Banks Adjust Slowly: Evidence and Theory Restrictions*

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Abstract

We investigate the behavior of bank balance sheet's in the United States during 2007-2015. The goal is to deepen the understanding of the behavior of banks. During this period, bank aggregate book-equity losses were entirely offset by equity issuances whereas market-value losses were catastrophic and never recovered. We find evidence that supports a theory where banks target market leverage, but where adjustments to a target are very gradual. We also find that, in contrast to the pre-crisis period, during the post-crisis banks relied more on retained earnings rather than on assets sales to adjust to a market leverage target. We present a heterogeneous-bank model that rationalizes these facts and can serve as a building block for future work.

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1 Introduction

The sub-prime mortgage losses that began in 2007 in the US led to a chain of events that culminated in a global crisis. The belief that a crisis of this scale can be prevented in the future instigated a wave of criticisms to standing macroeconomic theories. The basis of these criticisms is that standing macroeconomic theories lacked an explicit role for financial intermediaries and, thus, weren't useful to prevent the next crisis.[1] Macroeconomics responded with a wave of models that featured a meaningful role for financial intermediaries.[2] These new theories are influencing policy views and regulation. However, there is yet no consensus on the best way to model banks. What is the bank's objective function and what constrains their behavior?

This paper reports four facts that can serve as a guide to derive and calibrate a new class of macroeconomic models with banks. Any theory of banks must postulate an objetive and a budget constraint. Any policy relevant theory of banks must do more, it must also describe why the funding of banks matters. In other words, it must present a violation to the Modigliani-Miller Theorem. Economic theory provides plenty of arguments that can break that irrelevance result, but we need data to sort those theories. The four stylized facts that we present here are thus a useful guide to the design of banking models because they narrow down the set of theories that we should look at. The four facts are:

- First, there were large discrepancies between book and market value behavior. Between 2007 Q3 and 2014 Q4, bank holding companies (traditional banks) lost $710 billion, about 54% of their market capitalization. Book equity losses were only 7% and were entirely made up for with equity issuances.

- Second, banks did not behave as if market nor book based constraints were strictly binding. Moreover, there is cross-sectional dispersion in how close banks were to either constraint. These constraints could have influenced bank's decisions, but there was no strict relation between either form of equity and bank assets holding in the cross section.

- Third, banks operate with a target for market leverage. However, banks adjust very slowly to meet that target after shocks affect their market capitalization.

- Fourth, prior to the crisis, banks adjusted to their target leverage in response to shocks by primarily reducing assets. Post-crisis, banks used equity adjustments through retained earnings and equity issuances.

[1] A similar push towards deepening banking theories and empirical understanding of banks occured after the savings and loan crisis, e.g. the survey by Berger et al. (1995).

[2] See for example, Gertler and Kiyotaki (2010); Gertler and Karadi (2011); He and Krishnamurthy (2012); Brunnermeier and Sannikov (2014); Woodford (2010) among many others.

We establish these facts from regulatory filings and market data of the universe of bank holding companies in the United States.

The first fact exposes a dichotomy between the time series evolution of banks' book equity and market-value equity.[3] This discrepancy is important because it produces a clash between the two most popular classes of models: a class where market-based equity (ME) is the natural state variable and another class where book-based equity (BE) is the natural state variable. In the first class of models, the connection between ME and bank credit hinges on agency frictions. Examples of these frictions include costly-state verifications (Townsend, 1979; Bernanke and Gertler, 1989), lack of commitment (Hart and Moore, 1994), as well as moral hazard (Holmstrom and Tirole, 1997, 1998).[4] In those models, market-based equity is the appropriate measure because restrictions on bank problems emerge from private contracting. Post crisis, a number of influential macroeconomic models were constructed by introducing agency frictions into macroeconomic models with banks (Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011; He and Krishnamurthy, 2012; Brunnermeier and Sannikov, 2014). In the second class of models the connection between BE and bank credit is financial regulation. This second class of models does not take a stance on why regulation is there to begin with, but takes capital requirements as a primitive. For example, Brunnermeier and Pedersen (2009); Martinez-Miera and Suarez (2011); Bianchi and Bigio (2017); Begenau (2016); Corbae and D'Erasmo (2013a,b); Adrian and Boyarchenko (2013) are all models where bank capital plays a fundamental role because of capital requirements. Since regulation is based on regulatory capital measured in books, the appropriate empirical counterpart of equity in those models is BE.

In either class of models, a rough description is that violations to Modigliani-Miller Theorem show up as a leverage constraint:

$$L_t \leq \Lambda_t E_t, \tag{1}$$

where Λ_t is a leverage constraint —possibly time varying—, L_t is credit, and E_t is a corresponding notion of bank equity —i.e., book or market equity. An implication of the first fact is that each class of models yields different predictions for about the supply of credit during the crisis unless, of course, Λ_t varies differently among both classes of models. The

[3]In fact, this dichotomy seems be an that prompts policy discussions in every banking crisis (see post savings and loan crisis survery in Berger et al., 1995). From a theoretical angle, the banking literature stresses the importance of bank equity for the provision of credit —and hence economic performance. Adrian and Shin (2010) and He, Kelly, and Manela, (Forthcoming) also document highly pro-cyclical market-based leverage for broker-dealers. Minton, Stulz, and Taboada (2017, (Forthcoming)) study why market-values have remained persistently depressed since the financial crisis.

[4]Bernanke and Mark (1989) and Kiyotaki and Moore (1997) were the first to model the connection between firm equity and aggregate outcomes. In a bank-specific context Diamond and Rajan (2000) argued that bank runs (a là Diamond and Dybvig, 1983) occur as a disciplinining device in presence of agency frictions.

second fact highlights that any mechanical rule like in equation (1) does not reflect bank behavior, neither applied to ME, or to BE.

First, let's discuss why Facts 1 and 2 represent a challenge to agency models based on ME. To match the increase in market based leverage during the crisis period, ME models must produce pro-cyclical movements in Λ_t and this follows from Fact 1. How else could we explain a massive increase in market leverage together with a massive market-values losses? Translated into the logic of agency models that produce a value for Λ_t, this means that agency frictions are relaxed during a banking crisis (see for example Gertler et al., 2016). A literal interpretation is that, holding ME fixed, depositors are willing to lend more to a bank during a financial crisis! Casual observation, thus, suggests that we should not interpret agency models literally, but then it also raises concerns about the validity of their microfoundations. A further challenge to ME constraints is that they must explain the persistence and cross-sectional dispersion of market-based leverage —this follows from Fact 2. Some banks, Citi being the e\pitome, experienced market-based losses of up to 90% without a corresponding decline in liabilities.[5] The only way we can rationalize this cross-sectional behavior is if we say that agency frictions become more relaxed for coincidentally those banks that suffered the largest market losses.

Models that use book capital and regulatory constraints face a different challenge. In the body of the paper, we show that, as matter of fact, book equity poorly predicts bank losses in the future. We know this because the cross-sectional market-to-book ratios are strong predictors of bank performance with predictive power for up to two years forward. Furthermore, during and after the crisis, the reported regulatory capital of most banks appear to be above the formal regulatory limit. This suggests that banks avoid capital regulation with their accounting. These observations are consistent with the view that banks have a lot of flexibility to acknowledge book losses.[6] The differences between accounting and market values should be a key feature of bank modeling going forward.[7] To avoid confusion, we don't want to interpret these facts as evidence that market or book equity are not relevant for bank behavior. On the contrary, the conclusion is that we need a to model constraints in a more complex (perhaps dynamic) way. Facts 3 and 4 provide information on how market-based equity and accounting equity affect banks.

The third fact follows from evidence that banks target market-based equity, but that

[5] Adrian et al. (2016) share this view. Concretely, that paper argues that "as for market leverage, we show that virtually all the cyclical variation of market leverage is driven by fluctuations in the book-to-market ratio, reflecting the valuation changes of free cash flows generated by the bank." To meet this challenge, agency-based models would need to generate changes in time *and* in the cross section of leverage.

[6] This conclusion is shared with the accounting literature (see Laux and Leuz, 2010) that explains how banks have flexibility in accounting for losses. In fact, this was an issue raised by the United States Congress after the Savings and Loans crisis (General Accounting Office, 1990). Blattner, Farinha, and Rebelo (2017) show evidence for delayed loss recognition in a representative sample of Portoguese banks.

[7] Two papers that explicitly model the ability to avoid losses and its implications are the evergreening model by Caballero et al. (2008) and the trading-at-loss model by Milbradt (2012).

they take time to reach their targets. To reach this conclusion, we exploit the cross-sectional variation in market returns to individual bank stocks (return shocks). The idea behind our strategy is that bank stocks returns pick-up information about the bank's effective equity which is not contained in the books, as evident from the predictive power in Tobin's Q. We find that return shocks pick up information on future bank losses. This predictability allows us to investigate how banks' balance sheet and income statements evolve after a return shock. In particular, we estimate banks' partial equilibrium impulse-responses to innovations in their market returns. We find evidence that in response to a negative return shock, which mechanically pushes market-leverage on impact, banks take actions to slowly reduce market leverage. We also find evidence that banks slowly reduce liabilities, cut back on dividends and are more likely to issue equity. In summary, the response of market-leverage to a return shock is reverts to the initial market-leverage, a fact that is consistent with banks that have a market-leverage target and a slow adjustment to that target.

Fact 4 describes how banks adjusted their leverage back to target before and after the crisis. Pre-crisis, a bank that experienced negative excess-returns relied more on assets sales to gradually reduce their liabilities. In the post-crisis period, banks with negative excess-returns relied more heavily on alternative measures to increase their equity: either through external equity issuances or retained earnings, with many banks paying zero dividends. These facts favor models that feature a leverage target, but face frictions to adjust their portfolios that can be aggravated during financial crises.[8] They also suggest that selling assets became more difficult during the crisis.

