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An Empirical Economic Assessment of the Costs and Benefits of Bank Capital in the US

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We evaluate the economic costs and benefits of bank capital in the United States. The analysis is similar to that found in previous studies though we tailor the analysis to the specific features and experience of the U.S. financial system. We also make adjustments to account for the impact of liquidity and resolution-related regulations on the probability of a financial crisis. The conceptual framework identifies the benefits of bank capital with a lower probability of financial crises, which decrease economic output. The costs of bank capital are identified with increases in banks' cost of funding. These increases are passed along to borrowers in the form of higher borrowing costs, resulting in a lower level of economic output. Optimal capital levels maximize the difference between benefits and costs, or maximizes net benefits. Using a range of empirical estimates, we find that optimal bank capital levels in the United States range from just over 13 percent to over 26 percent.

We assess the benefits of bank capital through calculating (1) how the probability of a financial crisis declines as the economy-wide level of bank capital increases and (2) the output cost of a financial crisis. The probability of a financial crisis is estimated using a bottom up approach that uses bank-level data from advanced economies and a top down approach that uses aggregate data from the same economies. The output costs associated with a financial crisis are estimated by considering short-run and long-run output costs. Short run costs are taken primarily from recent research by Romer and Romer (2015) that is adjusted to focus more heavily on the experience of large, advanced economies which are more similar to the United States. The long-run costs are estimated assuming that financial crisis either have permanent or temporary but persistent effects. We find that the net present value of the output cost of a financial crisis ranges from roughly 40 to 100 percent of annual GDP.

The costs of bank capital arise from the effect of capital on banks' cost of funding. Bank equity is more expensive than debt, but an increase in capital makes investing in banks less risky. Informed by recent research that focuses on U.S. banks, we assume that a bit less than 50 percent of the increase in capital costs is offset by the reduced risk of bank equity. Overall, our results suggest that if banks pass all of the increase in funding costs onto borrowers then borrowing rates would increase by 0.07 percentage points. We also consider a situation in which only half of the increase is passed onto borrowers.

Considering the benefits and costs of bank capital in the U.S. that we measure, the level of capital that maximizes the difference between total benefits and total costs ranges from just over 13 percent to just over 26 percent. The reported range reflects a high degree of uncertainty and latitude in specifying important study parameters that have a significant influence on the resulting optimal capital level, such as the output cost of a financial crisis or the effect of increased bank capital on economic output. Finally, the study discusses a range of considerations and factors that are not included in the cost-benefit framework that could have a substantial impact on estimated optimal capital levels.

Contents

I. Introduction

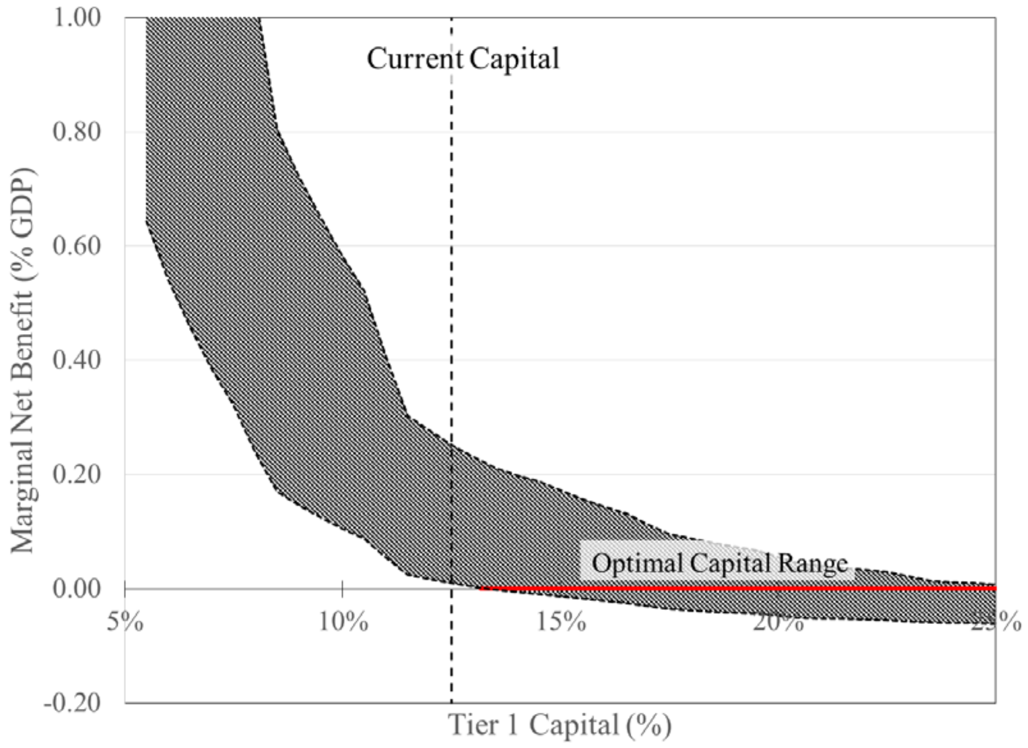
We perform an economic analysis of the long-run costs and benefits of different levels of bank capital, and estimate optimal Tier 1 capital levels under a range of modelling assumptions. Under our framework, we translate the level of capital into a probability of a financial crisis.[1] The main benefit of bank capital, under this framework, is to reduce the probability of a financial crisis as higher capital levels are associated with less frequent crises. In particular, we multiply this probability by the estimated severity of future US financial crises in order to estimate the aggregate economic benefits of bank capital. The benefits of additional capital generally decrease as capital levels rise; the potential improvement from reducing the frequency of crises becomes more limited as crises become more infrequent. The aggregate economic costs of capital stem from an increase in banks' cost of capital, which is passed along to borrowers in the form of higher credit costs and lowers gross domestic product (GDP). These costs are proportional to the increase in bank capital.

Because of several necessary assumptions and uncertainty about specific parameters, we provide ranges of the economic costs and benefits resulting from many models rather than a single estimate of the net effects. The greatest source of uncertainty in the net benefit we model arises from uncertainty around the long-run effects of a crisis. There is also uncertainty regarding the extent to which banks can pass along the costs of increased capital to borrowers. We examine different assumptions about these two effects.

The shaded region in Figure 1 shows a range for our estimated net benefits of additional capital (i.e. marginal net benefits). At levels of capital up to about 13 percent, the shaded region lies above the horizontal axis. This implies that our estimated range for the benefit of additional capital remains positive until Tier 1 capital ratios reach 13 percent. For levels of capital between 13 percent and a bit above 25 percent, the shaded region overlaps the horizontal axis. This overlap implies that our estimated benefits of additional capital over this range may be positive or negative, depending on the modeling assumptions used.

[1] Throughout the paper, unless otherwise noted, when we refer to capital we mean Tier 1 risk-based capital.

Figure 1: Estimates of the Net Benefits of Additional Tier One Capital (Marginal Net Benefits of Capital)



The width of the shaded region in the plot represents uncertainty around our estimates of the benefits and costs associated with the level of bank capital. The upper bound of this region represents our high estimate of the benefits and low estimate of the costs of bank capital. Specifically, it assumes that the effects of a financial crisis are permanent, and that banks only pass 50 percent of capital related cost increases through to borrowers. The lower bound of this region represents our low estimate of the benefits and high estimate of the costs. Specifically, it assumes that the effects of crises diminish gradually over time, and that banks pass all capital related cost increases through to borrowers.[2] We note that this plot shows levels, rather than minimum required capital. Since banks generally hold a buffer above and beyond the minimum required capital, we expect that optimal minimum capital requirements may be a bit below the range shown above.

The plotted region is downward sloping, representing the fact that marginal benefits from increased capital fall as capital increases, while the cost of increased capital remains constant. The red line where the region intersects the horizontal axis represents the range of estimated optimal capital; the point at

[2] The low estimate of benefits also incorporates an assumption that total loss-absorbing capacity (TLAC) regulations independently reduce the probability of financial crises by 30 percent. Our high estimate of benefits assumes that TLAC reduces only the cost of financial crises, but not their probability.

which further capital reduces the net benefit. We find that optimal capital levels are uncertain, but likely range between roughly 13 percent to over 25 percent.

Our framework for producing these estimates require that we model (1) the probability of financial crises given the level of bank capital, (2) the cost of financial crises in terms of the present value of lost GDP, (3) the impact of capital on lending spreads, and (4) the impact of lending spreads on long run GDP.

In order to predict the probability of a crisis under different levels of capital, we follow two approaches. The "bottom-up" approach uses simulations of U.S. bank capital levels under shocks of different severities. The "top-down" approach employs logistic regression with country-level data. We average the results from these two approaches into a single estimate of the relationship between capital levels and the probability of a financial crisis.

For calculating the cost of a financial crisis, we consider both short-term and long-run effects. As there have been relatively few financial crises in the United States, we use research on all advanced economies. We primarily rely on results from two studies. Furceri and Mourougane (2012) study the long-run effects of financial crises on GDP for a variety of advanced countries, comparing potential output to actual output. The gap between the two is the effect of the crisis. They estimate autoregressive growth equations, using data from 1960 to 2008, and find that a financial crisis has a durable effect of reducing GDP by 2 percentage points. Romer and Romer (2015) create a new measure of financial crises based on semi-annual Organisation for Economic Co-operation and Development (OECD) narratives about member countries. Romer and Romer (2015) use this measure and regression analysis to calculate the short-term effects of a financial crisis. We use results from Romer and Romer (2015) for the short term effects, and Furceri and Mourougane (2012) for the long-run effects.

To calculate the effect of increased capital on GDP, we calculate the effect on a representative U.S. bank's weighted average cost of capital. We assume that either all or half of the increase is passed on to borrowers in the form of a higher rate on loans, and use the Federal Reserve Board's FRB/US macroeconomic model to forecast the effect of an increase in lending rates on GDP.

The calculation of the effect of the level of capital on banks' cost of capital depends on how responsive the cost of banks' equity is to changes in leverage. The intuition is that, as leverage decreases, the risk of equity decreases, and so too should the required return. This intuition was formalized by Modigliani and Miller (1958) in their Nobel Prize winning research on the irrelevance of capital structure. Whether the "M&M" hypothesis applies to the banking sector has been debated by economists for some time. A common approach to addressing this question is to measure whether bank equity's covariance with the market or "beta" falls when leverage decreases. Recent work on U.S. banks includes Kashyap, Stein, and

Hanson (2010), who find such an M&M effect in general, and Clark, Jones, and Malmquist (2015), who show the effect varies by time and bank size. In this study, we consider a range of so-called M&M effects that are consistent with the findings of recent research on the U.S. banking system.

In addition to these effects, we also consider recent structural changes to bank regulation in the U.S. In particular, we consider how requirements that increase the resolvability of failing firms, and liquidity regulation as embodied by the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR) have increased the resilience of U.S. banks since the recent financial crisis. This increased resiliency will decrease the likelihood and cost of future crises, although the extent of this impact is uncertain. We offer adjustments to our baseline results accounting for these regulations whenever possible and appropriate.

As a final step, we compare the benefits of increased bank capital with its cost, and calculate a range of potential values for optimal bank capital. We find that increasing bank capital beyond the current average value of 12.5 percent of risk weighted assets (RWA) would have positive net benefits for the U.S. economy.[3] Optimal capital ratios are at least 13 percent, and may be even higher than 25 percent, depending on model assumptions.

There is an extensive literature on financial crises in advanced economies and the relationship between bank capital and macroeconomic risk. We compare our analysis with other key papers within the body of the report. Our methodology builds on studies by the Basel Committee on Banking Supervision (BCBS) (2010), the Bank of England (Brooks et al. 2015), and the Federal Reserve Bank of Minneapolis (2016). All studies use the same basic framework; the effects of increased bank capital on the probability and severity of a crisis are compared to the increase in loan rates and associated reduction in GDP level. The BCBS study uses meta-analysis of the academic literature, combined with results from various country-specific supervisory models, to quantify these effects. The Bank of England (2015) and Federal Reserve Bank of Minneapolis (2016) use both the existing literature and substantial original data analysis for calibration to the UK and U.S. economies.

Our approach differs from these studies in some significant ways. For example, we use adjustments and controls to account for the effects of new liquidity requirements and resolution requirements for failing firms. We also use Romer and Romer (2015) generalized least squares (GLS) estimates of the severity of financial crises in order to reduce the result’s dependence on data from inherently more volatile and smaller economies that are arguably less relevant to the United States, while the Bank of England uses other methods to adjust for the presence of such countries in the sample. We provide estimates alternately

[3] We compute an average Tier 1 capital ratio of 12.5 percent for the U.S. banking system using year-end 2015 data from Bankscope, from Bureau van Dijk.

using both permanent and persistent but decaying effects of financial crises on GDP. Finally, unlike the BCBS (2010) and Bank of England (2015) studies, we design the research to ensure, where possible, that the analysis is tailored to the specific features of the U.S. financial system so that the results are relevant for considering capital regulatory policy in the United States.

We summarize the results of our study alongside previous studies in Table 1. In Table 1, we report the impact of increasing bank capital from its current average U.S. level of 12.5 percent of RWA to 13.5 percent. In the final column we also report the range of optimal capital levels found by each study.

Table 1: Effect of an Increase in Capital from 12.5% to 13.5% and Optimal Capital Ratios, Four Studies

	Benefits: Reduction in Pr(Crisis)* Crisis Cost (bp) [4]	**Costs: Reduction in GDP (bp)**	**Optimal Bank Capital**
Federal Reserve Board (this study)	8 to 27	4 to 7	13% to 25+%
BCBS (2010)	~3 to 24	9	9% to 15+%[5]
Bank of England (2015)	~2 to 10	1 to 5	10% to 14%
Federal Reserve Bank of Minneapolis (2016)	~11	~6	22%

Our results imply larger optimal capital levels than the Bank of England (2015), and similar levels to the BCBS (2010) and Federal Reserve Bank of Minneapolis (2016) studies. The Bank of England study arrives at a lower optimal capital level in large part because of a 30 percent reduction in the estimated probability of crisis and a 60 percent reduction in the estimated cost of crisis that they attribute to the role of Total-Loss Absorbing Capacity (TLAC). The Federal Reserve Bank of Minneapolis (2016) arrives at an optimal capital level near the upper end of our range. While they find a relatively small impact of capital on the probability of a crisis, they use a significantly higher estimate of the cost of financial crises and an estimate of the economic costs of bank capital that is similar to our low estimate.

