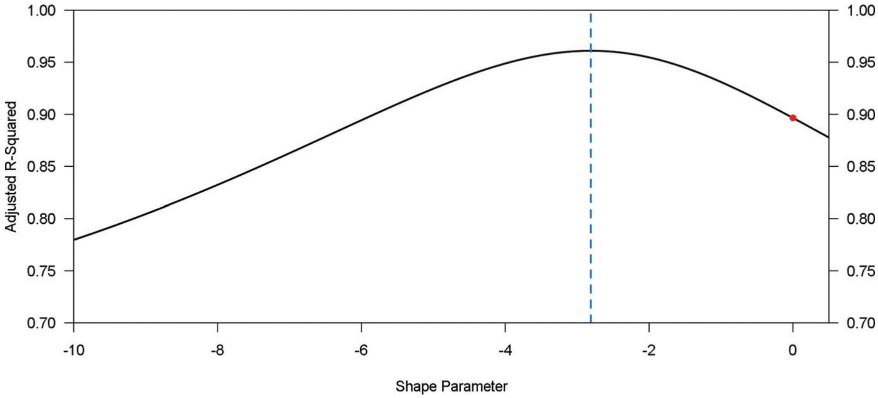
where *Crisis* is one for observations from 2008, 2009, and 2011 and zero otherwise, and *High STWF* is one for observations with STWF higher than the annual median and zero otherwise.

First, we estimate the goodness-of-fit over a range of shape parameters, shown in figure 7. It shows the adjusted R-squared for the estimation of the bottom 5 percent tail with shape parameters that range between negative five and positive one-half. The red circle indicates the adjusted R-squared from the estimation of the Gumbel distribution shown in table 3. The blue dotted line indicates the maximum goodness-of-fit.

The “best fit” approach yields lower capital surcharges than the capital surcharges based on the Gumbel distribution, although both are higher than the Basel III capital surcharges. The drawback of this method is that it may result in a support that does not include all relevant values for RORWA. In particular, the upper bound on the support is −1.15 percent, which may be inconsistent with the range of RORWA that is relevant when setting bank capital regulation.

As an alternative to the “best fit,” we estimate capital surcharges that assume the support of the GEV distribution covers all negative values of RORWA. Based on the support of the GEV distribution (if $\xi < 0$), we set $\xi = \frac{\sigma}{\mu}$. Thus, the equation that was estimated above with an assumed ξ via ordinary least squares simplifies to the following equation:

Figure 7. Generalized Extreme Value Distribution Goodness-of-Fit



Source: Annual bank balance sheet data are available from Moody's Analytics BankFocus (Bureau van Dijk).
Notes: The black line shows the adjusted R-squared for the estimation of the bottom 5 percent RORWA tail. The red circle indicates the adjusted R-squared from the estimation of the Gumbel distribution shown in table 3. The blue dotted line indicates the maximum goodness-of-fit, which is at $\xi = -2.81$. For the "negative support only" approach, the ξ values are -2.36 for the crisis low-STWF distribution and –3.01 for the crisis high-STWF distribution; the adjusted R-squared for this regression is 0.969.

$$RORWA = \mu(-\ln F(RORWA))^{-\left(\frac{\sigma}{\mu}\right)}$$

$$\ln(-RORWA) = \ln(-\mu) + \left(\frac{\sigma}{\mu}\right)(-1)\ln(-\ln F(RORWA)).$$

Defining $\alpha = \ln(-\mu)$ and $\beta = \frac{\sigma}{\mu}$, we can estimate the following equation using ordinary least squares:

$$\ln RORWA = \hat{\alpha} + \hat{\beta}(-\ln[-\ln F(RORWA)]).$$

The equation implies that $\hat{\mu} = -e^{\hat{\alpha}}, \hat{\sigma} = -e^{\hat{\alpha}}\hat{\beta}$, and $\hat{\xi} = \hat{\beta}$.

Although the capital surcharges from the "negative support only" approach are somewhat less than capital surcharges estimated with the Gumbel distribution, they remain substantially higher than Basel III capital surcharges.

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