In sum, our findings suggest that a model going forward should account for (1) a leverage target, a (2) slow adjustment to the target, and (3) differences in book and market accounting, (4) the rich cross-sectional behavior of book and market leverage. Although not used in general equilibrium macro models, there are some corporate finance models that have some of those features. For example, a target leverage as a result of optimally trading off the costs —e.g. bankruptcy— and benefits of leverage is a classic theme in corporate finance (e.g. Kraus and Litzenberger (1973), Myers (1984), Hennessy and Whited (2005), Frank and Goyal (2011)).[9] In more recent work, for example, DeMarzo and He (2016) and Gomes et al. (2016), a leverage target and slow adjustment emerge in a model with long-term debt and default, when firms cannot commit to a path of liabilities. Our facts suggest that the slow liquiditation of bank assets is also an important feature missing from models. In particular, Fact 4 suggests that using asset liquidations to delever became more difficult during the crisis. The slow liquidation of bank assets can be rationalized with

[8]In the midst of the crisis, Acharya et al. (2010) argues that banks receiving capital infussions where deliberately paying dividends to shareholders.

[9] In an early dynamic model of banks, O'Hara (1983), a leverage target follows from undiversified equity holders.

costly equity issuances and illiquid bank assets.[10] One interpretation is that this reflects an aggravated cost of selling assets (as conceived in Shleifer and Vishny, 1992) in addition to facing pressures to raise common equity, which is why they moved to issuing equity and retaining earnings. Gorton and Ordonez (2011) and Dang, Gorton, and Holmström (2010)[11] are models where assets become more illiquid during crises do to adverse selection.

We synthesize the lessons from the data into a bank-portfolio model that can reproduce our four facts. Our model is admittedly a reduced form model. However, it captures many relevant forces and is tractable. We hope it can guide future work that provides proper microfoundations. The model has the following features: As in O'Hara (1983), banks are risk averse. The model distinguishes between book and market values, and features both a regulatory (book) constraint and a market constraint on leverage. Banks have to default if they cross a certain leverage ratio, (this is as in Leland and Pyle, 1977b, but the default barrier is exogenous). Default risk and risk-averse behavior produces a leverage target. Book equity faces a regulatory constraint, but banks delay the acknowledgment of losses as in Caballero et al. (2008). An alternative is not to trade assets at loss as in Milbradt (2012).[12] Banks face shocks to their loans that induce heterogeneity in their initial leverage, so in equilibrium they want to lever up. Some banks may want to delever, but it is costly to sell loans. These costs of reselling loans are modeled as price adjustment costs in spirit of O'Hara (1983) or Shleifer and Vishny (1992). The simulated model generates qualitatively similar cross-sectional impulse responses as in the data — both for the pre-crisis period and the post-crisis period that is associated with higher adjustment costs.

In a related paper, Adrian, Boyarchenko, and Shin (2016) take a long-run perspective also to discuss which theories of financial intermediation are supported by the data. Consistent with their analysis, our model captures that book-leverage matters because losses cannot be delayed forever.

Section 2 presents our set of four facts while section 3 presents the model. Section 4 concludes.

[10]This was the topic of Darrell Duffie's presidential address to the American Finance Society in 2010 (Duffie, 2010). Early models of equity issuance costs based on agency problems are Myers (1977, a debt overhang model) and Myers and Majluf (1984, a private information model). Adjustment costs on assets arise naturally when banks hold informationally sensitive assets, typically viewed as a specialty of banks (e.g. Leland and Pyle (1977a); Diamond (1984a); Williamson (1986); Tirole (2011); Dang, Gorton, Holmström, and Ordonez (2017)).

[11]In Gorton and Ordonez (2011) and Dang, Gorton, and Holmström (2010) the equity of constrained agents determines their incentives to acquire information: Thus, equity losses may trigger adverse selection because the economy swings from states where information is symmetric and assets are liquid to states where information is asymmetric and assets illiquid.

[12]In the appendix, we present a model with strategic accounting that shares the spirit of Milbradt (2012).

2 Four Facts

In this section, we present four facts that inform our understanding of the constraints banks face during crises. The next section presents a reduced form model that rationalizes these facts and discusses potential microfoundations.

Data

We use individual bank-level data to reconstruct aggregate time series and exploit the cross-section. Among the universe of banks, we focus on top-tier Bank Holding Companies (BHCs) based in the United States.[13] BHCs provide a comprehensive picture of the activities of a financial organization rather than the narrow accounts of their commercial bank subsidiaries (e.g. Citigroup vs. Citibank). Moreover, only BHCs can be matched to market data. Book data is obtained from the FR Y-9C regulatory reports that BHCs file with the Federal Reserve, and merged with market data from the Center for Research in Security Prices (CRSP). For most of our analysis, we analyze data from 2000 Q1 to 2015 Q4; we extend the sample back to 1990 Q3 when we estimate impulse response functions. The FR Y-9C is only filed by BHCs with total assets above \$500 million.[14] However, since the industry is highly concentrated, our sample represents the majority of the industry. We drop new entrants to correct for the entry of major financial institutions into the sample.[15]

2.1 Aggregate Flows

We begin by studying aggregate flows in terms of market capitalization, book equity, common equity, and lending, where a large shock, triggered by the housing crisis, is expected to show up. To estimate the shock, we fit a linear trend to the logged real series,[16] estimating the trend using the data through 2007 Q1.[17] We also report the real change in the series

[13] A bank holding company is an umbrella company which holds banks, and other financial institutions, while a commercial banks is a single bank which provides traditional banking services like deposits and loans. For example, Citibank is a commercial bank, which is held by Citigroup, which is a BHC which holds Citibank and other banks, including non-commercial banks.

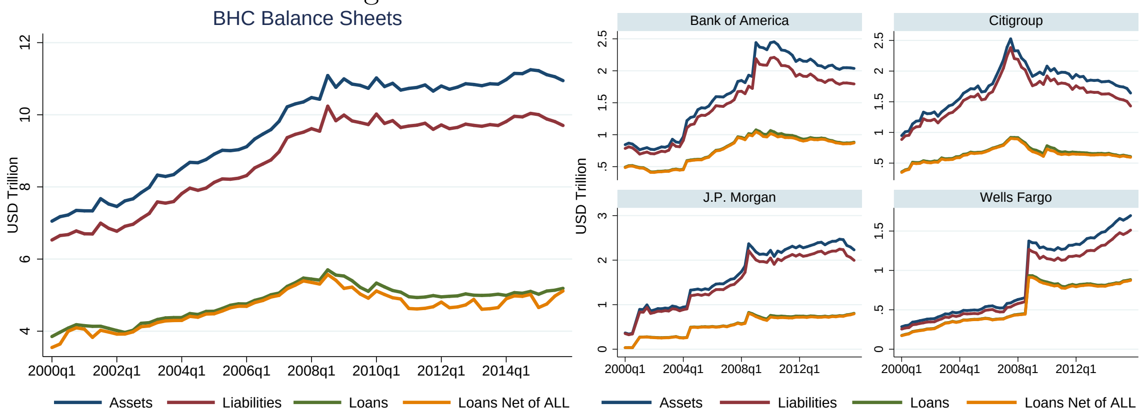
[14] Prior to 2006 Q1, this threshold was \$100 million, and the threshold became \$1 Billion in March 2015.

[15] Without this correction, we see a spurious increase in the assets of the traditional industry due to the reclassification of large actors such as Morgan Stanley and Goldman Sachs into bank holding companies.

[16] We use the seasonally-adjusted GDP deflator to adjust for inflation, and report all values in 2012 Q1 dollars.

[17] Since market return and book ROE are flows rather than levels, we detrend by simply subtracting the pre-crisis average. Also, since flows can be negative, we use $\log(1+r)$ instead of $\log(r)$. A concern with log-linear detrending is that it could be based on an unsustainable boom, yielding an overestimate of the size of the cyclical deviation. Simply looking at raw changes in this series sidesteps these concerns, but only by not dealing with the trend altogether. We report both estimates for completeness, but we acknowledge that each of these estimates is imperfect. We also computed (available upon request) estimates from HP-filtered data. The HP-filtered residuals were typically of substantially smaller magnitude then the residuals estimated with a log-linear trend. The HP-filter seemed to be overfitting the data and treating as trend

Figure 1: Balance Sheets of BHCs



Notes: These figures show data on assets, liabilities, loans, and loans net of ALL for BHCs. Data come from the FR Y-9C. Loans net of ALL refers to loans minus the allowance for loan losses (this subtracts out "probable and estimable" future losses on the current stock of loans). All variables converted to 2012 Q1 dollars using the seasonally-adjusted GDP deflator. Left panel shows aggregate series, dropping new entrants. Right panel shows data for the "Big Four" largest BHCs.

since 2007 Q3. The values for the fourth quarter of 2008, 2009, and 2010 are reported in Table 1. Similarly, in Figures 1 and 2, we plot the key balance sheet items and equity for BHCs, as well as showing these time series for the "Big Four" largest BHCs. In the appendix, we also provide a similar analysis of aggregate issuances and dividends.

The market capitalization data (market capitalization and bank's market return) suggests that banks suffered large losses during the crisis, although book data (book equity and common book equity) shows only small changes. Between the 2007 Q3 and 2008 Q4, market cap dropped \$705 billion; by the fourth quarter of 2010 the gap was still \$378 billion, with much of this rebound coming from new equity issuances. In contrast, real book equity did not fall during the crisis and actually increased substantially post crisis. This suggests that book losses were made up for by equity issuances. We also have information on flows: real market losses cumulated to \$708 billion by 2008 Q4, while real book losses cumulated to just \$66 billion over the same period. Most losses occured in income categories related to the real estate market.