[4] The range reported for benefits of capital in BCBS comes from the difference in the benefits at 12 percent and 13 percent TCE/RWA ratios under the alternative assumptions of cost of crises of 19 and 158 percent (Table 8). Bank of England figures for benefits use approximate changes in the after TLAC crisis probabilities at mid-cycle and peak from Table 7, multiplied by a 43 percent cost of financial crises. Minneapolis cost of a crisis is 158 percent. We approximate the reduction in the probability of crisis as 7bp based on the 69bp reduction in probability of a bailout between capital levels of 10 and 20 percent (Table 2).

[5] The reported figure represents a ratio of Basel II tangible common equity (TCE) to risk-weighted assets. Table 8 of the BCBS report indicates that net benefits of capital requirements are maximized TCE to risk-weighted asset ratios ranging from 9 percent (no permanent effect of financial crises) to over 15 percent (large permanent effect of financial crises). Our analysis suggests the equivalent figures for the Tier 1 capital ratio would be 9.3 percent to 15.5+ percent.

II. Analytical Framework

Our framework for measuring the long-run net benefits of bank capital levels follows previous work by the BCBS (2010), Miles et al. (2013), Bank of England (2015), and the Federal Reserve Bank of Minneapolis (2016).[6] In the interest of simplicity, this framework allows bank capital to affect the economy via just two channels: (1) the probability that a financial crisis starts and (2) banks' cost of capital. By using this framework, we do not incorporate the impact of capital on risk premia or lenders' behavior. In addition, we do not measure benefits accruing to other economies, or benefits in the form of increased utility of risk averse consumers. Section VII discusses these issues in further detail. With this two-channel framework, the benefits of bank capital arise from a lower probability of financial crisis related output gaps. The costs of bank capital are a lower equilibrium level of output, through the effect of banks' cost of capital on lending spreads. By subtracting the costs from the benefits, expressing both as a percentage of annual GDP, we arrive at the equation below.

$$\begin{aligned}&Net\ Benefits\ of\ Bank\ Capital\\ &= \underbrace{Reduction\ in\ Probability\ of\ a\ Financial\ Crisis}_{\text{increasing with capital (see section IV.a)}}\ X\ \underbrace{Net\ Present\ Cost\ of\ a\ Financial\ Crisis\ (\%\ of\ GDP)}_{\text{unaffected by capital (see section IV.b)}}\\ &- \underbrace{\%\ Reduction\ in\ GDP\ Due\ to\ Higher\ Lending\ Spreads}_{\text{increasing with capital (see section V)}}\end{aligned}$$

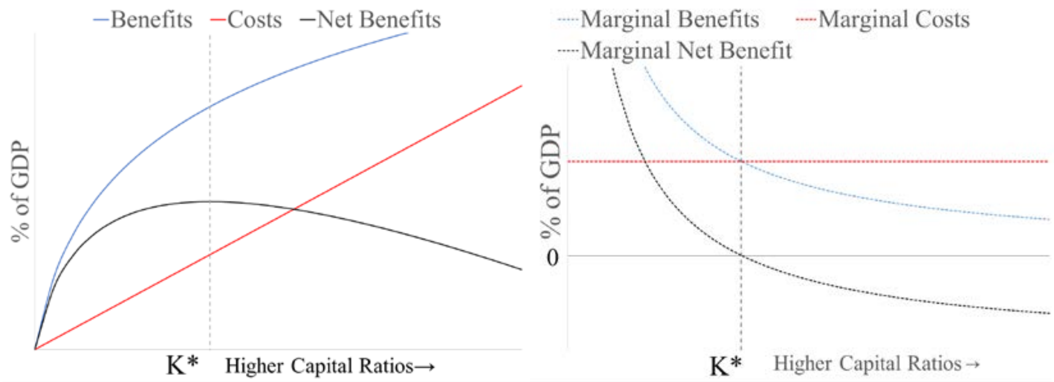
As mentioned above, banks generally keep buffers of capital above minimum requirements, so optimal bank capital requirements would be lower than the capital levels shown below.

Figure 2 illustrates our basic solution concept for finding the optimal level of bank capital. As in the other papers using this framework, the benefits of *additional* (marginal) capital that we estimate are decreasing as capital rises, and eventually approach zero.[7] This decrease can be seen in the downward slope of the blue marginal benefits curve on the right-hand side plot.

Intuitively, at higher levels of capital there are fewer shocks left that are large enough to generate a crisis. However, the costs of marginal capital that we estimate increase linearly. As a result, the marginal net benefits in our framework steadily decrease and become negative beyond some level of capital K* that represents optimal capital. As mentioned above, banks generally keep buffers of capital above minimum requirements, so optimal bank capital requirements would be lower than the capital levels shown below.

[6] The International Monetary Fund's (IMF's) analysis (Dagher et al. 2016) follows a similar framework but does not estimate of the cost of financial crises or net benefits.
[7] Certain models of Miles et al. (2013) are an exception here as they use a bimodal distribution of financial system shocks.

Figure 2: Relationship of Benefits, Costs, and Optimal Capital Level (K*)



The remainder of this study is devoted to conducting analysis designed to provide estimates of the marginal benefit and marginal cost curves that are pictured in the right-hand panel of Figure 2. As discussed previously, a variety of data and models are employed in estimating these relationships. This study attempts to focus on data that is most relevant to the experience of the United States while acknowledging that a variety of different models would produce varying results for the estimated marginal benefit and cost curves. In addition it is worth noting that the analytical framework used to determine optimal capital levels is rather stylized and abstracts from a number of real world considerations.

In particular, our framework addresses broad changes in capital rather than targeted requirements that apply to specific banks such as the global systemically important banks (GSIBs) surcharge and the Comprehensive Capital Analysis and Review (CCAR).[8] Our framework assumes that all banks choose the same capital ratios, and we do not account for the heterogeneity of the U.S. capital framework resulting from targeted regulations. It is possible that this heterogeneity could affect both estimated costs and benefits. For example, if only certain banks were affected by higher capital ratios, a smaller share of their increased cost of capital might be passed on to borrowers, decreasing the economic costs of the extra dollar of capital. On the benefits side, additional capital has the greatest effect on the probability of failure for the least well capitalized banks. Therefore, the microprudential benefits may be lower under heterogeneous requirements. However, there may be greater macroprudential benefits in reducing the failure rate of systemically important firms.

At the same time, this framework has been employed by all of the previous studies that have been conducted in this area and so its use here reflects its widespread adoption in the academic literature and

[8] See www.federalreserve.gov/newsevents/press/bcreg/20150720a.htm for more information on the GSIB surcharge. See www.federalreserve.gov/bankinforeg/stress-tests-capital-planning.htm.for more information on CCAR.

also facilitates comparison with those studies. Future analyses may benefit from considering richer and more complex models that consider important effects not captured in this framework.

Section III discusses the institutional environment in which our analysis takes place. In particular, many new regulations have been adopted in the wake of the recent financial crisis that need to be accounted for in our analysis. The rest of the paper is arranged as follows in order to build upon the analytical framework. The economic benefits and costs of bank capital are estimated in Sections IV and V, respectively. Section VI uses the results of the prior two sections to assess the net benefits of capital. We discuss economic benefits and costs of capital not explicitly captured by our analysis in Section VII and Section VIII concludes.

III. Institutional Environment

Two new U.S. enhancements to large bank safety and soundness will affect the relationship between bank capital levels and the macro-economy: increased resolvability of failing firms and liquidity requirements. In our analysis, we consider the effects of capital in the presence of both.

A number of resolution planning requirements have been adopted in order to ensure rapid and orderly resolution in the event of financial distress or failure of a company. Of particular importance are the long-term debt requirement and the TLAC requirement. These requirements are designed to create a source of funds for recapitalization.[9] They apply to top-tier U.S. bank holding companies that have been designated as GSIBs and U.S. intermediate holding companies (IHCs) of foreign GSIBs. These institutions must maintain a certain amount of eligible long-term unsecured debt that can be converted to equity for the purpose of absorbing losses or recapitalization in the event of failure. Requirements are effective as of January 1, 2019. The aggregate TLAC shortfall for U.S. GSIBs was estimated at $70 billion as of the third quarter of 2016 (Total Loss-Absorbing Capacity 2016).

TLAC's most direct effect will be a change from public "bail-outs" for large banks that are in severe stress to private "bail-ins," where the eligible debt held by private-sector creditors is converted into equity. Such a mechanism is designed to quickly resolve distressed banks by rapidly providing a new source of capital rather than resorting to taxpayer support.

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[9] See www.federalreserve.gov/newsevents/press/bcreg/20151030a.htm for more information on the long-term debt and TLAC requirements. See www.federalreserve.gov/bankinforeg/resolution-plans.htm for more information on living wills. See www.fdic.gov/regulations/laws/federal/2011/11finaljuly15.pdf for more information on the orderly liquidation authority.

In addition to complying with the long-term debt and TLAC requirements, U.S. bank holding companies with total consolidated assets of $50 billion or more must submit annual orderly resolution plans, commonly known as living wills, to the Federal Reserve. These plans should facilitate the rapid and orderly resolution of a firm in the event of failure and prevent contagion among broader financial markets.

Beyond resolution planning requirements, the orderly liquidation authority (OLA) provided to the Federal Deposit Insurance Corporation (FDIC) by Title II of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 increases the resolvability of financial firms. The OLA provides an alternative to standard bankruptcy that allows the FDIC to carry out the liquidation of a failing financial company, aiming to minimize systemic risk and moral hazard.

We account for the benefits associated with increased resolvability of failing firms whenever possible. We model a projected reduction in the length of a crisis, based on work by Homar and van Wijnbgergen (2016), and find it reduces the expected cost. We also consider the effects of possible reductions in the probability of a crisis due to reduced bank risk-taking.

Liquidity requirements are designed to permit a bank to maintain sufficient liquid assets during a period of stress. There are two main liquidity requirements: a short-term Liquidity Coverage Ratio (LCR) and a long-term Net Stable Funding Ratio (NSFR).[10] The LCR was adopted in the United States in 2014, with all phase-in to be completed by January 2017. It applies in full to all U.S. institutions with at least $250 billion in total assets or at least $10 billion in on-balance sheet foreign assets. Less stringent requirements apply to institutions with between $50 billion and $250 billion in total assets and less than $10 billion in on-balance sheet foreign assets. The LCR requires banks to maintain an amount of high-quality liquid assets (HQLA) sufficient to cover expected net cash outflows during a 20-day stress period. HQLA is a weighted sum of specific high quality liquid assets, with higher weights on the most liquid assets. Expected net cash outflows are fixed by regulation and based on the type of liabilities. Shorter term and more runnable liabilities are associated with the highest outflow rates.

The NSFR also has a two-tiered approach for institutions, based on the same total and foreign asset thresholds. It is designed to ensure sufficient liquidity over a one-year horizon, compared with the 30 day horizon of the LCR. It also requires an appropriate match between assets and liabilities. NSFR requirements were the subject of a Notice of Proposed Rulemaking in April 2016. Almost all covered

[10] See www.federalreserve.gov/newsevents/press/bcreg/20140903a.htm for more information on the LCR and www.federalreserve.gov/newsevents/press/bcreg/20160503a.htm on the NSFR.

institutions as of December 2015 were already in compliance with the NSFR, and the few that were not had relatively small shortfalls.

Shocks to the value of financial system assets are amplified by liquidity shortfalls. Banks with short-term funding requirements exceeding their liquid assets may find themselves vulnerable to "fire sales" of illiquid assets when such shocks occur. These sales can trigger losses, loss of funding liquidity, and asset sales at other banks, potentially threatening the solvency of the entire system.[11] Consequently, liquidity requirements are also likely to reduce the probability of a financial crisis. We include adjustments for the effect of liquidity regulations in our estimated financial crisis probabilities.

IV. The Economic Benefits of Bank Capital

As in past studies (BCBS 2010; Miles et al. 2013; Bank of England 2015; Federal Reserve Bank of Minneapolis 2016), we measure the benefit of bank capital by first estimating bank capital's role in reducing the probability of a financial crisis (Section IV.a), and then multiplying this by the cost of financial crises (Section IV.b). Our estimates are tailored where possible to the specifics of the U.S. financial system, and include adjustments to account for the impact of additional liquidity and loss absorption requirements on the marginal benefit of bank capital.

We rely on definitions of financial crises developed in previous surveys, as defining crises is a non-trivial exercise. When estimating the probability of financial crises, we rely on the criteria and crises identified by Laeven and Valencia (2012). When estimating the cost of financial crises, we use results from Romer and Romer (2015), who develop a continuous narrative-based measure of financial distress. Romer and Romer (2015) include an extensive comparison of their definition with that in Laeven and Valencia (2012). They are almost equivalent in identifying if crises occur, but have a few differences with regard to the crisis start dates.

We discuss additional, potentially significant, benefits of bank capital not captured in this framework in Section VII.

a. Probability of a Financial Crisis

As with past studies, we estimate the probability of a financial crisis starting via two approaches with distinct strengths and weaknesses; a "bottom-up" bank-level simulation and a "top-down" country level regression. In our reported results, we use the average of the probabilities generated by the two

[11] See Shleifer and Vishny (2011) for a review of the literature on asset fire sales. See Brunnermeier and Pedersen (2009) for a discussion of the destabilizing link between market and funding liquidity.

approaches.[12] For use in both approaches, we collect data spanning 24 developed OECD countries over the period 1988 through 2014.[13] These data include 23 of the financial crises identified by Laeven and Valencia (2012). In both approaches, we estimate the long-run average effect of bank capital on financial crises, whereas the Bank of England (2015) analysis estimates the impact at the peak and trough of credit cycles separately and later combine these.