We provide context for the size of these losses by comparing these shock estimates with the changes in the S&P 500. The percentage drop in the stock market is substantially smaller (a drop of 28.83% by 2009 Q4) than the cumulative drop in market returns (55.28% over the same time period).

At the same time, loans stagnated and eventually fell. By 2009 Q4, loans net of the allowance for loan losses had fallen by \$361 billion, a drop of 6.84%.[18] This number is

what is really just a persistent cyclical component.

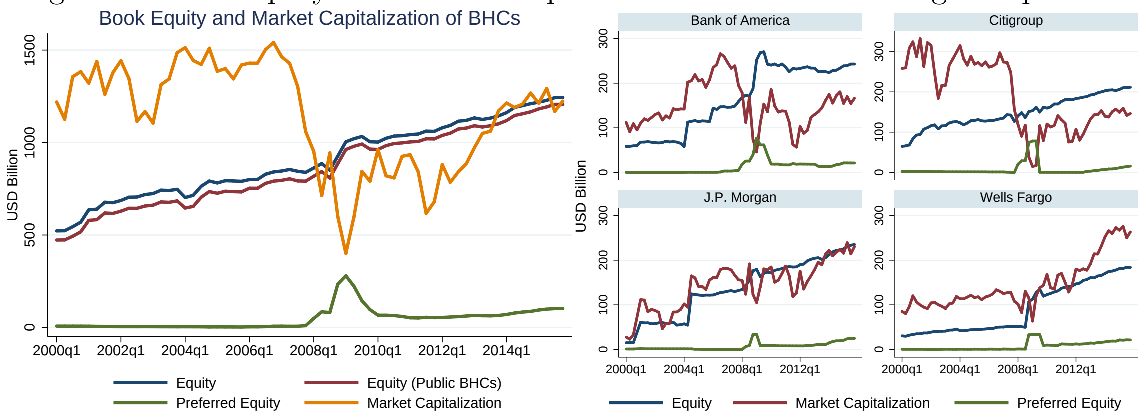
[18] The allowance for loan losses is an estimate of probable loan losses for the loans currently on the balance sheet. The next subsection will provide more detail on how bank accountants come up with this number.

Table 1: Shocks to Bank Holding Companies.

	Log-Linear			Real Change Since 2007 Q3		
	2008	2009	2010	2008	2009	2010
Market Cap.	-61.21%	-49.98%	-42.86%	-54.08%	-39.35%	-29.03%
	(-$945B)	(-$790B)	(-$694B)	(-$705B)	(-$513B)	(-$378B)
Book Equity	-3.46%	-1.50%	-4.41%	11.83%	21.70%	25.97%
	(-$32B)	(-$15B)	(-$46B)	($94B)	($172B)	($206B)
Common Equity	-28.44%	-11.69%	-10.42%	-17.35%	8.29%	16.64%
	(-$275B)	(-$120B)	(-$114B)	(-$145B)	($69B)	($139B)
Loans Net of ALL	2.68%	-10.41%	-14.33%	2.58%	-6.84%	-7.27%
	($141B)	(-$571B)	(-$819B)	($136B)	(-$361B)	(-$384B)
S&P 500	-25.55%	-7.01%	4.63%	-42.08%	-28.83%	-21.20%
Bank Market Return	-57.87%	-61.42%	-60.23%	-54.26%	-55.28%	-50.78%
	(-$755B)	(-$801B)	(-$785B)	(-$708B)	(-$721B)	(-$662B)
Book Return on Equity	-20.30%	-27.89%	-33.58%	-7.84%	-6.34%	-3.11%
	(-$171B)	(-$236B)	(-$284B)	(-$66B)	(-$54B)	(-$26B)

Notes: Top row shows cyclical deviations in percentage points; bottom row shows deviations converted into raw values. Book equity refers to book equity of publicly traded BHCs. Loans net of ALL refers to loans minus the allowance for loan losses (this subtracts out "probable and estimable" future losses on the current stock of loans). All variables deflated using the seasonally-adjusted GDP deflator. Level variables are converted to 2012 Q1 dollars, flow variables are deflated by subtracting inflation. Bank market return deviations and book return on equity are cumulated since the end of 2007 Q3, and dollar values are obtained by multiplying the cumulative percentage point deviation by real market capitalization and real book equity at the end of 2007 Q3, respectively.

Figure 2: Book Equity and Market Capitalization for Bank Holding Companies.



Notes: These figures show data on book equity, market capitalization, and preferred equity for BHCs. Book equity and preferred equity data come from the FR Y-9C, and market capitalization data is based on CRSP data. All variables converted to 2012 Q1 dollars using the seasonally-adjusted GDP deflator. The left panel shows aggregate series, dropping new entrants, with "Equity" referring to book equity for all BHCs in sample and "Equity (Public BHCs)" referring to only publicly-traded BHCs that can be matched to CRSP data. The right panel shows data for the "Big Four" largest BHCs, with "Equity" referring to book equity.

driven only in part by loan writedowns: banks slowed down their issuance of new loans, which results in contracting balance sheets when existing loans mature faster than new loans are issued. Figure 1 shows similar patterns for total assets, liabilities, and loans (not netting out the allowance for loan losses).

2.2 Book vs. Market Equity

The stark discrepancy between book and market equity losses over the financial crisis motivate the next fact. Figure 2 plots market equity (market capitalization), book equity, and preferred equity, both for BHCs in the aggregate[19] (left panel) and for the four largest banking institutions in the U.S. (right panel). The pattern for the largest banks is very similar.[20] Citigroup exemplifies the problem with using book equity as a measure of a banks' health: : Citi shows a 90% drop in market capitalization, but no perturbation in the trend of book equity.[21] The figure also makes clear that this discrepancy cannot be explained by preferred equity, which is included in book equity but not in market capitalization.[22]

[19]The fact that book equity for public BHCs is so close to book equity for all BHCs is a result of the high concentration of equity in the largest banks.

[20]The discontinuities in the individual bank series reflect mergers and acquisitions, e.g. the acquisition of Wachovia by Wells Fargo during the crisis.

[21]Citigroup suffered heavy losses during the crisis and did not undergo any major mergers or acquisitions, making it a particularly clean test case.

[22]Preferred equity rose temporarily during the crisis due to TARP.

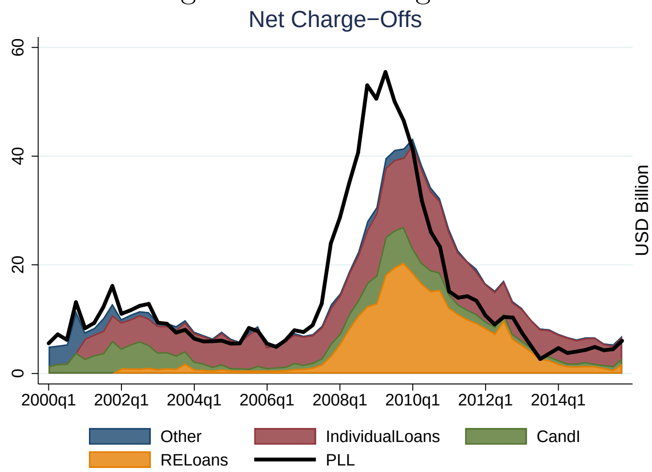
Book Accounting and Delayed Acknowledgment of Losses The discrepancy between book and market equity reflects bank accounting practices. Banks can delay acknowledging losses on their books (e.g. Laux and Leuz 2010), because banks are not required to mark-to-market the majority of their assets. There are many incentives to delay book losses. In practice, a key metric for measuring success of a bank is the book return on equity (ROE).[23] Given that ROE is a measure of success, manager compensation is linked to performance on the books. Moreover, shareholders and other stakeholders may base their valuations partly on information from book data. Finally,banks are required to meet capital standards based on their book leverage (if Citi had acknowledged a 90% loss of equity on the books, it would have been severely undercapitalized).

Banks' ability to "massage" their accounts is studied extensively in the accounting literature (Bushman 2016 and Acharya and Ryan 2016 review the literature on this issue, Francis et al. 1996 studies the same issue for non-financial firms). In practice, banks can record securities on the books using two methodologies: either amortized historical cost (the security is worth what it cost the bank to buy it with appropriate amortization) or fair value accounting.[24] In addition to mis-pricing securities, another degree of freedom is the extent to which banks acknowledged impairments: banks have the right to delay acknowledging impairments on assets held at historical cost, if they deem those impairments as temporary (i.e. they believe the asset will return to its previous price). This gives banks substantial leeway, and led banks to overvalue assets on the books during the crisis. Huizinga and Laeven (2012) find that banks used discretion to hold real-estate related assets at values higher than their market value. (Laux and Leuz, 2010) note some notable cases of inflated books during the crisis: Merrill Lynch sold $30.6 billion dollars of CDOs for 22 cents on the dollar while the book value was 65 percent higher than its sale price. Similarly, Lehman Brothers wrote down its portfolio of commercial MBS by only three percent, even when an index of commercial MBS was falling by ten percent in the first quarter of 2008. Laux and Leuz (2010) also document substantial underestimation of loan losses in comparison to external estimates.

[23] For example, JP Morgan's 2016 annual report states "the Firm will continue to establish internal ROE targets for its business segments, against which they will be measured" (on page 83 of the report).