In the bottom-up approach we use bank-level data to simulate shocks to U.S. banks' capital. We estimate how frequently these shocks would be large enough to start a financial crisis at different levels of starting capital. Specifically, our simulations assume that a financial crisis occurs whenever the capital shortfall exceeds 3 percent of GDP, which is the definition used by the Bank of England (2015), and is the threshold for "significant restructuring costs" used by Laeven and Valencia (2012). This approach recognizes that the amount of capital required to avoid crises varies across historical stress periods. Since losses in some historical episodes were very high, the probability of crisis in the bottom-up approach does not become very small until capital levels reach relatively high levels. However, this approach does not predict or account for financial crises whose proximate causes are other than the loss of capital.

The Bank of England (2015) impact study also includes a simulation of bank income, though the details of their simulation differ, such as the relationship between the draws of income for different banks. The International Monetary Fund (IMF) (Dagher et al. 2016) and Federal Reserve Bank of Minneapolis (2016) also rely on what is essentially a bottom-up approach as well, but use country-level data on non-performing loans instead of bank-level data on net income.

In the top-down approach we use historical country-level data to estimate the probability of a financial crisis given the financial system's capitalization, liquidity, and economic conditions. This approach applies the less rigid definition of financial crisis developed by Laeven and Valencia (2012). Also, by abstracting away from bank-level distress, the top-down approach implicitly focuses on the macro-prudential role of capital regulations. Key data are unavailable for many countries in our sample, so we estimate two separate regression specifications as a compromise. In one, we use the full sample, with a more limited set of control variables. In the other, we use a larger set of control variables, but only over the subsample where these variables are available. The average of the predictions from the two models is used as our top-down estimate.

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[12] We apply a 50 percent weight to our bottom-up approach, and a 25 percent weight to each of the two models we rely on in our top-down approach.

[13] The sample includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

The Bank of England (2015) impact study employs a top-down regression that differs from one of our specifications only to the extent that our variable definitions and coverage are a bit different. BCBS (2010) also employs a range of similar reduced form models within the set of estimates they present.

The two sections that follow describe each of these approaches and the results they deliver in greater detail.

Bottom-Up Approach

In this approach, we simulate net income for U.S. banks and then determine whether the aggregate capital shortfall that results is large enough to classify as a financial crisis using the definition of "financial crisis" that was described previously. In the process, we adjust the simulated income to account for the fact that large U.S. banks are now subject to liquidity requirements as well. This adjustment is discussed in more detail below.

To implement this approach, we use bank-level data on total assets, risk-weighted assets, net income, Tier 1 capital, and asset liquidity ratios from Bankscope, from Bureau van Dijk. These data have good coverage over the period spanning 1988 through 2014.[14]

We use these historical data to simulate net income for U.S. banks. For each simulation, we first randomly pick a single country-year scenario; for example, "France 2008." Then, for each of the 5,935 U.S. banks at the end of 2015, we randomly draw (with replacement) a value for two-year net income / RWA from within the set of large banks present in that country-year scenario.[15,16] We use two-year net income to roughly match the length of CCAR stress periods. This captures the fact that bank losses are predictable over multiple years in stress periods, possibly because of the smoothing of asset value shocks on balance sheets. We exclude small banks from the distribution of net income we draw from, as this distribution may be different for small banks.[17]

Next, we compute the aggregate capital shortfall that results under the simulated net income draws and a range of initial Tier 1 capital levels. We follow the Bank of England's approach by identifying crises as

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[14] We exclude 30 country-years where coverage either appears particularly incomplete and/or includes banks representing less than $10 billion in aggregate total assets.

[15] In contrast to our approach, the Bank of England impact analysis pools country-years into just two scenarios: one where credit/GDP and equity volatility are high, and one where they are not.

[16] In order to account for the average difference between Basel III risk weights and risk weights under Basel I and II regimes, we increase risk weighted assets for all years prior to 2011 by the increase in U.S. average risk weights over 2011 to 2015 (about 11 percent). For 2012 through 2014, we increase risk-weighted assets by the increase in U.S. average risk weights between that year and 2015.

[17] We define the cutoff between small and large banks so that 90 percent of each country's financial system assets in each year are within "large" banks. Across countries, we have an average of about 915 large banks per year.

simulations where the aggregate shortfall exceeds three percent of GDP (or $540 billion), or a significant recapitalization as defined by Laeven and Valencia (2012). This shortfall is measured relative to a threshold of 8.24 percent. This threshold is chosen so that the average probability of crisis generated by the model when applied to the United States (1989 through 2014) equals the advanced economy average probability of crisis (4.0 percent per Laeven and Valencia 2012).[18] With our shortfall threshold and crisis definition, if all U.S. banks had the same Tier 1 capital ratios, a crisis occurs whenever this ratio falls below about 4.7 percent. We run our simulation 10,000 times, in each one using a random set of net income draws from a randomly selected country-year scenario as described above.

For most of the historical data period, major liquidity regulations (LCR and NSFR) were not in effect. If they were, banks may have had more liquid assets to sell off during stress periods, reducing the extent of loss magnifying fire sales. To account for the effect of liquidity regulations on loss magnitudes, we use the following procedure outlined below.

First, we construct a set of proxies for LCR compliance, as these figures are generally not available historically.[19] We identify a cross-section of 12 large U.S. banks in 2012 for which both LCR and liquid asset share (from Bankscope) are available. The correlation of these two variables is significant (about 0.52), and a least squares regression of LCR on liquid asset share (without an intercept) yields: LCR=2.55*liquid_asset_share. For each of these 12 observations, we then estimate the liquid asset share required to set LCR equal to one (the required level) as: required_liquid_asset_share=(1-LCR)/2.55. These 12 values are proxies for the liquid asset share equivalent to LCR compliance.

Next, we estimate the historical relationship between the (lagged) liquid asset share of a bank, and the magnitude of banks' losses. We run least squares regressions of the log magnitude of losses (relative to RWA) on log liquid assets, alternately controlling for (lagged) log assets and bank type in addition to log assets. The estimated coefficient on log liquid assets varies from -0.095 to -0.107, so we use -0.10 as our estimate of the impact of log liquid assets on log loss magnitude.[20]

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[18] When using a different threshold, such as is done by the Bank of England, additional adjustments are required in order to match the historical frequency of financial crises.

[19] We focus on LCR compliance as we lack decent proxies for the NSFR in our Bankscope data.

[20] Depending on the specification, this coefficient is statistically significant at the 5 or 10 percent level with standard errors clustered at the country level. We treat this result with caution as we have not controlled for the fact that liquidity is an endogenous decision by banks. There is to our knowledge very little empirical work on the relationship between balance sheet liquidity and loss severity. Cifuentes, Ferrucci, and Shin (2005) use simulations and find that liquidity ratio requirements can limit "contagion" of bank failures because of illiquid asset fire sales. Malherbe (2014) finds in a theoretical model that liquidity ratio requirements can *increase* the probability of a financial crisis.

To integrate these findings within the simulations described above, we draw the liquid asset share in addition to the net income (relative to RWA) from the banks in each country-year scenario. We also randomly assign one of the 12 proxies for LCR compliance based on liquid asset share to each bank. Then, if the net income draw is negative and the liquid asset share drawn is less than the assigned LCR proxy, net income is adjusted toward zero based on the relationship of log liquid assets to log loss magnitude estimated above.

Table 2 provides three examples of this procedure. Bank A receives a draw of negative net income from some bank X with relatively low liquid assets.[21] Based on the randomly assigned LCR proxy of 40 percent, bank X's log liquid asset share would need to be higher by ln(40 percent)-ln(20 percent)=0.693 in order to have been LCR compliant. The regression of log net losses (relative to RWA) above implies in turn that log losses would have been lower by -0.1*0.693=-0.0693, or that losses would have been 93.3 percent as large. In this case, we apply this modifier to the losses before computing the size of any bank-specific or aggregate shortfall. The table shows that no such modifier is applied when the draw comes from either a bank deemed already LCR compliant (as in the case of bank B) or the net income drawn is positive (as in the case of bank C).

Table 2: Example of Liquidity Requirement Adjustments to Net Income Draws

	U.S. Bank A	U.S. Bank B	U.S. Bank C
Randomly drawn net income/RWA	-0.12	-0.11	0.09
Liquid asset share (from same random bank as above)	20%	40%	10%
Randomly assigned LCR proxy	40%	20%	35%
Net income multiplier	0.93=(40%/20%)^(-0.1)	0 (bank already LCR compliant)	0 (net income is positive)
Net income/RWA to use	-0.1116=0.93*-0.12	-0.11	0.09

Finally, other impact studies have suggested loss absorption requirements, such as TLAC, may reduce the probability of financial crises. In theory, greater reliance on debt that is priced to reflect risk may restrain bank risk-taking. TLAC may reduce the risk of individual or even systematic bank failures. Based on this

[21] Recall that bank X is drawn from within the country–year pair (e.g., France 2008) that is randomly selected in the given simulation.

argument, the Financial Stability Board (2015) relies on work by Afonso et al. (2014) and Marques et al. (2013) to estimate that TLAC reduces the probability of financial crises by 30 percent.[22]

Table 3 shows our bottom-up estimates of the probability of a financial crisis across a wide range of Tier 1 capital levels. Column [1] presents our estimates without the liquidity required-based adjustment to loss magnitudes described above. Column [2] includes this adjustment, showing that it reduces the estimated probability of financial crises by about 3 to 14 percent, depending on the level of capital. In column [3], we apply a 30 percent reduction to all probabilities to account for increased resolvability of failing firms. Given the multiple uncertainties in this approach, we treat the magnitude of this adjustment with caution. Finally, columns [4] and [5] provide a comparison with results of the bottom-up approaches in other impact studies.

Table 3: Results of the Bottom-Up Approach: Estimated Probability of Financial Crisis

Tier 1 Capital Ratio (percent)	**No adjustment for liquidity regulations or increased resolvability**	**Adjustment for liquidity regulations, but not increased resolvability**	**Adjustment for liquidity regulations, and 30 percent reduction for increased resolvability**	**Results from Bank of England, peak credit/GDP (2015)[23]**	**Results from Minneapolis Fed & IMF (2016)**
	[1]	**[2]**	**[3]**	**[4]**	**[5]**
8.0	3.8	3.2	2.6	2.2	
11.0	1.9	1.8	1.3	1.5	~1.2
14.0	1.4	1.4	1.0	1.3	~1.0
17.0	1.0	1.0	0.7	~0.9	
21.0	0.8	0.7	0.5		~0.5
25.0	0.7	0.7	0.5		

Source: Federal Reserve calculations.

Our estimates are based on a shortfall threshold that is calibrated to yield a 4 percent probability of crisis when applied to the United States over 1989–2014. Estimates reported by the Bank of England and Federal Reserve Bank of Minneapolis are not comparably calibrated and are significantly lower.[24] Extreme aggregate loss outcomes may be less likely in the Bank of England’s analysis as they likely use net income from a single year, and draw these net incomes from a pool that spans multiple countries and

[22] The Financial Stability Board analysis uses 30 percent as a baseline estimate, but also provides a range of estimates for the impact of TLAC ranging from under 10 percent to over 40 percent.
[23] Results are given before further adjustments applied by the bank.
[24] At the time of implementation, Bank of England (2015) multiplies the probabilities estimated by their bottom-up approach to match a historical probability of crisis at lower levels of capital.

years.[25] The Minneapolis Fed's results, which adopt the methodology employed by the IMF (Dagher et al. 2016), may be less comparable, as they impute losses from historical country-level (as opposed to bank-level) peak NPLs from a larger panel (with a lower average incidence of crises). However, all approaches yield roughly proportional (i.e. equal percentage) reductions in the probability of crisis as capital levels change. This is important since, as discussed in the analytical framework section, the marginal benefit of capital is of greatest relevance and relates to the change in the probability of a financial crisis as capital changes rather than the overall level of the probability of a financial crisis.

The probability of financial crises declines sharply as capital levels rise. However, the rate of this change in probability, in absolute and relative terms, is more gradual as the level of capital rises. This observation is due to the fat-tailed historical distribution of stress losses, upon which all empirical bottom-up approaches rely. Once the relatively common milder stress periods are avoided (at Tier 1 ratios around 15 percent) there are relatively few crises remaining that can be avoided without substantially greater amounts of capital.

Top-Down Approach

In our top-down approach, we use a cross-country logit model to predict the probability of a financial crisis starting given the financial system's capital and asset liquidity, and controlling for other sources of economic fragility. Our annual data covers the same set of countries and years as used in our bottom-up approach, although we omit country-years where there is an ongoing crisis.[26] We adopt the definition and dates of systemic banking crises developed in Laeven and Valencia (2012). This definition requires the following two conditions to be met:

1) significant signs of financial distress in the banking system (as indicated by significant bank runs, losses in the banking system, and/or bank liquidations).
2) significant banking policy intervention measures in response to significant losses in the banking system.

This definition is more flexible than the capital shortfall based definition of a crisis used in the bottom-up approach, allowing for a more nuanced definition of what constitutes a crisis.

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[25] The Bank of England estimates for moderate parts of the credit cycle yield significantly lower probabilities of crisis. Given the large difference between the predicted and observed frequency of crises, the Bank applies a significant multiplier to the estimates produced by their bottom-up approach.

[26] We omit country-years where there is an ongoing crisis because we are interested in predicting the probability of a financial crisis starting. This probability is implicitly conditional on a financial crisis not yet having occurred.

We derive country-level Tier 1 capital and asset liquidity ratios for each year using the bank-level data from Bankscope described previously. Consistent with the related Bank of England exercise, we collect implied volatility (VIX) from the Chicago Board Options Exchange and the ratio of total private-sector credit to GDP from the World Bank.[27] To further control for fragility related to trade imbalances and asset valuation, we also collect data on the current account balance (as a percent of GDP) from the World Bank and the price-to-income ratio from the OECD. Note that VIX is the only explanatory variable in our model that is not country specific.