[24] Fair value accounting can be done at three levels: Level 1 accounting uses quoted prices in active markets. Level 2 uses prices of similar assets as a benchmark to value assets that trade infrequently. Level 3 is based on models that do not involve market prices (e.g. a discounted cash flow model). Banks are required to use the lowest level possible for each asset. In practice, most assets are recorded at historical cost. The majority of fair value measurements are Level 2 (Goh et al. 2015; Laux and Leuz 2010). Recent work has shown that the stock market values fair value assets less if they are measured using a higher level of fair value accounting. This leaves room to mis-price assets on books. Particularly during 2008, Level 2 and Level 3 assets were valued substantially below one (Goh et al. 2015; Kolev 2009; Song et al. 2010). Laux and Leuz (2010) document sizable reclassifications from Levels 1 and 2 to Level 3 during hhe period. They highlight the case of Citigroup, which moved $53 billion into Level 3 between the fourth quarter of 2007 and the first quarter of 2008 and reclassified $60 billion in securities as held-to-maturity which enabled Citi to use historical costs.

Figure 3: Net Charge-offs



Notes: These figures show data coming from the FR Y-9C. The data are aggregate time series, dropping new entrants. The left panel shows net trading revenue and profits/losses on credit exposures and interest rate exposures. The right panel shows net charge-offs of loans (charge-offs minus recoveries), and decomposes this into loans backed by real estate, commercial and inustrial (C&I) loans, loans to individuals (these loans are for consumption purposes and are not secured by real estate), and all other loans (e.g. interbank loans, agricultural loans, and loans to foreign governments).

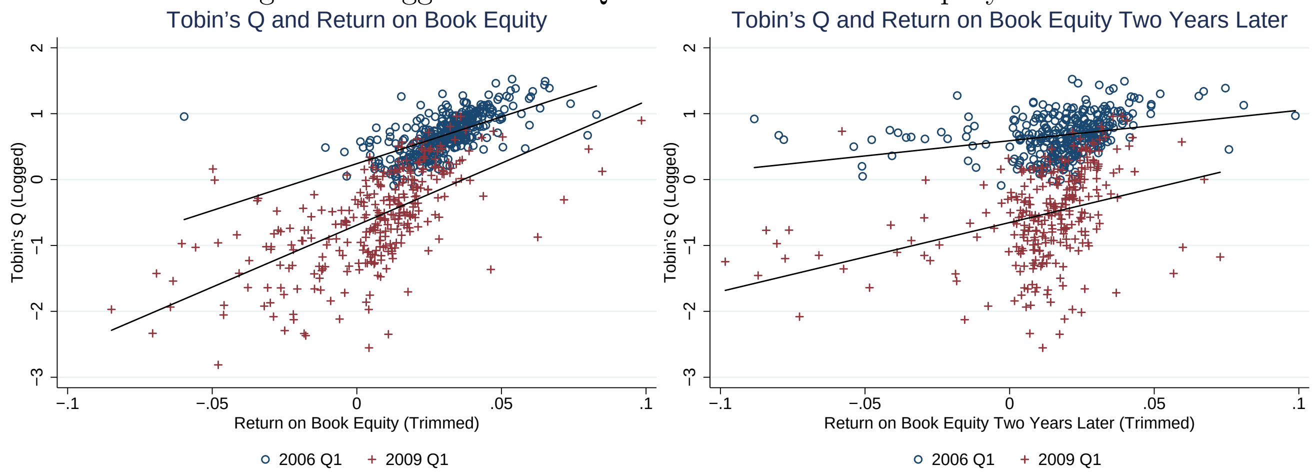
This shows up in our own analysis as well: Figure 3 shows that provisions for loan losses and net charge-offs only reached their peak in 2009 and 2010 respectively, and remained quite elevated at least through 2011, well after the recession had ended. The decomposition of net charge-offs shows that these losses were heavily driven by real estate, suggesting they were associated with the housing crisis.[25] Banks' books were only acknowledging in 2011 losses that the market had already predicted when the crisis hit.

Harris et al. (2013) construct an index, based on information available in the given time period, that predicts future losses substantially better than the allowance for loan losses.[26] This implies that the allowance for loan losses is not capturing all of the available information to estimate losses. This may in part be strategic manipulation, but there may also be a required delay in acknowledging loan losses. Under the "incurred loss model" that was the regulatory standard during the crisis, banks are only allowed to provision for loan losses when a loss is "estimable and probable" (Harris et al., 2013). Thus, even if banks know that many of their loans will eventually suffer losses, they were not supposed to update their books until the loss was imminent.

[25]When a bank has a loss that is estimable and probable, it first provisions for loan losses, which shows up as PLL. Later when the loss occurs, the asset is charged off and thus taken off the books, which shows up as charge-offs, although occasionally the bank can recover the asset later. Net charge-offs is charge-offs minus recoveries. We show a decomposition by category for net charge-offs but not for PLL because the FR Y-9C does not provide information on PLL by loan category.

[26]The ALL is the stock variable corresponding to the PLL.

Figure 4: Logged Tobin's Q and Return on Book Equity



Notes: The figures show data on Tobin's Q (defined as market capitalization over book equity) and return on book equity (defined as quarterly net income on the books divided by book equity) for BHCs. Book equity and net income on the books comes from the FR Y-9C, and market capitalization is from CRSP. The left panel compares logged Tobin's Q to return on book equity in the same period, while the right panel compares logged Tobin's Q to return on book equity two years later. The figures are trimmed to exclude observations for which return on book equity is above 0.1 or below -0.1, in order to exclude outliers and maintain appropriate scale.

Predictive Power in Book Values and Market Capitalization To study the the information content of market capitalization, we run cross-sectional regressions of Tobin's Q, defined as the the ratio of market equity to book equity, against a few important explanatory variables. We work with Tobin's Q rather than raw market capitalization to control for scale effects.[27] We examine how current and future profits as well as loan delinquencies and dividends are correlated with the log of Tobin's Q. The extent to which these variables are correlated with Tobin's Q reflects how market values pick up cross-sectional information that books do not. If market values are responding to information quickly, while books take a long time to adjust, then we would expect "good" variables (like dividends and profits) to be positively correlated with Tobin's Q, and "bad" variables (like loan delinquency) to be negatively correlated with Tobin's Q.

Current and future returns on book equity are correlated with Tobin's Q. Figure 4 shows the relationship between logged Tobin's Q and return on book equity (profits over book equity), with return on book equity being measured in the present year and two years ahead, but now in the cross-section of banks. The analysis shows that Q changes in anticipation of future book returns. Further analysis is detailed in the appendix. Logged Tobin's Q is negatively correlated with the ratio of delinquent loans to book equity, especially during the post-crisis. Dividends also predict Tobin's Q. Appendix Table 3 examines these relationships

[27]If we had simply regressed market capitalization on the stock of delinquent loans, without dividing by book equity, we would have mistakenly found that delinquent loans increase market capitalization!

more formally in a regression setting, and finds similar results.

Implications This analysis culminates in our first fact:

Fact 1. *Book values and market values diverged during the crisis. Between 2007 Q3 and 2008 Q4, bank holding companies (traditional banks) lost $705 billion in market capitalization, a decline of 54%. Book equity losses were only $66 billion (7.84%) and were entirely made up for with new equity. Market values capture information that book values do not, and book values do not fully respond to shocks.*

The divergence in book and market equity has important implications for our understanding of bank behavior during the crisis. Since book values can easily be manipulated and do not capture all available information, we should be skeptical of book data on asset values. Instead, we propose using market capitalization as a more timely and accurate measure of bank net worth.[28] For example, in Figure 5 we compute leverage based on book values (1 + liabilities / book equity) and based on market values (1 + liabilities / market capitalization).[29]

The path of book leverage and market leverage are very different. From Figure 1 we know that liabilities were relatively flat during the crisis, and from Figure 2 we know that book equity continued to rise while market equity crashed. The result is what we see in Figure 5. Book leverage rose moderately before the crisis and actually fell after the crisis. Market leverage, however, spiked dramatically during the crisis, and remained almost twice as high as its pre-crisis level for at least four years. Thus book and market values tell very different stories: books tell a story of intentional delevering, while market values suggest banks were hit by a large negative equity shock and only partly adjusted back towards their pre-crisis level of leverage.

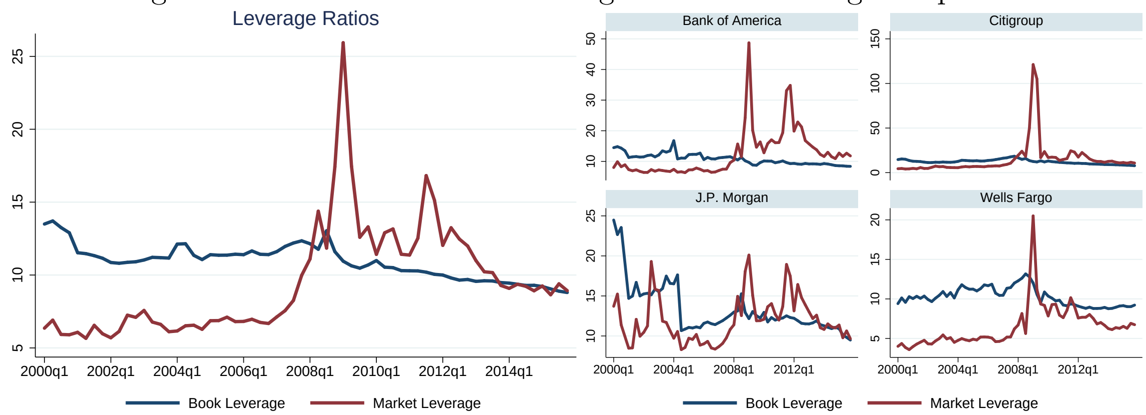
2.3 Constraints on Leverage

Given the dramatic rise in market leverage in Figure 5, and the divergence of market and book leverage during the crisis, we next turn to analyze the extent to which banks face binding constraints on their leverage. The aggregate time series results above narrow down the types of constraints that might be relevant for banks during the crisis: Banks do not seem to have been facing a hard upper bound on their market leverage, since that

[28]This is not to say that market values are perfect measures of net worth either: if the efficient market hypothesis fails then market values may be excessively volatile. However, we think the problems with book equity are more severe.

[29]For both measures, we use liabilities from banks' books. Although book assets likely suffer from substantial mispricing, book liabilities are fairly straightforward to compute and thus difficult to mis-price. We thus believe our measure of market-based leverage does not suffer from the same mispricing issues faced by the book-based measure.

Figure 5: Book and Market Leverage of Bank Holding Companies

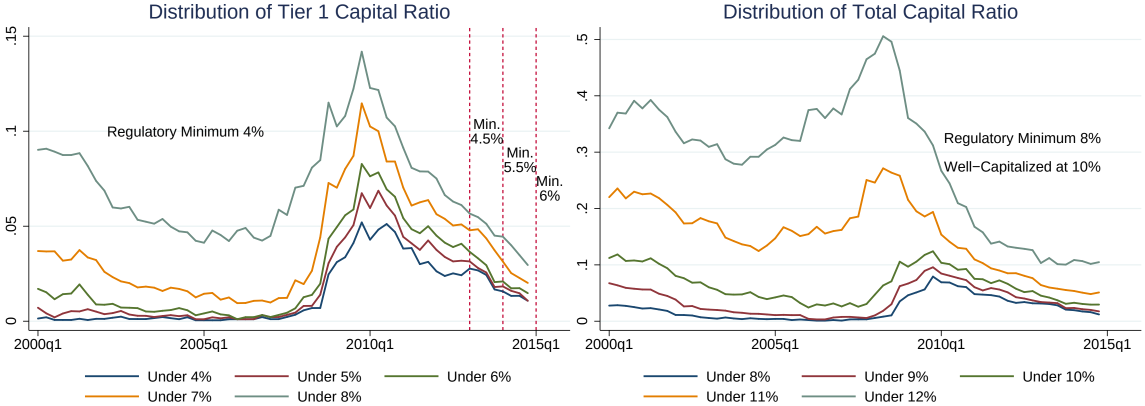


Notes: These figures show data on book and marketleverage for BHCs. Book data (book equity and liabiities) come from the FR Y-9C, and market capitalization data is based on CRSP data. The left panel shows aggregates from BHC balance sheets (dropping new entrants), and the right panel shows data for the "Big Four" largest BHCs. Book leverage is computed as assets/book equity, and market leverage is computed as (liabilities + market capitalization)/market capitalization. The aggregate leverage ratios are computed as (aggregate liabilities + aggregate equity)/aggregate equity.

leverage rose dramatically during the crisis. Banks definitely do face regulatory constraints on their book leverage, but banks appear to choose and hold levels above the regulatory limit, even during the crisis. In fact book leverage fell after the crisis. Banks could avoid hitting the regulatory constraint on book leverage because, despite facing severe market losses as in the case of Citigroup, they largely insulated book equity from these losses, in part by taking advantage of accounting rules. Thus, any complete theory of regulatory constraints on bank leverage should "account for accounting" — bank accounting rules enable banks to delay acknowledging losses and avoid the regulatory constraint. Some existing work in macrofinance has begun to do this: Milbradt (2012) analyzes the distorted incentives brought about by Level 3 fair-value accounting, and Caballero et al. (2008) note that regulatory constraints may be one factor contributing to evergreening during Japan's stagnation, because evergreening allows banks to delay acknowledging losses on the books.

To further examine the degree to which regulatory capital constraints did or did not bind during the crisis, we turn to the cross-section: even if the constraints did not bind on average, they may have been binding for some banks. Under Basel II (the regulatory standard in place during the crisis), bank holding companies were subject to regulatory minimums on their total capital ratio and their tier 1 capital ratio. These capital ratios are computed as Qualifying Capital/Risk-Weighted Assets, and thus a bank with a higher capital ratio has lower leverage. Basel II required banks hold a minimum tier 1 capital ratio of 4% and a minimum total capital ratio of 8%. In order to be categorized as "well-capitalized," banks had to meet minimum capital ratios that were two percentage points higher (6% and 10% respectively); being categorized as well-capitalized is helpful because banks that

Figure 6: Book and Market Leverage of Bank Holding Companies



Notes: These figures show data on regulatory capital ratios for BHCs from the FR Y-9C. The left panel shows data on the distribution of the tier 1 capital ratio, and the right panel shows data on the distribution of the total capital ratio. The figures plot the share of banks whose regulatory capital ratio falls below a given level, computed using the full, unweighted sample. The regulatory capital requirements are shown on the graph and described in the text.

are not well-capitalized are subject to additional regulatory scrutiny (Basel Committee on Banking Supervision, 1998, 2006). After the crisis, tighter capital requirements were phased in under Basel III. The minimum total capital ratio stayed at 8% throughout our sample period, but the Tier 1 capital ratio rose to 4.5% in 2013, 5.5% in 2014, and finally settled at 6% starting in 2015. Also under Basel III, additional capital ratios (e.g. tier 1 leverage and common equity capital ratio) began being monitored (however these ratios are quite similar to the pre-existing tier 1 and total capital ratios), and starting in 2016, a "capital conservation buffer" and special requirements for systemically important financial institutions were introduced (Basel Committee on Banking Supervision, 2011).

Figure 6 shows the share of BHCs close to the regulatory minimum for different capital ratios. The panels show that although some banks were close to the regulatory minimum, and this share rose during the crisis, the vast majority of banks were not near the regulatory constraint. Interestingly, the share rose to its peak in 2010 similar to when loan losses peaked, suggesting delay in the accounting of losses. Thus, although regulatory constraints may have been relevant for some banks, they do not bind strictly for most banks, especially since even banks that are near the regulatory constraint can often avoid activating the constraint by manipulating their books.

This yields our third fact:

Fact 2. *Neither regulatory nor market constraints bind strictly for most banks. However, these constraints may still influence the bank's decisions.*

The caveat is important: just because the constraint does not bind directly does not mean it could never bind in the future. For example, banks could choose to keep leverage low in order to avoid a future shock that causes the constraint to bind. Since a small but non-negligible share of banks do find themselves below the regulatory minimum during the crisis, and a larger share find themselves below the threshold to be considered well-capitalized, this is a real concern for banks. However, since regulatory constraints do not bind for most banks even in the crisis, and since banks can manipulate their books, a model in which regulatory constraints binds directly for most banks will not accurately describe bank behavior. Banks have discretion not just over valuing assets and over when to acknowledge loan writedowns, they also have some discretion over what risk weights to use in the calculation of risk-weighted assets (Basel Committee on Banking Supervision 2005, The Federal Reserve Board 2006). The precise importance of regulatory constraints in determining banks' leverage is difficult to pin down because we only observe the ex post realizations of book leverage, but we are interested in the ex ante distribution of possibilities, as well as the counterfactuals if the bank were to take different actions. Moreover, the regulatory environment has changed in response to the crisis, becoming more strict and giving regulators more discretion, which may make regulation more important in the future. We are thus unable to precisely determine the relative importance of regulatory constraints vs. other factors in determining bank leverage, although it seems likely that both play a role.

2.4 Target Leverage with Adjustment Costs

Figure 5 has shown that outside of the financial crisis, leverage ratios were fairly constant, both at the aggregate as well as the individual bank level. This, together with the evidence above that showed that both book and market value leverage constraints are not strictly binding suggests that banks choose a target leverage ratio. A target leverage ratio as an interior solution arises from standard capital structure problems, such as the trade-off theory between risk and returns associated with the leverage choice.

The choice of leverage becomes a dyamic problem when we add leverage adjustment costs (e.g. equity issuance costs and balance sheet stickiness). With adjustment costs, shocks to equity can dynamically affect banks' lending and capital decisions through the target leverage ratio, because banks adjust their balance sheets and equity over time to try to return to the target leverage ratio.

In order to investigate whether a target leverage level with adjustment costs determines bank behavior, we explore how bank responds to shocks. We focus on excess-return shocks as a measure for ex-ante unpredictable return innovations. For the rest of the paper we refer to these innovations as return shocks. These return shocks can be interpreted as a linear transformation of default shocks to the bank's portfolio of assets, and this is the interpretation we will assign them when we introduce our reduced-form model. We will find that the target leverage theory with adjustment costs seems to describe the data well, and provides insights into potential ways to endogenize the frictions that banks face, which we will discuss in the next section.

Econometric Specification We estimate the following panel regressions:

$$\Delta \log(y_{i,t}) = \alpha_t + \sum_{h=0}^{k} \beta_h \cdot \log(1 + r_{i,t-h}) + \gamma_h \cdot Post_t \ \log(1 + r_{i,t-h}) + \epsilon_{i,t}$$

where i indexes over banks, t indexes over quarters, $r_{i,t}$ indicates the market return over the past quarter for bank i in quarter t, α_t is a time fixed effect, and $Post_t$ is an indicator variable equal to one if the current quarter is post-crisis (we treat 2007 Q4 as first quarter for which $Post_t = 1$), and $y_{i,t}$ is the outcome of interest.[30] Time-fixed effects soak up aggregate shocks (e.g. changes in the price of loans due to demand shocks) giving us a partial equilibrium, supply-side impulse response, estimated off of the cross-sectional variation. In all specifications, we use $k = 20$. Given the high number of lags, we extend our data to 1990 Q3, which is the first quarter in which we can identify which banks are top-tier BHCs from the FR Y-9C. This extension is necessary to obtain precise pre-crisis estimates. We cluster standard errors by bank. Finally, to report the impulse response function, we cumulate the coefficients: the pre-crisis contemporaneous response is β_0, the next period is $\beta_0 + \beta_1$, and so on. For post-crisis, we also add the corresponding γ terms.