We run two separate logit regressions. The specifications for these regressions are indicated by the two equations below, where the function f in each one is the logistic function. Our first specification, equation (1), is most similar to the Bank of England's, and uses only VIX and credit to GDP as macroeconomic controls. Our second specification, equation (2), adds current account balance and home price-to-income ratios. We opt to use two specifications because the additional control variables in specification (2) are missing for around one-third of our observations. The first specification thus uses a larger sample, while the second specification uses a more complete set of variables.

$$(1)\quad Probability(Crisis_t) = f(Tier1\_Capital_{t-1}, Liquid_{Asset}\ \%_{t-1}, VIX_{t-1}, Credit\_GDP_{t-1})$$

$$(2)\quad Probability(Crisis_t) = f(Tier1\_Capital_{t-1}, LiquidAsset_{t-1}\%_{t-1}, VIX_{t-1}, Credit\_GDP_{t-1}, CurrAcct\_GDP_{t-1}, HomePrice\_Inc_{t-1})$$

Results of both specifications are shown in

Table ***4***. Specification (1) is a more appropriate fit for the data based on log likelihoods and Akaike Information Criterion but it is important to note that the differences in fit and common coefficients between the specifications are largely driven by the completeness of the data in the samples rather than the covariates chosen.

The VIX is highly statistically significant in both specifications. Liquid asset share is not statistically significant in either specification, which will impact how we consider the effect of liquidity regulations, as discussed shortly.

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[27] We use the Chicago Board of Exchange VXO volatility index prices until the VIX index becomes available in 1990. Historical VIX data is available at www.cboe.com/products/vix-index-volatility/vix-options-and-futures/vix-index/vix-historical-data.

Table 4: Regression Results of Both Top-Down Model Specifications

	Dependent variable:	
	Probability of a financial crisis	
	(1)	**(2)**
Tier 1 ratio	-7.251	-24.733*
	(10.089)	(15.691)
Liquid asset share	1.744	4.034
	(1.768)	(2.603)
Credit to GDP ratio	1.243***	0.733
	(0.454)	(0.702)
VIX	0.090***	0.095***
	(0.031)	(0.035)
Current account balance		-3.388
		(5.231)
Price to income ratio		2.707**
		(1.134)
Constant	-5.879***	-6.893***
	(1.230)	(1.797)
Observations	434	328
Log Likelihood	-82.144	-66.512
Akaike Inf. Crit.	174.288	147.024
Note:	*p<0.1; **p<0.05; ***p<0.01	

We first use estimates from these two regressions to predict the probability of crisis under counterfactual levels of Tier 1 capital without any adjustments for regulations put in place after the 2008 financial crisis. For each Tier 1 capital level we take the average of the probabilities across all country-years as our estimate of the average probability of crisis over the business cycle (i.e. over the distribution of non-crisis macroeconomic states) for that capital level. These baseline results are in columns 2 and 3 of Table 5. These results may overestimate the probability of a crisis because recent regulations have greatly increased the resiliency of the U.S. financial system and this is not reflected in the data used to estimate the regressions.

To account for this overestimation of the probability of a financial crisis, we consider the effects of compliance with new liquidity regulations and the increased resolvability of failing financial firms.

Liquidity regulations, particularly the LCR requirement, would be best captured by our share of liquid asset variable. As shown in

Table 4, the estimated coefficient for this variable is positive but insignificant in both specifications of our model. For this reason accounting for liquidity regulation compliance would not significantly alter the results of the top-down method and we do not perform an adjustment for liquidity regulation.

We next consider the effect of increased resolvability of failing financial firms. As described in the Institutional Environment section, new resolution regulations such as TLAC create a source of funding for recapitalization that is not directly reflected in either specification of our model. Therefore we follow the adjustment method of the bottom-up approach and assume a 30 percent reduction in the probability of a crisis as a result of the increased resolvability of firms. Results reflecting this reduction are shown in the final two columns of Table 5. These results are most representative of the probability of a crisis in the current regulatory environment.

Table 5 provides the results of the top-down method. The first column shows various counterfactual levels of the Tier 1 capital ratio. The next two columns show probabilities of crisis resulting from both specifications of the model with no adjustment for increased resolvability or liquidity regulations. The last two columns consider the effect of increased resolvability.

Table 5: Results of the Top-Down Approach

Annual probability of financial crisis (percent)

	No adjustments		**Adjustment for increased resolvability**	
Tier 1 capital ratio	**Specification (1)**	**Specification (2)**	**Specification (1)**	**Specification (2)**
8.0	6.3	6.8	4.4	4.7
11.0	5.2	3.3	3.6	2.3
14.0	4.3	1.5	3.0	1.1
17.0	3.5	0.7	2.5	0.5
21.0	2.7	0.2	1.9	0.2
25.0	2.0	0.1	1.4	0.1

The differences between the two specifications show that the relatively limited number of financial crises mean that results can be sensitive to the sample selection and choice of macroeconomic control variables. As in the bottom-up method, both specifications of the model attribute higher Tier 1 capital ratios with lower probabilities of crisis. However, specification (2) shows far greater sensitivity of probabilities to capital ratios and produces estimates more similar to those of the bottom-up method. In this case, most of this difference is driven by differences between the data sample used in the two specifications.

Our top-down approach is very similar to that taken by The Bank of England (2015). The Laeven and Valencia (2012) definition of a systemic banking crisis is used in both studies. The Bank of England considers one specification of their logit model which differs from our specification (1) only in that it includes total deposits to total liabilities as an additional explanatory variable. This variable is also included as a control in the BCBS LEI (2010). While total deposits to total liabilities is a useful variable for distinguishing between asset and liability liquidity, we were unable to include it in our analysis for data availability reasons. Table 6 offers a comparison between our top-down results and those of The Bank of England (2015).

Table 6: Comparison of Top-Down Results with Bank of England (2015)

Tier 1 capital ratio	Results from our top-down method (average of both specifications)	Results from Bank of England, peak credit/GDP (2015)[28]
8	6.5	11.8
11	4.2	5.9
14	2.9	3.9

Note: Results in this table are shown before any adjustments are made for other factors.

Our top-down models yield average results that are roughly proportional to those estimated by the Bank of England (2015). However, our estimates are only about two-thirds as high as those that the Bank of England calibrates based on peak credit/GDP scenarios.

b. Cost of Financial Crises

There are several reasons why financial crises reduce economic growth. A negative shock to lending reduces demand for output, leading to less investment in capital and research. The increased uncertainty of an economy in crisis can further reduce investment. We quantify the size of this effect in this section.

There are three steps to measuring the effect of a financial crisis on GDP. They are deciding if a crisis's effects are permanent, measuring the time-varying effects of the crisis throughout its duration, and calculating the present value of the sum of these effects over time. If there are no permanent effects, the

[28] Taken from the probability of systemic crisis (peak) column of Table 6 of Bank of England (2015).

cost is simply the present value of the short- and medium-term effects. We discuss each of these steps below.

Does a Crisis Have Permanent or Persistent Effects?

Measuring the duration of the effects is especially important because it has a large impact on the cost estimate, even changing the order of magnitude. A permanent effect, even with a high discount rate, will have a much larger present value than a transitory effect. Some studies assume that a crisis' duration is the length of time required for a country to attain the same growth rate in the years prior to the crisis.[29] An example of such a study is Bordo et al. (2001), who analyze financial crises in a variety of countries on 120 years of data.[30] They find the duration is quite short, an average of two-and-a-half years for crises occurring between 1973 and 1997.

A shortcoming of such studies is that they ignore performance of the economy after one period of prior trend growth. If the economy achieves high growth for one period, and then growth falls below the pre-crisis trend again and generally stays there, such approaches would state that there is no permanent effect. They also rule out permanent effects by construction.

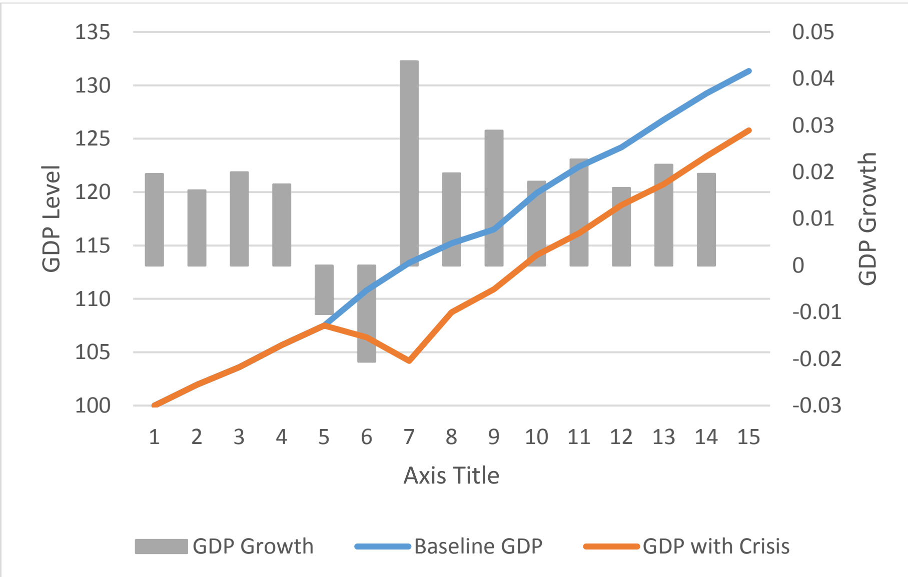
Other studies leave the duration of a crises' effects open as an empirical question, and generally find support for long lasting effects. Furceri and Mourougane (2012), analyze OECD countries and compare actual output after a crisis with a measure of potential input. They estimate autoregressive equations and the implied impulse response functions, finding an average permanent reduction in GDP of 2 percent. Cerra and Saxena (2008), analyzing data from over 120 countries, find evidence that effects of a financial crisis on GDP are barely reduced by one percentage point after ten years, remaining at a level of six percent. These studies provide evidence for robust long-lasting effects. We assume that financial crises have persistent effects in the rest of the analysis.

To illustrate the difference between the two approaches to measuring the cost of a crisis, consider Figure 3, below. The blue line represents growth without a crisis, while the orange line represents the baseline until Year 5, when a financial crisis reduces growth for two years. The grey bars are annual GDP growth rates. Exiting the crisis leads to one year of above-trend growth in Year 7, followed by a return to trend growth. The transitory costs of a crisis would be given by the area of the difference between the blue and

[29] Homar and van Wijnbgergen (2016) take a different approach, measuring the duration of post-crisis recessions. Another alternative is to use when a country's GDP attains the *level* that it would have reached if prior-crisis trend growth had continued, rather than the prior growth rate.
[30] Other examples are Hoggarth et al. (2002), Hutchison and Noy (2005), and Demirgüç-Kunt et al. (2006).

orange lines for Years 5 and 6, adjusted for discounting.[31] Measuring the permanent effect would include the area of the discounted difference between the two lines from Year 5 onwards. Of course, if the effects are not permanent then at some point the blue and orange lines coincide and the effect of the crisis is reduced to zero as is the area between the two lines beyond that point.

Figure 3: GDP Level (Left Axis) and Growth (Right Axis), Hypothetical Economy



Given the empirical results in Furceri and Mourougane (2012), we think it is sensible to include long-lasting effects. However, as it is very difficult to statistically distinguish between permanent and highly persistent effects, we present results using an alternative assumption of a persistent but temporary effect that fades gradually over time.

Using the Gordon Growth formula, the value of a perpetuity paying once a year is:

$$PV = \frac{Annual\ Benefit}{Discount\ Rate - Growth\ Rate}$$

We can treat the rate of decay as a negative growth rate, yielding:

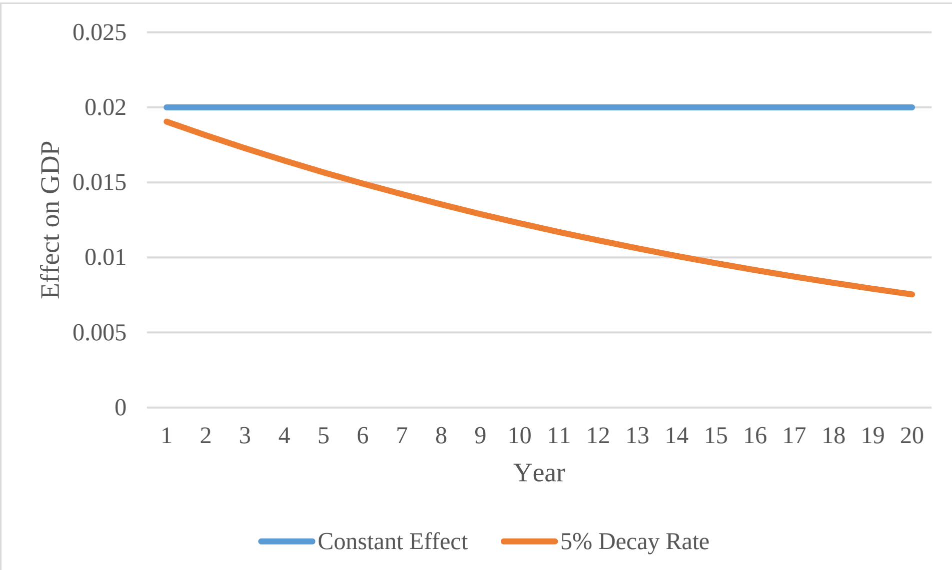
$$PV = \frac{Annual\ Benefit}{Discount\ Rate + Rate\ of\ Decay}$$

As this value is as of the beginning of the perpetuity flow, we further discount it back to the beginning of the crisis. There is no empirical work to our knowledge indicating the proper rate of decay of long-lasting

[31] Defining the end of a crisis' effects as when the economy exits recession would give the same results. If we define the temporary effects as occurring when the economy reaches its pre-crisis growth path, the crisis would end when the two lines intersect.

effects of a financial crisis. We choose 5 percent as a reasonable parameter. A 5 percent rate of decay implies that 60 percent of the effect remains after 10 years, and 38 percent after 20 years. Figure 4 shows the effect on GDP under each assumption.

Figure 4: Permanent versus Decaying Effect



Notice that in the growth formula, the present value is unaffected by whether an increase of a set amount impacts the discount rate or the decay rate. Therefore, in quantifying the cost of crises, we could think of this decay as equivalent to a 5 percent increase in the discount rate applied to the years following the crisis.

In comparison to our study, the Basel Committee (2010) performs a literature survey, and includes both studies that measure temporary and permanent effects in their scope. The Bank of England (2015) assumes a permanent effect, as does the Federal Reserve Bank of Minneapolis (2016). None of these studies explore the possibility of persistent, steadily decaying effects.

Short and Medium Term Severity of a Crisis

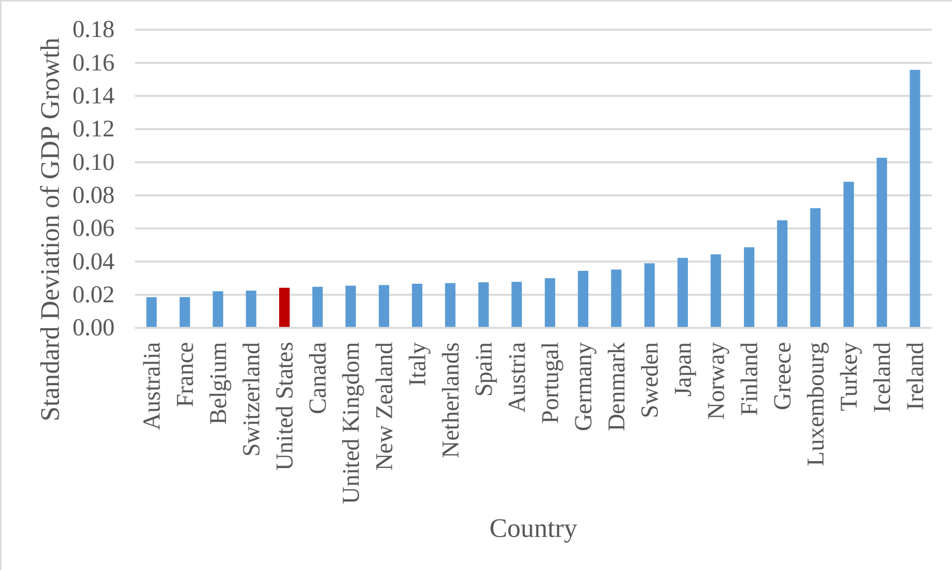
In addition to analyzing permanent effects of a crisis, it is important to analyze the effects during the crisis, which are generally larger per year than long-run effects. We use results from Romer and Romer (2015) on financial crises in advanced economies to estimate the short- and medium-term cost of a financial crisis in the United States. The data are from 1967 to 2012, and include the 24 OECD members as of 1973. The authors use narrative data from semi-annual OECD reports to generate a continuous measure of the intensity of a crisis, and run a regression with GDP growth, the state of a country's financial system, lags of both variables, and other controls.[32]

There are other studies measuring the overall short and medium term costs of a financial crisis. Examples include Hoggarth et al. (2002), Hutchison and Noy (2005) and Demirgüç-Kunt at al. (2006). We use results from Romer and Romer (2015) because they are focused on advanced countries, and thus most relevant to the United States. Romer and Romer (2015) are also unique in that they provide estimates of the semi-annual dynamics of the effect on GDP, rather than a single aggregated number. A further advantage is that they incorporate results from the 2008 financial crisis. The dynamics allow a more credible analysis of the effects of shortening crises through prompt recapitalization, as discussed below.

Romer and Romer (2015) present estimates of the effect on GDP using a standard, ordinary least squares (OLS) regression, which weights each observation equally. They also present estimates using a statistically superior generalized least squares (GLS) approach, which provides less weight to observations from countries with a high variance of GDP growth. Most of these high variance countries are smaller or less economically advanced. For example, the variance of GDP in Turkey, Iceland, and Ireland is much larger than the United States or other advanced countries (see Figure 5). Such countries' economies are more influenced by international capital markets and/or sovereign risk. Nonetheless, data on financial crises are limited, and it is useful to include these countries in the analysis. As a compromise, we focus on Romer and Romer's GLS estimates, as they provide less weight to these high-variance countries that are arguably less comparable to the United States.

[32] Note that our analysis of the probability of a crisis uses the definition in Laeven and Valencia (2012). See section I.D of Romer and Romer (2015) for a comparison of the financial crises identified by their method and an updated version of the data used by Laeven and Valencia (2012). The two are almost identical. Furceri and Mourougane (2012) use the same definition as Laeven and Valencia (2012).

Figure 5: Standard Deviation of Quarterly GDP Growth by Country



Source: Analysis of OECD data, https://data.oecd.org/gdp/quarterly-gdp.htm#indicator-chart. Standard deviation of annualized quarterly growth rates, 2001:Q1–2015:Q3. Note 2016:Q3 data for Luxembourg, New Zealand, and Turkey are not yet available. Sample is OECD early members.

The authors give estimates of the reduction in GDP due to financial crises in advanced economies on a semi-annual basis over five years. Their results with both GLS and OLS are shown below in Table 7.[33]

Table 7: Short-to-Medium Effects of Financial Crisis per Half Year % of GDP, From Romer and Romer (2015)

Specification	Time Lag: 0	Time Lag: 2.5 Years	Time Lag: 5 Years	Max Response
OLS	-2.08	-4.72	-4.61	-5.96
GLS	-1.24	-3.26	-2.25	-4.07

Source: Romer and Romer (2015), Table 2

Both specifications show that a relatively small effect, which is contemporaneous with the crisis, becomes larger in magnitude and reaches a peak after two-and-a-half years, afterwards slowly becoming smaller.

Present Value Calculation

We use a linear interpolation of Romer and Romer's (2015) GLS results for the effect of a financial crisis up to five years and assume a permanent reduction in GDP as found by Furceri and Mourougane (2012)

[33] These numbers are calibrated to represent a "moderate" crisis. The last time they designate the United States as having been in such a crisis state was the second half of 2009.

of 2 percent afterwards. We also calculate the impact of an effect whose magnitude decays 5 percent a year. In order to turn these estimates into a net present value, we need to apply a discount rate to the future reductions in GDP. Standard asset pricing models imply that the real risk-free rate reflects the intertemporal preferences for the economy. We use the average real yield on 10 year Treasury bonds, or 2.7 percent.[34] Table 8 shows the estimated present value of the cost of a financial crisis, under our two assumptions about the permanence of effects. As discussed below, we adjust these results for the effects of prompt recapitalization requirements and the increased resolvability of failing financial firms. The magnitude of the effect is quite sensitive to assumptions about decay (or discount) rates, falling by more than half if we assume a 5 percent rate of decay.

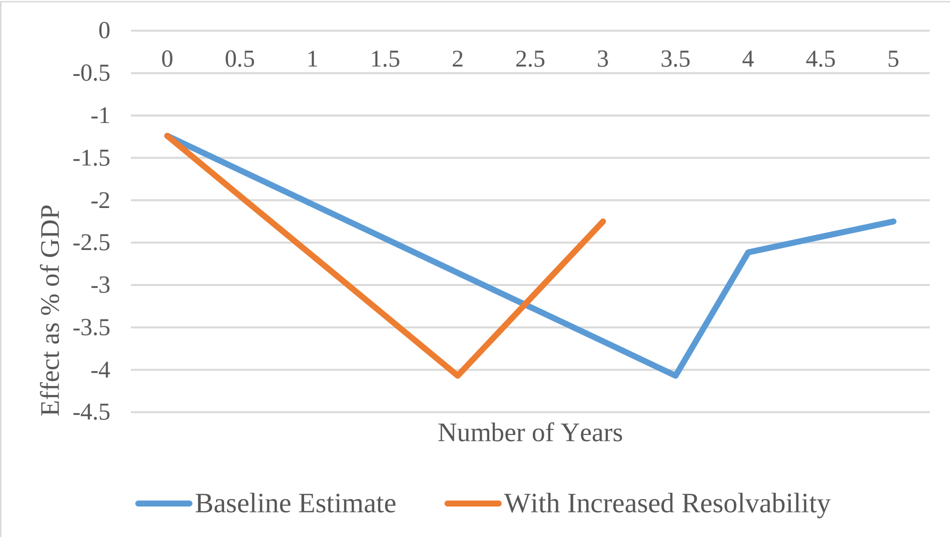
Table 8: Estimated Cost of a Financial Crisis, Unadjusted for Increased Resolvability

Rate of Decay	Estimated Cost (percent of GDP)
0 percent	103 percent
5 percent	44 percent

Improved resolvability requirements, discussed above, likely will cause future recapitalizations to happen more rapidly than is typical for advanced countries in the past. Research suggests that prompt recapitalization reduces the duration of financial crises. Homar and van Wijnbgergen (2016) conclude that with prompt recapitalizations, the time to a GDP trough is two years, rather than three-and-a-half years, and the duration of effects is three years, rather than five. We maintain the Romer and Romer (2015) estimates of the peak and final semi-annual costs of a financial crisis and calculate the revised costs given the shorter duration. Figure 6 shows the estimated semi-annual cost under this assumption.

[34] We use all monthly data from 1962 to 2006, and calculate inflation from the CPI for all urban consumers. We stop at 2006 because the subsequent period represents an extreme in monetary policy. Data were obtained from the Federal Reserve Bank of St. Louis Economic Research web-site at https://research.stlouisfed.org/.

Figure 6: Short and Medium Term Effect of a Financial Crisis on GDP



Source: Baseline is a linear interpolation of Romer and Romer's (2015) Table 2 results with GLS estimation. "With Increased Resolvability" assumes that per Homar and van Wijnbergen (2016) the duration of the crisis effects is reduced. We assume the beginning, maximum, and final effects are as in the baseline, and again use linear interpolation to obtain the results with prompt recapitalization requirements.

With the effects of increased resolvability, the estimated effects fall by 3 to 4 percentage points.[35]

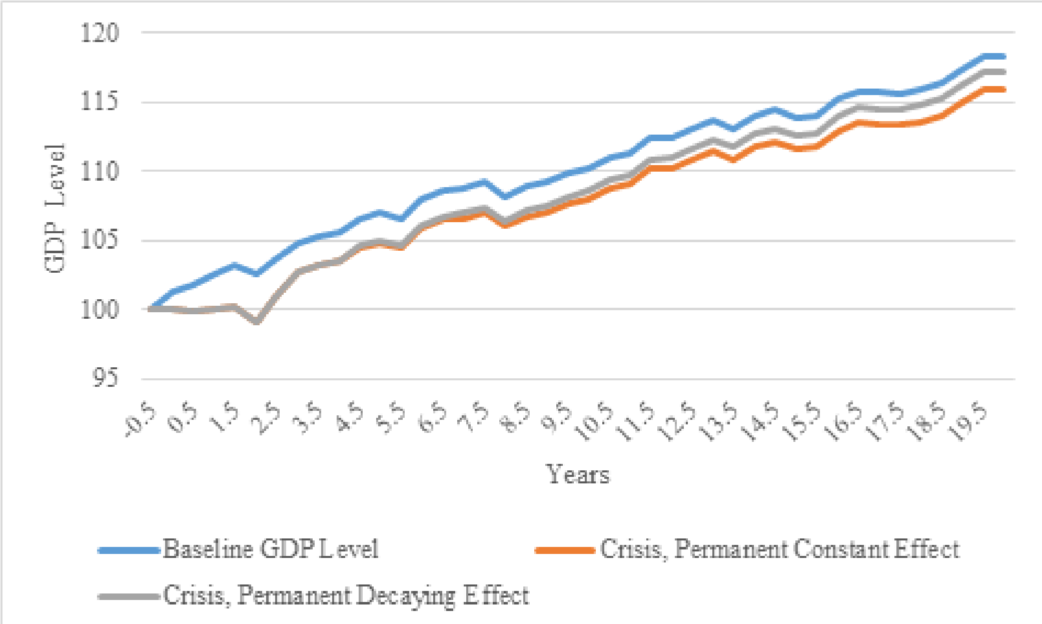
Table 9: Estimated Cost of a Financial Crisis, Adjusted for Increased Resolvability

Rate of Decay	Estimated Cost (% of GDP)
0%	99%
5%	41%

Figure 7 shows the level of GDP for a hypothetical economy under a baseline represented by the blue line, a crisis with a permanent and constant effect represented by the orange line, and a decaying effect represented by the grey line. At time "-0.5," right before the crisis occurs, all three lines overlap. The orange and grey lines overlap for the short and medium term or first three years of the crisis. After that, the grey line steadily converges to the blue line as the potential output loss because of the crisis decays.

[35] While this may seem small, given that U.S. GDP in 2015 was $18.2 trillion, this translates into a reduction in cost of $546 to $728 billion.

Figure 7: Level of GDP, No Crisis, Crisis with Permanent Constant Effects, and Crisis with Decaying Effects



For the sake of comparison, the Basel Committee (2010) report, as shown below, reports the average cost of a financial crisis ranges from 19 percent to 158 percent depending whether the effects are permanent. Their results are based on a meta-analysis of other studies, and do not focus on advanced economies. Their low estimates include several studies that assume no permanent effect. The Federal Reserve Bank of Minneapolis (2016) adopts the high estimate of 158 percent from the Basel Committee report.

The Bank of England (2015) estimates a 43 percent cost for the UK, based on the Romer and Romer (2015) OLS methodology, with multiple adjustments. They also assume the effect of a crisis is permanent. Their adjustments include a different approach to estimating the effects of increased resolvability that implies a much larger impact. They focus on TLAC in particular and assume that TLAC will lead to a rapid, credible bail-in which will ensure that any crises will be like the least severe historic crises, and thus adjust their estimated cost of crisis down by approximately 60 percent. Given that there has not yet been a TLAC “bail-in” and that there are multiple differences between the U.S. economy and many economies in their sample of “less severe” crises, we opt for a more conservative approach to measuring the effects of increased resolvability. Other studies’ results are summarized in Table 10.