The choice of market return shocks instead of equity shocks is important for our identification strategy: market capitalization is a choice variable (banks can affect their equity by issuing equity or lowering dividends), and is thus endogenous. On the other hand, the efficient-market hypothesis tells us that variation in excess returns should be unpredictable *ex ante*, except, of course, for a risk-premium adjustment. This forms the basis of our identification strategy: we treat cross-sectional variation in returns as unanticipated shocks that perturb bank equity.

Estimated Responses We estimate impulse response functions for logged stock variables (liabilities, market capitalization, book equity, and market leverage), as well as for log flows (issuance rates, common dividend rates, and book return). Results are shown in Figure 7

[30] Since market returns are changes in equity, taking first differences in logs provides a tight conceptual link between the outcome and the regressor. Using levels would mean that the outcome was highly correlated with bank size. This would raise concerns about stationarity, and if the market returns of banks exhibit a size premium then this would also lead to omitted variables bias. Using levels could also result in a regression that was heavily influenced by a few large banks, given the highly skewed bank size distribution. For the same reason we do not weight our regressions: the bank size distribution is highly skewed, and so a weighted regression would be equivalent to a regression with only the handful of largest banks. If the variance of the residuals were lower for larger banks, then using weights would yield a more efficient estimator. Empirically however, the variance of the residuals does not appear to vary substantially by bank size.

for stocks and in Figure 8 for flows. Importantly, we are showing the response to a negative returns shock, since we find this easier to think about in the context of the financial crisis. The x-axis of our plots shows the contemporaneous response ($-\beta_0$ for pre-crisis and $-\beta_0-\gamma_0$ for post-crisis) as quarter 1, the response one quarter later ($-\beta_0-\beta_1$ and $-\beta_0-\beta_1-\gamma_0-\gamma_1$) as quarter 2, and so on.

Responses of stock variables. Under a framework where banks have a target leverage, we'd expect banks to respond to a negative wealth shock (which mechanically increases leverage) by moving back towards their target leverage. The data is consistent with such an adjustment in response to return shocks. The data also reveals that this response is slow, suggesting adjustment costs play an important role. The impulse response of log market leverage, defined here as log(Liabilities/Market Capitalization), is simply the difference between the response of log liabilities and log market capitalization. In the initial quarter, the mechanical effect on the denominator dominates. Thanks to the great deal of post-crisis adjustment on the equity side, banks adjusted their market leverage faster in response to cross-sectional shocks post-crisis than pre-crisis. However, the effect of return shocks on market leverage does not vanish, even five years out, suggesting adjustment costs are quite important.

This yields our fourth fact:

Fact 3. *Banks appear to operate with a target leverage to which they only return slowly after shocks, suggesting adjustment costs.*

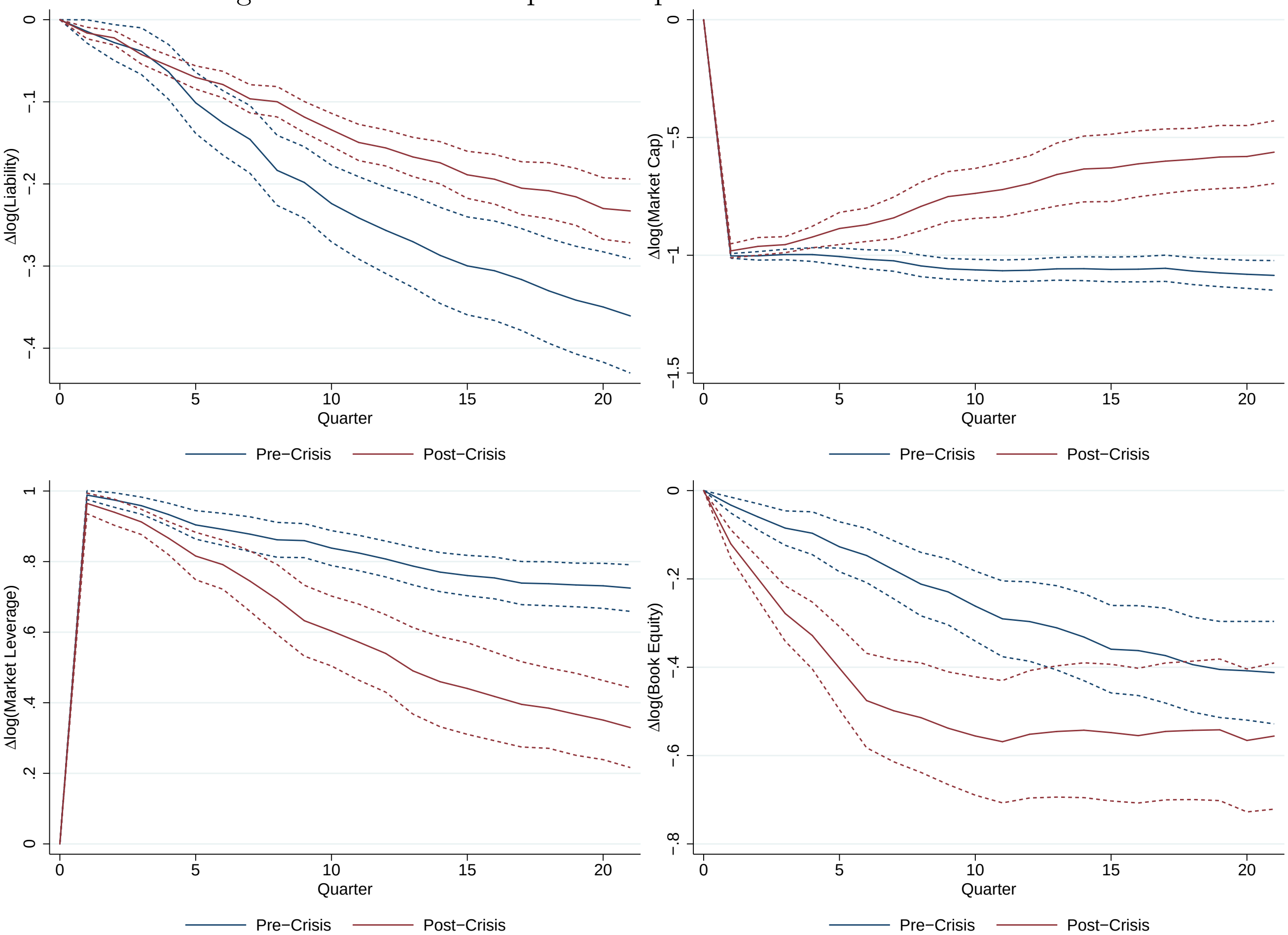
We can decompose the impulse response of market leverage into the responses of liabilities and of market capitalization. After a 10% return shock, five years out, there is a decrease of 3-4% in liabilities in the pre-crisis environment and of 2-3% in the post-crisis. Although banks appear to adjust liabilities more slowly post-crisis, this is reversed for market capitalization. In the pre-crisis, market equity falls mechanically in the period of the shock (a return shock automatically lowers equity one-for-one), with little further response of equity afterwards. By contrast, in the post-crisis, five years out, a 10% shock to returns yields only a roughly 5% decrease in market capitalization. These impulse responses show that banks switched from responding exclusively by decreasing assets and liabilities, in the pre-crisis to a combination of balance sheet and equity adjustment in the post-crisis, with equity adjustment being more important.[31]

This yields our fifth and final fact:

Fact 4. *Prior to the crisis, banks adjusted leverage primarily by reducing debt keeping equity unchanged. Post-crisis, banks also raised equity through retained earnings and issuance.*

[31] When we say equity was the more important margin of adjustment, we mean that the adjustment of log market equity is larger, which means that the equity adjustment is more important for adjusting leverage. Of course, if we did not take logs, the balance sheet response would be larger since banks are highly levered.

Figure 7: Estimated Impulse Responses for Stock Variables



Notes: These figures show estimated impulse response functions for BHCs. The figures show the estimated impulse response to a one unit negative returns shock. Dashed lines denote the 95% confidence interval. Standard errors are clustered by bank. The "post-crisis" period begins in 2007 Q4. Data on market capitalization and returns are from CRSP, and all other data are from the FR Y-9C. The panels display the impulse responses of log liabilities, log market capitalization, log market leverage, and log book equity. Market leverage is defined as log(Liabilities/Market Capitalization), so that it represents the difference between the response of log liabilities and log market capitalization (results using log(Liabilities + Market Capitalization)/Market Capitalization) are extremely similar).

Finally, our analysis in the previous section suggested that books respond only slowly to losses that are reflected quickly in market returns. Thus, book equity (see Figure 7) and book returns on equity (see Figure 8) should exhibit a delayed response to market returns. This is exactly what we see in the data.

Response of Flow Variables. We now describe movements in flow variables such as the dividend rate, the return on book equity (ROE), and equity issuance rate. For flows, we modify the methodology. We estimate the following equation:

$$\log(1 + y_{i,t}) = \alpha_t + \sum_{h=0}^{k} \beta_h \cdot \log(1 + r_{i,t-h}) + \gamma_h \cdot Post_t \ \log(1 + r_{i,t-h}) + \epsilon_{i,t}.$$

where now $y_{i,t}$ now represents the dividend rate, equity issuance rate, or book returns. Thus, when we report the impulse responses, rather than tracing out the rate, we are summing up cumulative deviations from the mean.[32]

Corporate finance makes a distinction between internal and external equity financing (Myers and Majluf, 1984). Agency and pecking-order theories suggest that internal financing (retaining earnings by reducing dividends) should be cheaper than outside equity finance. We do not find evidence for this theory. The cumulative response of the common dividend rate to a negative return shock is small and actually positive pre-crisis[33] and the issuance rate response is small and negative. During the post-crisis periods, banks both reduced dividends[34] and increased issuances. Most importantly, the cumulative response of issuance rates is much larger than that of dividend rates: the post-crisis response of issuance rates is three times the magnitude of the dividend rate response. When shocks were large and profits low, recapitalization via retained earnings would have taken a lot of time.