Table 10: Estimated Cost of a Financial Crisis,

Estimate Description	Present Value Cost (% of GDP)	Discount Rate
Federal Reserve Board (2017)	41%-99%	2.7%
Basel Committee, No Permanent Effect	19%	5%
Basel Committee, Moderate Permanent Effect	63%	5%
Basel Committee, Large Permanent Effect	158%	5%
Bank of England, Permanent Effect	43%	3.5%
Minneapolis Fed, Permanent Effect	158%	5%

Note that while other studies use higher discount rates, none use a persistent but decaying crisis effect. Our assumption of a 5 percent decay rate, from the perspective of calculations, is almost equivalent to assuming the discount rate is 5 percent higher, or 7.7 percent. We can thus treat the results with a 5 percent decay rate as a sensitivity test if we were to use a discount rate higher than any in other studies.

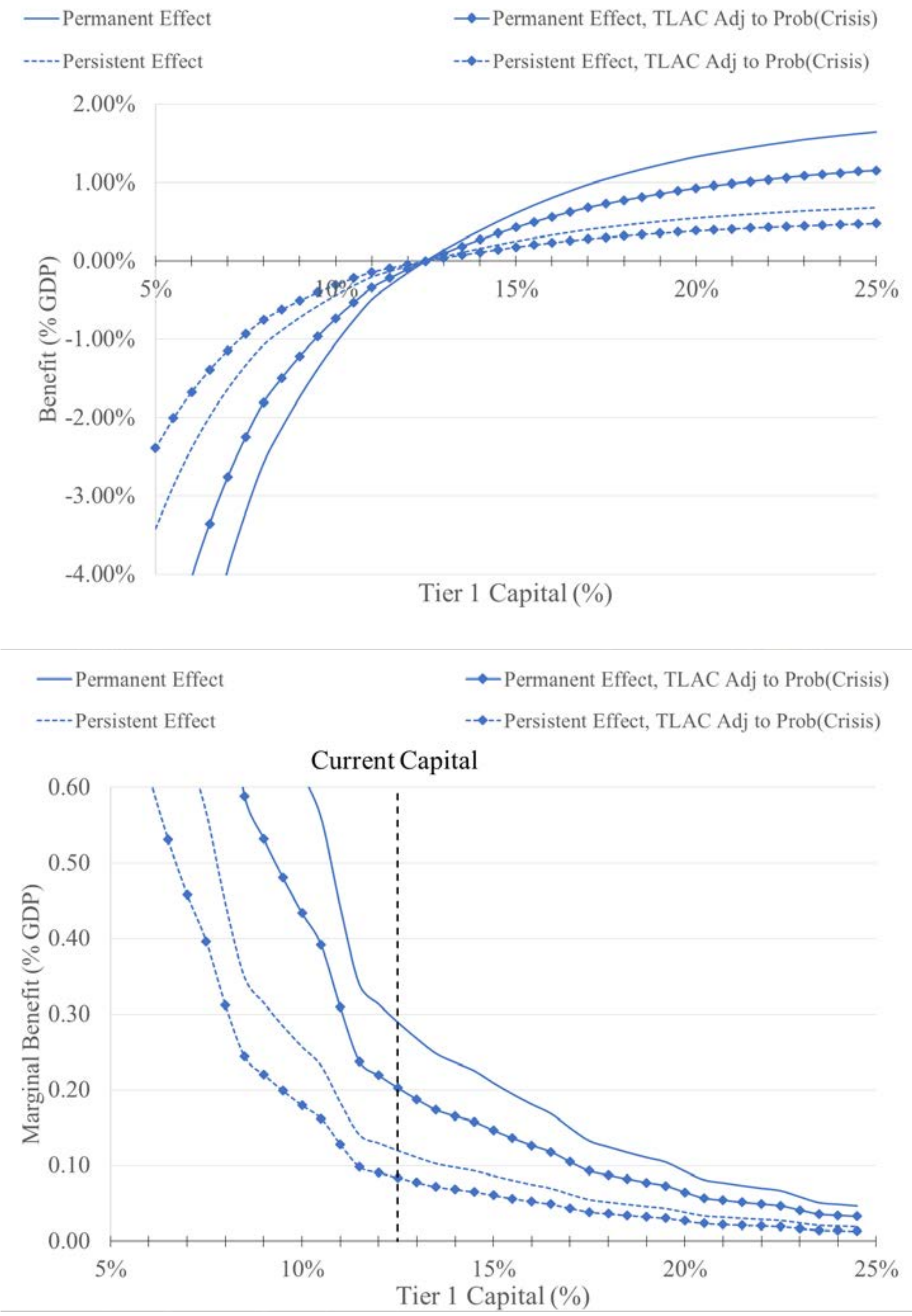
c. Estimated Range of Benefits of Capital

Under our framework, the benefits of bank capital equal the reduction in the probability that a financial crisis starts (estimated in Section IV.a), multiplied by the costliness of the avoided financial crises (estimated in Section IV.b). Our estimates of each of these components vary because of different modelling assumptions. We alternately assume that increased resolvability has either no effect or apply a 30 percent reduction in the probability of financial crises for it. We compute the cost of crisis alternately assuming that crises have a permanent or transitory though highly persistent effect on the level of GDP.

Figure 8 plots the range in benefit estimates due to this modelling variation.[36] Benefits are plotted relative to the benefits received at the current average level of Tier 1 capital ratios in the United States. The bottom plot, which presents marginal benefits, shows that at current capital levels, the marginal benefit of increasing capital ratios by 1 percentage point likely falls between 8 basis points and 27 basis points of GDP per year. However, at lower capital levels, this marginal benefit is far higher.[37]

[36] In order to remove minor non-monotonicities in the plot of marginal benefits, we approximate the probability of financial crisis generated by the bottom-up model by a piecewise log function with segments that are 2 percentage points wide. This adjustment has little effect on the level of the curves or the estimated optimal level of capital.
[37] The marginal benefit of capital is "lumpy" due to lumpiness in distribution of the net income implicit in the bottom-up simulation. For example, the marginal benefit is slightly higher at a 21 percent capital ratio than at a 20 percent capital ratio as there are more scenarios where a roughly 21 percent capital ratio is just barely required to avoid crisis. Miles et al. (2013) also look at a model where the presence of rare, but very large, shocks to capital mean that the marginal benefit of capital is not decreasing everywhere.

Figure 8: Total (top) and Marginal (bottom) Benefits of Bank Capital, Relative to Current U.S. Average Tier One Capital Ratios (12.5 percent)



V. Economic Costs of Bank Capital

Increased bank capital has negative effects on GDP because of changes in lending costs. Banks' weighted average cost of capital rises in response to higher capital, and some of this cost increase may be passed along as an increased cost of credit to borrowers. A higher cost of credit discourages investment, thus decreasing the equilibrium level of GDP.

The first step in estimating the impact of bank capital on the level of GDP is to estimate how changes in capital affect the cost of loans. To do this, we estimate the impact of capital on a representative bank's weighted average cost of capital. Next, we calculate how much loan rates would have to change in order to offset these changes to the cost of capital. We alternately assume that banks are able to pass on 50 percent or 100 percent of these changes in the form of increased lending costs.

Once we have estimated the impact of capital on lending costs, we use the FRB/US macroeconomic model to assess the effect of these changes in lending costs on the equilibrium level of GDP.[38] The FRB/US macroeconomic model is a large-scale macro model used by Federal Reserve staff to track the evolution of the U.S. economy over time. The model is well documented and versions of it are freely available to the public.[39] It is used here as a baseline economic model to translate increased lending spreads into reduced GDP levels and follows previous work conducted by the Federal Reserve Bank of Minneapolis (2016).

Bank Capital Structure and the Modigliani-Miller Theorem

Bank equity is a residual claim on the bank's income and assets, therefore requiring a higher return than debt. One might think that increased capital would thus require a higher return on assets in order to fund these higher returns on part of the capital structure. However, the Modigliani-Miller Theorem implies no such effects, as decreased leverage reduces risk and results in decreased required rates of return on equity and debt. The extent to which the Theorem applies to U.S. banks is not clear, as discussed below. The relevance of Modigliani-Miller for banks is controversial, and has important implications for our findings. Notable papers arguing that the theorem applies to banks include Miller (1995) and Admati et al. (2014).

There are reasons, even in the presence of full Modigliani-Miller effects, that banks may need to increase their return on assets due to an increase in capital. These are discussed in Elliott (2013), among other places. The Modigliani-Miller Theorem assumes that capital structure has no effect on taxes. Interest payments on debt are tax-deductible while dividends are not, so higher equity means that banks lose some of the tax advantages of high debt levels.

Ultimately, whether the theorem applies or not is an empirical question. A common approach is to consider the effects of changes in bank capital structure on bank equity covariance with the market, or "beta." According to finance theory, market betas determine the required return on assets. If market beta

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[38] We thank Michael Siemer for using FRB/US to calculate the effect of an increase in lending costs on the level of GDP.

[39] For more information on the FRB/US model see the Federal Reserve Board's website at www.federalreserve.gov/econresdata/notes/feds-notes/2014/a-tool-for-macroeconomic-policy-analysis.html.

falls as the equity share of bank capital structure increases, then the required return on bank equity also falls, supporting the applicability of Modigliani-Miller. Kashyap, Stein and Hanson (2010) find this predicted relationship for a panel of publicly traded U.S. banks from 1976 to 2008. Clark, Jones, and Malmquist (2015) suggest that the relevance of Modigliani-Miller for U.S. banks is more nuanced, depending on bank scale and time. They find it holds most strongly for the largest banks, largely because their debt is closer to riskless. Since the financial crisis, Clark, Jones, and Malmquist find that the Modigliani-Miller Theorem holds for banks with assets of at least $100 billion.

Other authors have studied European banks, and find evidence of at least partial Modigliani-Miller offsets. We summarize them in Table 11.

Table 11: Studies Showing Evidence of Modigliani-Miller Offsets

Study	Geography of Sample	MM Offset
Kashyap, Stein and Hanson (2010)	US	Not Estimated
Clark, Jones, and Malmquist (2015)	US	65%-100%[40]
Junge and Kugler (2013)	Switzerland	36%
Miles et al. (2013)	UK	45%
Toader (2015)	Europe	42%
ECB (2011)	International	41%-73%

The body of empirical evidence strongly supports a partial Modigliani-Miller offset. We therefore assume a 50 percent Modigliani-Miller offset to rates of return throughout our estimates. The Bank of England (2015) uses this assumption, as does the Federal Reserve Bank of Minneapolis (2016). The BCBS (2010) considers different scenarios, assumes no Modigliani-Miller offset, and acknowledges this may lead to an overstatement of the costs.

Increased Loan Rates

We estimate the change in banks' weighted average cost of capital resulting from changes in the amount of bank equity.[41] We then assume that these changes in the cost of capital are offset by changes in the bank's return on its loan portfolio.[42] The cost of increasing equity capital ratios by 1 percentage point equals the amount of capital raised multiplied by the greater cost of equity capital, the return premium on equity over debt capital, adjusted for the Modigliani-Miller offset. It also includes the value of the tax shield provided by debt. The equation below represents this cost as a percentage of total assets.

[40] Their results depend on the size of the bank and the time period. They find full offsets for large banks since the U.S. financial crisis, and a 65 percent offset for banks with assets between $100 and $200 billion.
[41] We look at real, rather than nominal, returns and loan rates as below.
[42] The BCBS (2010) and the Bank of England (2015) also assume that all increased costs are reflected in loan rates. The Federal Reserve Bank of Minneapolis (2016) assumes only half of the costs are reflected in loan rates.

$$0.01 * \frac{RWA}{Assets} * [(1 - MM) * \ (R^E - R^D) + R^D * t]$$

R^E is the return on equity, R^D is the return on debt, *MM* is the degree of the Modigliani-Miller offset, and *t* is the corporate tax rate.

For the average risk weight, RWA/assets, we use the asset-weighted average for large U.S. banks as of the end of 2015, which is 66 percent.[43] Substituting, this becomes:

$$0.01 * 66\% * [(1 - MM) * (R^E - R^D) + R^D * t]$$

To estimate the return on bank debt, R^D, we look at the past fifteen years. We consider annual data on all U.S. top-tier bank holding companies with assets of at least $50 billion in 2015 dollars. During the past 15 years, median interest costs were 1.61 percent on average. However, we consider recent very low interest rates to be a historic abnormality, so we use the pre-crisis (2001 through 2006) period, for which median interest costs averaged 2.32 percent.[44] Thus we find:

$$0.01 * 66\% * [(1 - MM) * (R^E - 2.32\%) + 2.32\% \ * t]$$

In order to estimate the return on bank equity, R^E, we apply the capital asset pricing model (CAPM). Under the CAPM, the expected return on bank equity is equal to the risk free rate, R^f, plus a premium equal to bank equity's comovement with the market (given by beta) multiplied by the expected return on the market R^M in excess of the risk-free rate:

$$R^E = R^f + \beta * (R^M - R^f)$$

With 15 years of data, we calibrate the model to an average risk-free rate of 2.32 percent and average excess market returns of 5.24 percent. We estimate a daily beta of 1.35 for the domestic U.S. top-tier holding companies, based on data from 2010 to 2015, implying an expected return for bank equity of 8.71 percent.[45] To complete the estimate, we use a corporate tax rate, *t*, of 43.7 percent.[46]

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[43] Many recent changes have affected banks' asset composition and RWA calculations in recent years, including the implementation of Basel III, the Volcker rule, and liquidity and TLAC regulations. Therefore we use data on both RWA/assets, assets/loans, and interest expense from December 2015, the most recent full year for which data are available. Neither the interest rate environment nor regulations governing RWA calculations have changed since then in a way that would significantly affect our conclusions.