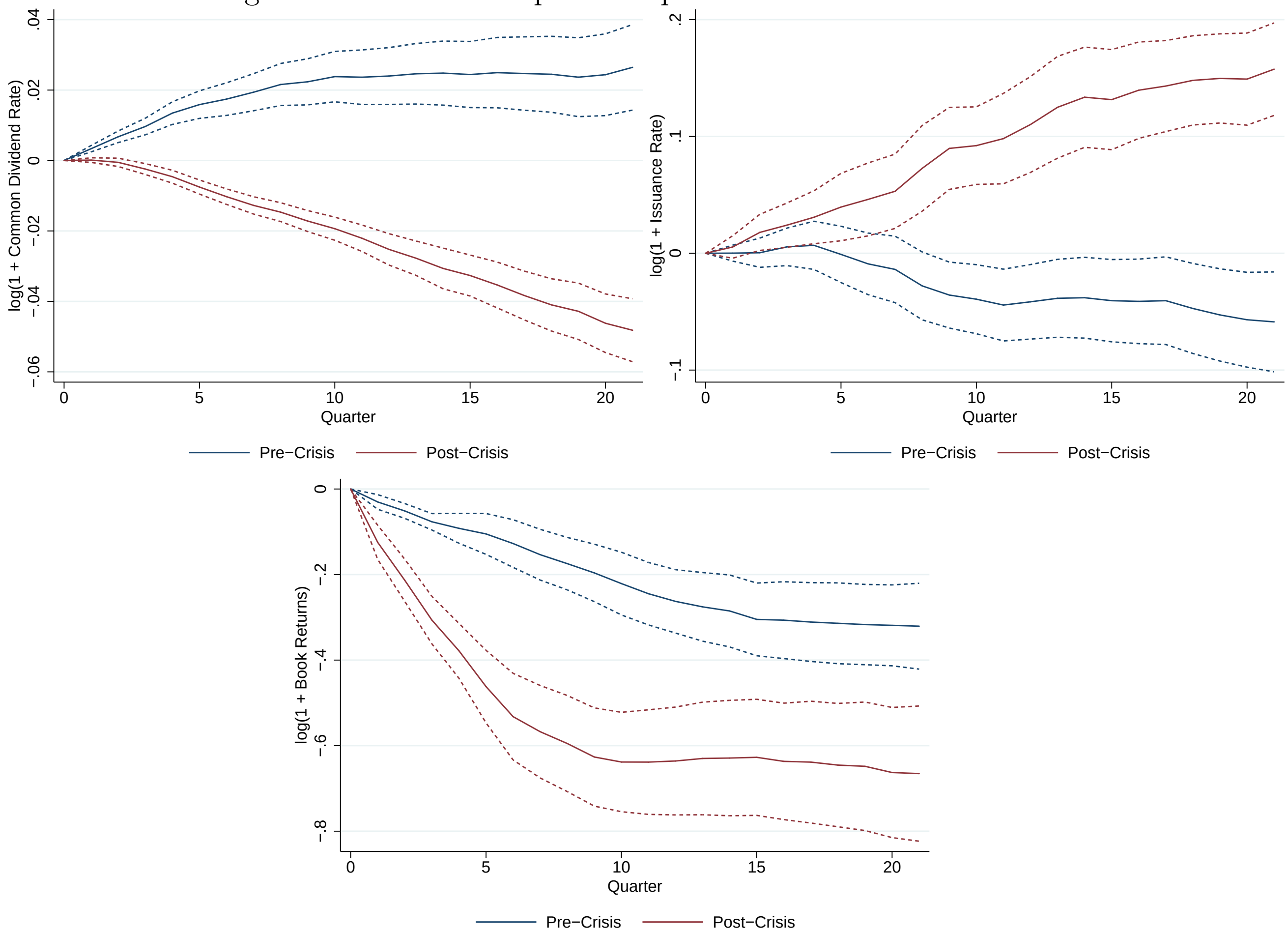
Identification Discussion and Robustness There are a few threats to identification. Returns in a given period may be correlated with other variables *ex-post* — e.g., banks with higher exposure to subprime mortgages should suffer heavier losses during the crisis. This means that returns in one period may be correlated with returns in another period *ex post*. This correlation will cause omitted variables bias if the outcome variable is affected by returns in both periods, but one of the periods is excluded. To deal with this issue, we include twenty lags of market returns. We also implement a placebo test where we

[32]We do this because for flows we are interested in how the flows cumulate over time to affect the stocks: elevated issuance rates cumulate to an increase in equity, book returns cumulate to a change in book equity, etc. In practice this is also useful econometrically: we are able to get precise estimates when we plot the cumulative response of these flow variables, while attempting to trace out the path of the flows gives us estimates that are mostly noise. Moreover, since our flow variables do not depend on the size of the bank, there is no need to take first differences as we do for the stock variables.

[33]Some of this effect may be mechanical: dividend per share tends to be fixed, and so a return shock leading to a fall in market capitalization will automatically raise the dividend rate, and this effect will cumulate until the dividend per share is newly set.

[34]Some of this may be regulatory: undercapitalized banks are not allowed to distribute dividends.

Figure 8: Estimated Impulse Responses for Flow Variables



Notes: These figures show estimated impulse response functions for BHCs. The figures show the estimated impulse response to a one unit negative returns shock. Dashed lines denote the 95% confidence interval. Standard errors are clustered by bank. The "post-crisis" period begins in 2007 Q4. Data on market capitalization and returns are from CRSP, and all other data are from the FR Y-9C. The panels display the impulse responses of the common dividend rate, equity issuance rate, and book returns. The logged common dividend rate is defined as log(1+Common Dividends/Market Capitalization), the logged issuance rate is defined as log(1 + Equity Issuances/Market Capitalization), and logged book returns are defined as log(1 + Book Net Income/Book Equity Last Quarter).

add leading values of returns into the specification —future return shocks should not affect the present, otherwise they aren't exogenous "shocks". Our placebo tests, shown in the appendix, suggest that the bias in our estimates is small.

Our estimates could also be polluted by omitted variables bias from other sources. Cross-sectional return shocks might incorporate idiosyncratic information not just about a bank's present portfolio (e.g. the default rate of mortgages on Citi's balance sheet will rise relative to those of other banks) but also about the relative profitability of its future portfolio (e.g. the default rate on the mortgages that Citi will issue in the future will rise relative to those of other banks) and thus affect the bank's problem through channels other than perturbing equity (if expected returns on future assets fall, then it could make sense to lower leverage). We do not think this problem is severe since we think most banks have access to fairly similar assets and thus the idiosyncratic element of shocks is mainly a function of the present portfolio (since we control for time fixed effects, our estimates are identified only off of the idiosyncratic component of the shocks). Our estimates could also be biased to the extent that the efficient markets hypothesis does not hold perfectly.[35] We acknowledge that our identification strategy is imperfect, but we think these issues are not crucial. Since it is infeasible for us to run a randomized controlled trial, we believe our approach provides very valuable information about the dynamic behavior of banks before and after the crisis.

2.5 Adjustment Cost Disscusion

The data is consistent with banks targeting a leverage level and facing adjustment costs. We now begin to examine what form these adjustment costs might take and what margin they operate along. We need adjustment costs on both liabilities and equity to explain the slow adjustment of leverage.[36] Without adjustment costs, banks could simply expand or shrink assets and liabilites to meet the target leverage ratio. Without equity adjustment costs, banks could simply expand or shrink equity to the desired level.

Adjustment costs can come in the form of illiquid assets or illiquid liabilities. Asset illiquidity could arise for a number of reasons, such as relational capital, bank specific expertise, asymmetric information, or the incentives to avoid acknowledging book losses on the books. We will discuss some of these in more detail in the next section. Liabilities can also be illiquid: in particular, banks could only have long term assets like deposits that are costly to terminate early (turning away depositors could be harmful if the bank wants to promote depositor loyalty for the future, and in many cases it is impossible to terminate

[35] The main concern here would be that the shocks were actually anticipated, perhaps because banks have access to information that doesn't reach the market until later. This would lead to pre-shock trends, which our placebo test is designed to test for. Our placebo tests find that any such bias is small.

[36] This assumes that the bank's problem is homothetic. Delevering by raising equity will increase size and delevering by shrinking assets and liabilities will lower size. Thus, non-homotheticity could serve the role of an adjustment cost, and the bank would have both a target leverage and a target size.

these liabilities early). We can examine this issue empirically by looking at the composition of bank liabilities in the cross-section.

In Figure 9, we present kernel density estimates of the distribution Deposits (an illiquid liability) as a share of total liabilities, and of Repo+Fed Funds (liquid liabilities) as a share of total liabilities. We think of Repo and Fed Funds as highly liquid liabilities because they mature very quickly (mostly overnight). The figures show that, both before and after the crisis, most banks had some Repo on their balance sheet and not all of their liabilities were deposits. This is particularly true for the larger banks that drive aggregate leverage. This suggests that banks indeed had room to pay off their liquid liabilities, so liquid liabilities were probably not a crucial friction for most banks.