[44] Kayshap, Stein, and Hanson (2010) assume that additional equity will displace either long-term or short-term debt. TLAC and liquidity requirements mean that banks are now less free to adjust their liability composition. Thus, we use the average liability cost.

[45] We use data starting in 2010 for calculating beta because the large number of mergers and acquisitions following the crisis would muddy the analysis prior to that date.

[46] We follow Clark, Jones and Malmquist (2015) in assuming a Delaware residence. Delaware has a tax rate of 8.37 percent, and the federal corporate tax rate is 35 percent. Only South Dakota and Wyoming have no corporate income

This implies

$$0.01 * 66\% * [(1 - MM) * (8.71\% - 2.32\%) + 2.32\% \ * 43.7\%]$$

We assume that half of the Modigliani-Miller offset occurs

$$0.01 * 66\% * [0.5 * (8.71\% - 2.32\%) + 2.32\% \ * 43.7\%]$$

We thus project an increase in asset return rates of 2.7 basis points per 1 percentage point increase in capital ratios, of which 0.7 basis points is attributed to the debt shield.

We assume this increase in cost is passed along entirely in the form of increased rates on loans. As loans currently comprise about 40 percent of bank assets, we divide the increase in cost of capital by 40 percent for our estimate of the increase in loan costs, arriving at 0.00027/0.4 or 6.9 basis points.

There are also reasons to think that banks may not be able to pass along 100 percent of any increased capital cost to borrowers. Competition with non-bank lenders, and the public debt markets may make it difficult for banks to pass along increases in the cost of capital. Even without such competition, banks might increase revenue by reducing the cost of operations, decreasing interest expense, or finding revenue increases from business lines other than lending.[47]

We consequently also calculate the effect if banks could only pass through half of their increased cost to borrowers, implying an increase in loan costs of 3.4 basis points per percentage point increase in equity capital.[48]

For the purposes of comparison, the BCBS (2010) study ignores Modigliani-Miller effects in an estimate, and thus finds a larger increase in lending costs of 13 basis points per percentage point increase in capital ratios. The Bank of England (2015) estimates an effect of 10 basis points, partially due to the higher bank equity premium (R^E - R^D) of 10 percent compared to the United States of 8.71 percent minus 2.32 percent or 6.39 percent.

or gross receipts tax. State corporate income taxes range from 4 percent to 12 percent for 2016. See http://taxfoundation.org/article/state-corporate-income-tax-rates-and-brackets-2016.

[47] Phillipon and Reshef (2012) show that wages in the financial sector from 1990 forwards earned a premiu.m over other sectors. This premium grew over time and cannot be fully explained by risk or technological change. This research suggests that cost reductions are feasible.

[48] If only half of the increased cost is passed along in the form of higher loan rates, banks might respond to increased costs in other ways, such as focusing more on higher-yield, and thus risky, lending. Banks might also raise fees for other services in a manner that could create distortions. To our knowledge, there is no adequate empirical basis for modeling such effects.

Translating Loan Rates into GDP

We use the FRB/US model to translate increases in lending rates into a long-run effect on the level of GDP. FRB/US is a large-scale model of the U.S. economy featuring optimizing behavior by households and firms as well as detailed descriptions of monetary policy and the fiscal sector. FRB/US has a neoclassical core that combines a production function with endogenous and exogenous supplies of production factors and key aspects of household preferences such as impatience. To account for cyclical fluctuations, the model features rigidities that apply to many decisions made by households and firms. The model does not explicitly include corporate loan spreads. Therefore, we use the spreads on corporate bonds to model a shock to corporate lending rates, and spreads on home mortgages and auto loans to model a shock to consumer lending rates.[49]

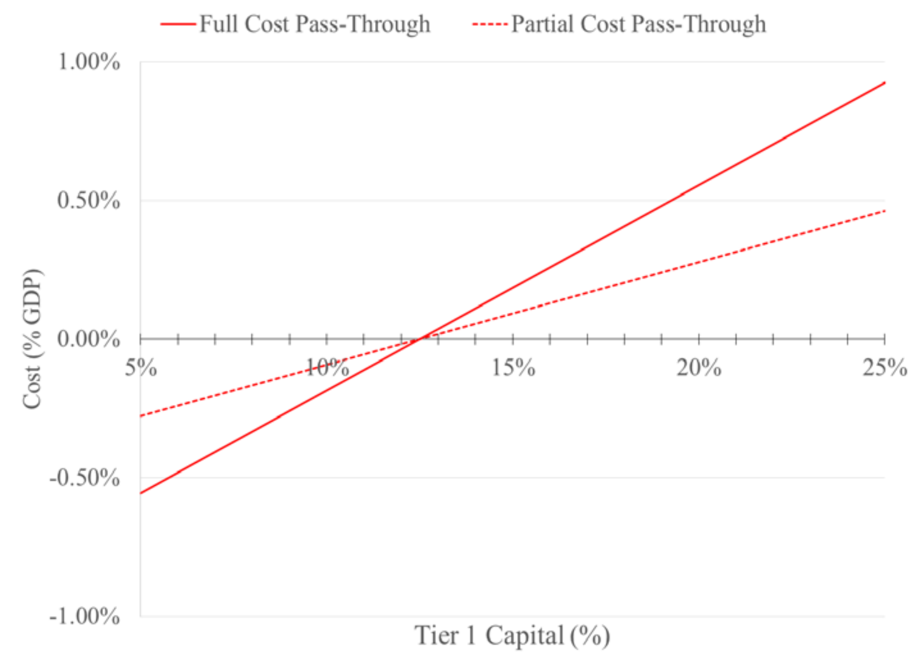
The model predicts that the effects on the equilibrium level of GDP from an increase in lending rates are approximately linear. A 1 basis point increase in lending rates implies a decrease in the level of GDP of approximately 1.07 basis points. [50] We estimate the effect of a 1 percentage point increase in capital ratios is a reduction in the level of long-run GDP of 7.4 basis points. If only half of the cost is passed through in the form of higher rates on loans, the effect on long-run GDP is 3.7 basis points.

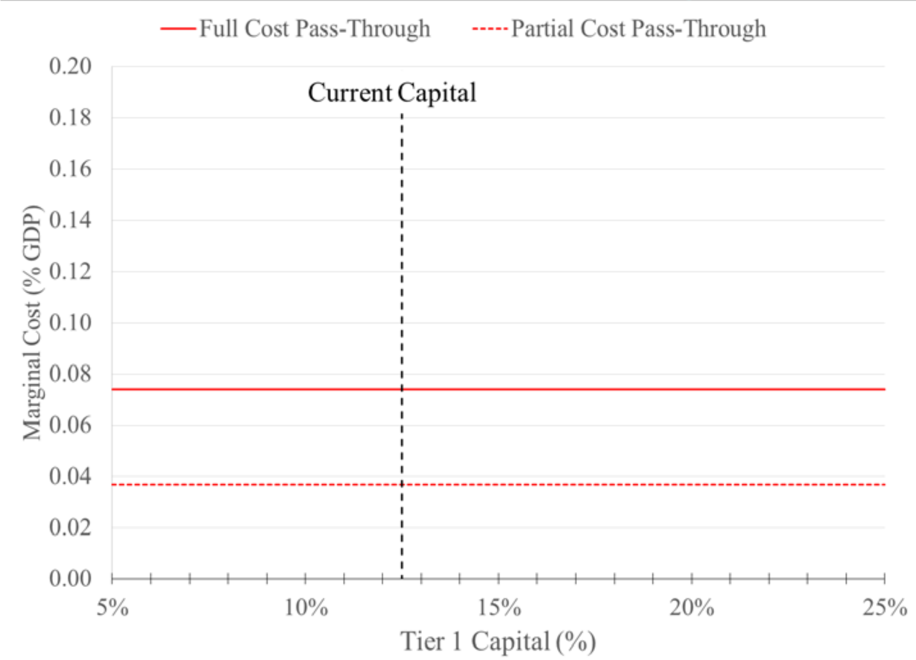
Figure 9 plots these alternative costs of bank capital. The left-hand plot shows total costs increasing linearly with the capital level, and the right-hand plot shows that this equates to a constant marginal cost of capital.

[49] Most of the effect on GDP is from an increase in corporate lending rates. To the extent that rate increases are limited to other loans, we may be overstating the effects.

[50] This is slightly different than the results calculated by the Federal Reserve Bank of Minneapolis (2016). The Federal Reserve Bank of Minneapolis (2016) calculates changes from a long-run baseline, while we use the present-day scenario.

Figure 9: Total (top) and Marginal (bottom) Costs of Bank Capital, Relative to Current U.S. Average Tier One Capital Ratios (12.5 percent)





We summarize the results from this and other studies in Table 12. For the purposes of comparison, the Bank of England (2015) study concludes that the effect of a one percent increase in capital ratios is a cost between 1 and 5basis The BCBS (2010) study found a cost of 9 basis points. They assume no Modigliani-Miller offsets, which necessarily implies a larger effect. The Minneapolis Federal Reserve predicts an effect between our full pass through and half pass through results.

Table 12: Estimated Decrease in GDP due to a One Percentage Point Increase in Capital[51]

	Effect on Lending Rates (bp)	Effect on GDP (bp)
Federal Reserve Board, Full Pass Through	6.9	-7.4
Federal Reserve Board, Half Pass Through	3.4	-3.7
BCBS (2010)	13	-9
Bank of England (2015)	5 to 10	-1 to -5
Federal Reserve Bank of Minneapolis (2016)	5.7	-5.7

VI. Assessment of Net Benefits

Our framework for assessing the net benefits of bank capital requires that we estimate (1) the long-run effect of increased bank capital on the probability of financial crises in the United States, (2) the net present cost of U.S. financial crises, (3) the impact of capital on banks' lending spreads, and (4) the effect of consequent higher lending rates on GDP. Because of uncertainty around the choice of modelling approach for several of these components, we report a range of estimates, and refer the reader to Section VII for a discussion of costs and benefits left out of our framework.

Table 13 summarizes the modelling approaches used in estimating each component of the net benefits framework, distinguishing between those we hold throughout and those that provide variation across our range of estimates.

[51] For comparison, the Bank of England (2015) study forecasts a 1 to 5 basis point effect on GDP per 1 percent increase in capital requirements, and the BCBS (2010) forecasts an effect between 2 and 35 basis points (with a mean across models of 12 basis points).

Table 13: Modeling Assumptions

	Key modelling approaches used in all of our estimates	Sources of variation within our estimates
Impact of capital on the probability of crises (accounting for liquidity regulations)	-use the average of bottom-up and top-down approaches	-whether increased resolvability has an impact on the probability of crisis
Cost of crises (accounting for enhanced resolvability)	-crises have a long-lasting effect on the level of GDP	-whether crises have a permanent constant or decaying effect on GDP
Impact of capital on bank lending spreads	-half of the Modigliani Miller offset applies to impact on the cost of capital	-extent to which changes in the cost of capital impact lending spreads
Impact of bank lending spreads on GDP	-estimated via model (FRB/US)	

The modelling decisions we make fall within the variation seen in other impact analyses.

We use the average of multiple distinct approaches to estimate the probability of financial crises, as is also done by the BCBS and Bank of England, though we include a (small) adjustment for U.S. liquidity regulations. The Bank of England study assumes enhanced resolvability (TLAC) reduces the probability of crises by 30 percent, but because of uncertainty over the magnitude of this effect, we present estimates both with and without this adjustment.

When estimating the cost of financial crises, we recognize that it is empirically very difficult to discern between permanent and highly persistent but temporary effects on GDP. Therefore, we produce estimates alternately assuming that crises have a permanent effect on the level of GDP (as in the Bank of England, Minneapolis Fed, and certain of the BCBS estimates), or merely persistent effects. Equivalently, we estimate the cost assuming permanent effects, but applying a much higher discount rate. As with the Bank of England analysis, we include an adjustment for increased resolvability, shortening the period of time where crises have a temporarily large effect on GDP. In our analysis, this adjustment has a relatively small effect on the overall cost of crisis, as the large long-run cost is unaffected. The Bank of England's far larger 60 percent reduction for TLAC is based on the difference in cost of crises sorted by whether they occurred under more or less credible orderly resolution regimes.

On the cost side, we assume that as banks de-lever, required rates of return on their equity and debt decline by only half as much as would be implied by the Modigliani Miller theorem adjusted for tax shield benefits. This assumption is supported by existing research and is also applied in the Bank of England and Federal Reserve Bank of Minneapolis studies. We express uncertainty over the extent to which changes in the cost of capital are passed along to borrowers, and assume that this pass-through is either 50 percent (as in the Minneapolis study) or 100 percent (as is used as the baseline in other studies). Like the Minneapolis study, we also use the Federal Reserve's macroeconomic model (FRB/US) to convert changes in lending spread into changes in long-run GDP. Other studies rely on a range of reduced form and semi-structural models.

In Figure 10, we plot the range of economic costs and benefits that we model, relative to the costs and benefits of the current Tier 1 risk-based capital ratio of 12.5 percent for the average U.S. bank. Our low estimate of the benefits assumes that financial crises cause only gradually decaying reductions in GDP and that increased resolvability reduces the probability of crises by 30 percent. Our high estimate of the benefits assumes the financial crises result in permanent reductions in output and that increased resolvability affects only the cost, and not the probability, of financial crises. Our low and high estimate of the costs vary only because of the extent that increases in banks' cost of capital are passed through to borrowers.

Figure 10: High and Low Estimates of the Costs and Benefits of Tier One Capital Relative to the Current Average U.S. Tier One Capital Ratio (12.5 percent)

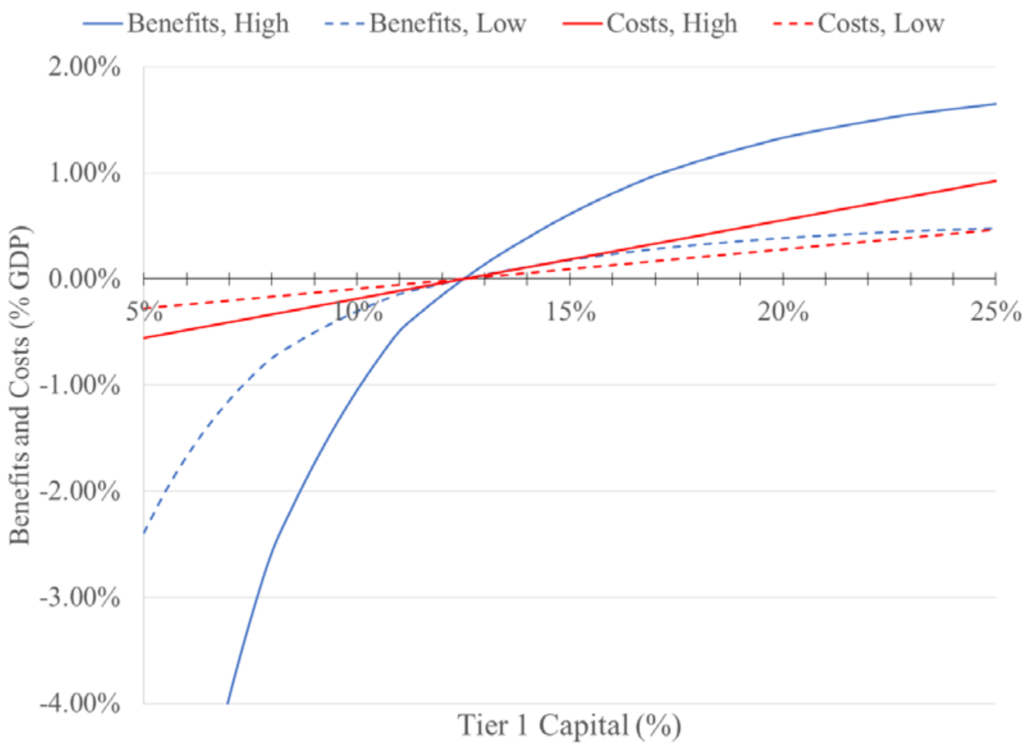


Figure 11 plots net benefits based on the cost and benefit curves above. Figure 12 plots marginal net benefits, or the net benefit of additional capital. The optimal capital levels are found where marginal net benefits equal zero.[52] These points are indicated by large diamonds. As mentioned above, banks generally hold significant capital above the minimum capital requirements, so optimal capital requirements would be lower than these levels.

[52] The wiggles in the marginal benefit curve occur because the density of loss severities in the historical data is not steadily decreasing as loss severity increases.

Figure 11: Estimates of the Net Benefits of Tier One Capital Relative to the Current Average U.S. Tier One Capital Ratio (12.5%)

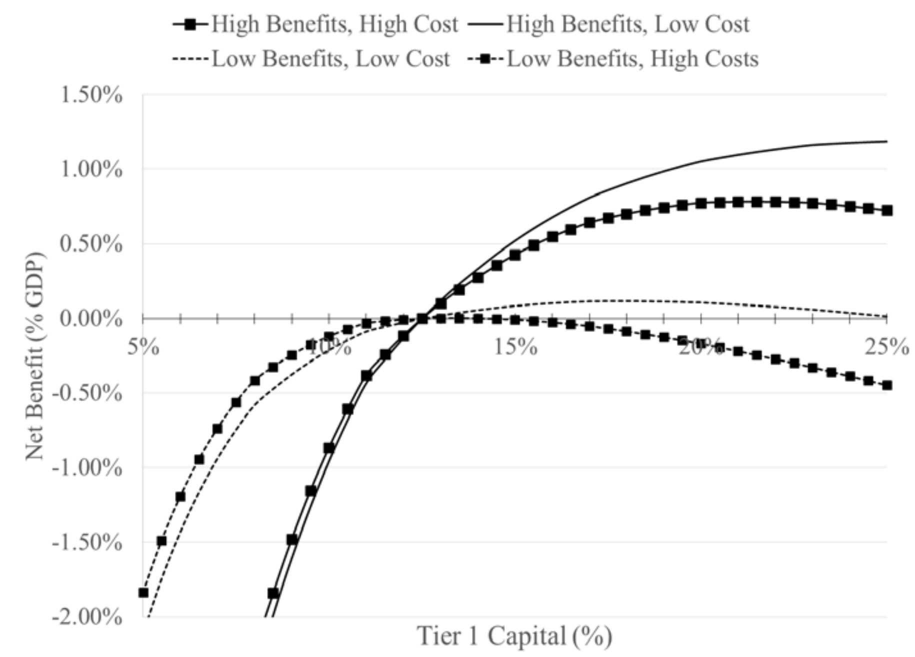
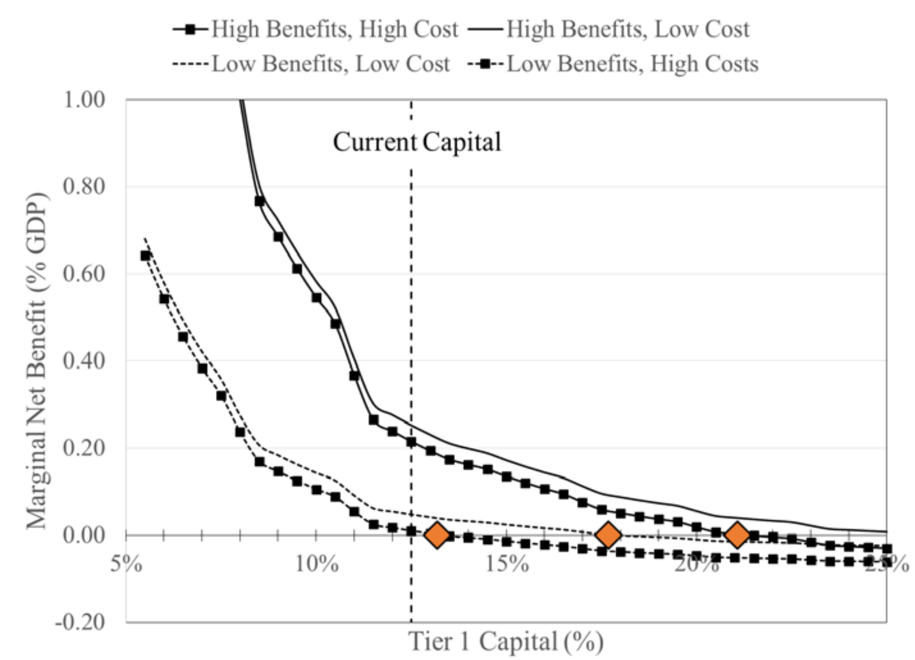


Figure 12: Estimates of the Marginal Net Benefits of Tier One Risk-based Capital



The net benefit of additional capital beyond current levels is very sensitive to assumptions about both the costs and benefits of financial crises. For example, the assumption of low, instead of high, costs of capital levels increases the optimal level of capital by about 4 or 5 percentage points. The impact of using our high estimate of the benefits of capital is even larger at about 8 percentage points. However, in all cases the economic benefits of moderate increases in capital levels above current levels exceeds the economic costs. At current levels of capital, this net benefit amounts to between 1 basis point and 23 basis points of annual GDP per percentage point increase in additional required capital. Depending on the modeling approach, net benefits are maximized at capital ratios that vary from a low of about 13 percent (high costs and low benefits) to levels above 25.0 percent (low costs and high benefits).

Table 14 compares these estimates of optimal capital levels with those estimated in other studies. Only the Bank of England analysis yields optimal capital requirement levels that are significantly lower. This is primarily due to the large size of the reduction to both probability and cost of financial crises that the Bank of England applies for the presence of TLAC regulations.

Table 14: Optimal Tier One Capital from Other Impact Analyses

Study	Optimal Tier One Capital
Federal Reserve Board (2017) – this study	13-25+%
Federal Reserve Bank of Minneapolis (2016)	~22%
IMF (2016)	15-23%
Bank of England (2015)	10-14%
Miles et al. (2013)	~20%
BCBS (2010)	9-15+%[53]

VII. Other Economic Benefits and Costs of Bank Capital

There are a number of economic benefits and costs of bank capital not explicitly captured in our results for a variety of reasons including availability of data, required assumptions and general feasibility. We will now discuss these benefits and costs and the expected impact they could have on capital.

Implications for a Risk-Averse World

A better capitalized banking system reduces the volatility of economic cycles, particularly where capital requirements include a counter-cyclical buffer. Using a DSGE model, BCBS (2010) suggests that output volatility decreases by a bit over one percent for each percentage point increase in Tier 1 capital.[54] Risk averse people prefer reduced consumption volatility, and especially dislike large negative shocks. For example, suppose a country produces one unit of output per year, except during crises, where output is instead 0.9 units. A hypothetical consumer of this output with a typical utility function would be willing to forgo up to about 0.4 percent of the expected output in return for reducing the probability of crisis from

[53] This represents a Basel II TCE/RWA ratio. We calculate the equivalent Basel III Tier I/RWA ratio would be 9.3 percent minus 15.5+ percent.
[54] The dynamic stochastic general equilibrium models used in BCBS (2010) also suggest that the use of a countercyclical buffer of plus-or-minus 2 percent reduces output volatility by around 15 percent.

4 to 1 percent.[55] This consumer might be willing to give up significantly more to avoid crises if, for example, crises were associated with greater idiosyncratic volatility (e.g. likelihood of job loss), or the consumer has large inflexible expenses (e.g. housing payments).

In addition, the macro-finance literature suggests that "rare disasters," such as financial crises, may explain much of the risk premia that risk averse investors require (e.g. Rietz 1988 and Barro 2006). A reduction in the probability of financial crises could thereby reduce the cost of capital across the economy and increase output.

Cross-Border Externalities

We have only attempted to quantify the benefits and costs of higher capital for U.S. banks that accrue within the United States. Improved stability of the U.S. financial system may also improve the stability of foreign financial systems. Kaminsky et al. (2003) describe financial crises whose effects were felt across international borders even where the linkages between countries are weak, a phenomenon known as "contagion." They also provide a review of the theoretical literature on why contagion may occur. Most of their analysis focuses on less developed economies. Kalemli-Ozcan et al. (2013) describe how the 2007-09 financial crisis spread across U.S. borders. By decreasing the probability of domestic financial crises, higher U.S. bank capital also decreases the probability of overseas crises.

Migration of Financial Intermediation

To the extent that higher bank capital increases lending costs for banks, financial intermediation could migrate out of the regulated financial sector. This has an ambiguous effect on optimal capital levels. Benefits are reduced as the systemic risks become less effectively controlled, but costs also decline as competition provided by non-regulated intermediation decreases lending costs. Pozsar et al. (2013) provide an overview of the institutional framework of the shadow banking system. Plantin (2014) presents a general equilibrium model which demonstrates the risk of banks shifting assets to less regulated money market funds. Harris, Opp, and Opp's (2014) analysis of a general equilibrium model with bank and non-bank lenders shows that, depending on the size of the increase in capital, the presence of competing shadow banks can be helpful or harmful because of changes in the nature of projects that receive funding.

[55] This calculation assumes the consumer has constant relative risk aversion utility with a coefficient of relative risk aversion of five.

Interaction of Cost of Higher Capital with TLAC and Liquidity Requirements

The greater reliance on long-term unsecured debt due to TLAC likely increases banks' cost of capital. The liquidity rules are likely to also increase banks' reliance on longer-term funding, which would also raise bank's cost of capital. As we use a cost of capital that neglects the impact of future effects of liquidity and TLAC requirements to calculate the cost of increasing equity financing, we may overstate the effect of higher equity capital on banks' cost of capital. Such adjustments would likely decrease the costs of higher capital.

Transitional Costs

We exclusively analyze the long-run economic costs of bank capital. Kiley and Sim (2010) analyze the cost of transition to higher capital levels. They assume that banks achieve these levels through raising new equity, reducing dividends, and reducing lending. Their estimates, like ours, are characterized by considerable uncertainty, and imply a reduction in GDP between 0.5 percent and 3 percent of GDP for a 2 percentage point increase in capital ratios. The magnitude of their results is partially due to their assumption that when banks reduce lending, there is no other substitute for financing, leading to a credit crunch. This assumption may be unrealistic where there is a bond market and non-bank lenders, and thus their results likely represent an upper bound on transitional costs. Their analysis also shows that the magnitude of the effect on GDP is reduced when banks are given a long period to comply with new requirements. Including such transitional costs would decrease the net benefits of higher capital.

VIII. Conclusion

This paper assesses the long run net benefits of the level of bank capital in order to provide an estimated range of optimal Tier 1 risk-based capital levels. Our basic framework is the same as that employed in previous studies conducted by the Basel Committee on Banking Supervision (BCBS) (2010), the Bank of England (2015), and the Federal Reserve Bank of Minneapolis (2016), though our modeling approaches differ at several points from each of these studies. This paper, like the Federal Reserve Bank of Minneapolis (2016) paper, tailors its analysis to the United States whenever possible. We also build upon the controls used in the Bank of England (2015) study to account for new long-term debt and liquidity regulations. Unlike the Bank of England, we estimate the optimal long run average effect of bank capital, rather than the impact conditional on the state of the economy.

We provide estimates of optimal capital levels under a variety of assumptions about the cost of financial crises and the extent to which lending rates could rise in response to higher levels of bank capital. When using a low estimate of the benefits and high estimate of the costs of capital, we find an optimal capital ratio around 13%, which is close to the current average capital ratio of 12.5% for U.S. banks. When using higher estimates of the benefits of capital, we find optimal Tier 1 risk-based capital levels may be above 25%. As banks generally hold substantial buffers above the minimum requirements, optimal capital requirements would be lower.

This range of estimates is limited by a framework that includes only two channels by which bank capital affects the real economy. Optimal capital levels may be even higher in a framework that accounts for the preferences of risk averse consumers or the international benefits of financial stability, and are likely lower when accounting for the cost of a transition to higher capital levels.

IX. References

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