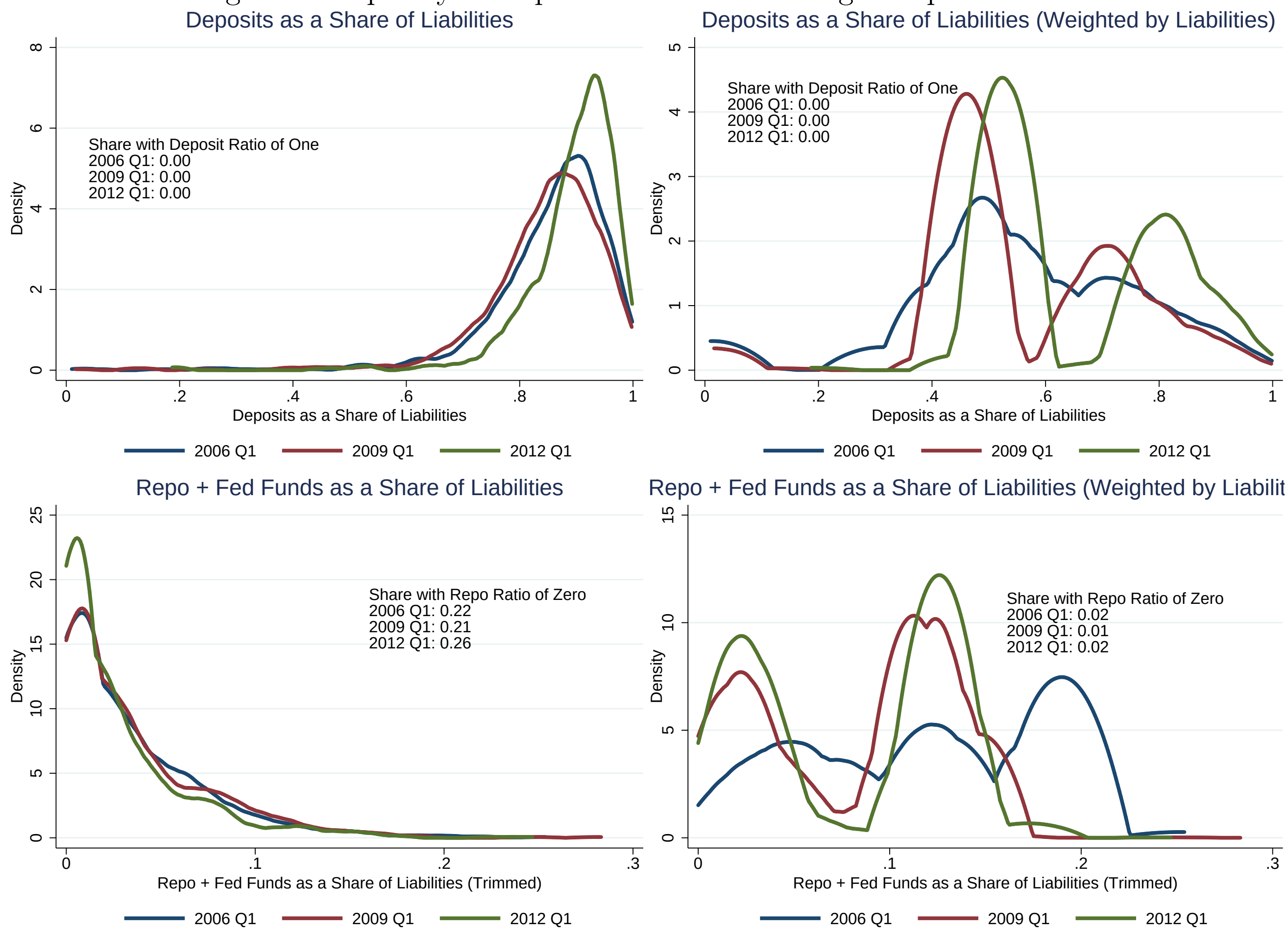
Equity adjustment costs can come on the issuance or dividend margin.[37] For issuances, agency theory suggests that banks may pay a premium on financing through equity issuances due to asymmetric information. Yet, in the post-crisis, banks actually responded to negative shocks mainly with increased issuances, rather than lower dividends. This may be in part because dividends are constrained to be non-negative, and many banks were up against the zero dividends constraint. To investigate this further, the left panel of Figure 10 shows kernel density estimates of the distribution of common dividend rates. The kernel density estimates and accompanying summary statistics indicate that a dividend rate of zero is common, and became more common during the crisis. The right panel shows a new impulse response function for the common dividend rate estimated via a Tobit model with left censoring of dividend at zero. The alternative estimate suggests that the cumulative response of post-crisis common dividend rates to return shocks would have been much larger had dividends not been constrained by 0. Whether this constraint is sufficient to fully explain the disparity between the response of dividends and issuances is unclear: the Tobit model imposes a particular assumption about the censoring process (e.g. the error term is normally distributed), and it is also not obvious how issuances would have behaved if dividends had not been constrained. We do not attempt to develop a full structural model of bank behavior in this paper. However, it is clear that the requirement that dividends be non-negative is an important constraint.

3 A Model to Rationalize the Facts

Where are we going? In this section we present a model that can rationalize the four facts we highlighted. The goal is to produce a reduced-form model that illustrates the features

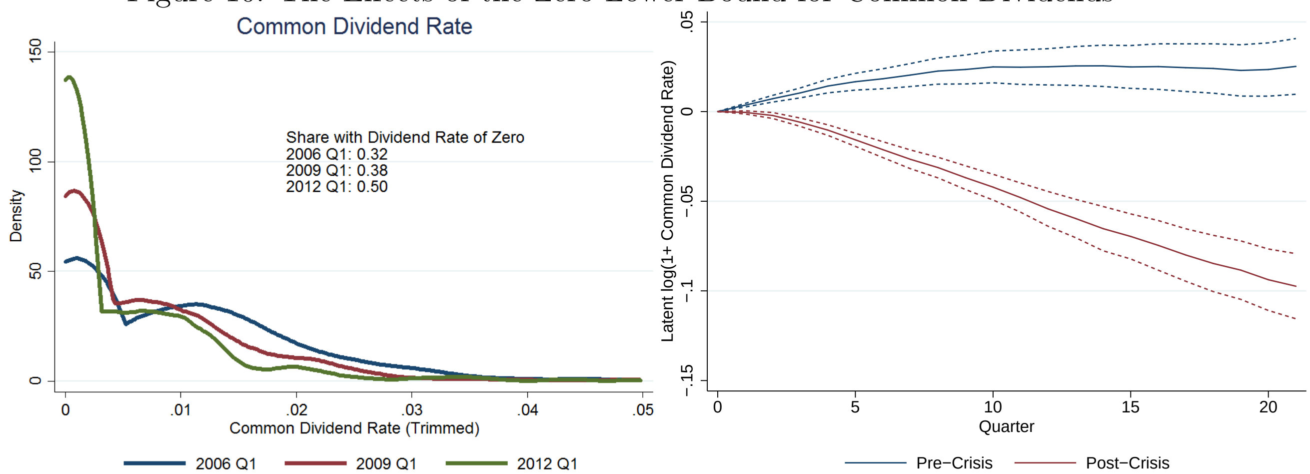
[37]Of course, the path of bank equity also depends on profits. However, since in our framework equity is measured as market capitalization and thus profits are measured as market returns, the efficient market hypothesis tells us that, setting aside the issue of risk adjustment, there should be no effect of past variables on market profits.

Figure 9: Liquidity of Deposits for Bank Holding Companies



Notes: These figures show kernel density estimates of liability composition ratios for BHCs. Data are from the FR Y-9C. We use 2006 Q1, 2009 Q1, and 2012 Q1 as reference quarters, and restrict to banks that are present in the data in all three reference quarters, in order to ensure comparability. The top panels show deposits as a share of total liabilities, and the bottom panels show repo (securities sold under agreement to repurchase) plus federal funds purchased as a share of total liabilities. The left panels are unweighted estimates, and the right panels are weighted by the total liabilities of the bank. The bottom panels are trimmed at 0.3 in order to improve legibility.

Figure 10: The Effects of the Zero Lower Bound for Common Dividends



Notes: The left panel shows kernel density estimates of common dividend rates (with book equity as the denominator) for BHCs. Data are from the FR Y-9C. We use 2006 Q1, 2009 Q1, and 2012 Q1 as reference quarters, and restrict to banks that are present in the data in all three reference quarters, in order to ensure comparability. The panel is trimmed at 0.5 in order to improve legibility. The right panel shows the estimated impulse response of log common dividends to a one unit negative returns shock. The impulse response is estimated using a Tobit model with left censoring at zero. Data on market capitalization and returns are from CRSP, and all other data are from the FR Y-9C. Dashed lines denote the 95% confidence interval. Standard errors are clustered by bank. The "post-crisis" period begins in 2007 Q4. The logged common dividend rate for the right panel is defined as log(1 + Common Dividends/Market Capitalization), to maintain consistency with the rest of the impulse response section.

that a quantitative model needs to match the facts. Some model features are ad-hoc, but we comment on what theories can give rise to those reduced form assumptions.

To generate the four facts in a parsimonious way, we study the individual problem of a unit mass of heterogeneous banks that take loan rates and the price of deposits as given. The only risks are idiosyncratic loan-default shocks. We use the solution to a bank's optimization problem to simulate a panel of aggregate banks whose behavior is consistent with the four facts highlighted in the paper.

3.1 The Model

Environment. Time evolves to infinity and is indexed by t. The only source of risk for a bank is idiosyncratic loan default risk.

Bank objective. The banker maximizes the expected discounted value of dividends d_t. Bankers have preferences over dividends defined recursively by:

$$u_t = U\left(d_t\right) + \beta U\left(\mathbb{CE}_t\left(U^{-1}\left(u_{t+1}\right)\right)\right)$$

where:

$$U\left(d_t\right) = \frac{d_t^{1-\theta}}{1-\theta} \text{ and } \mathbb{CE}_t\left(v_{t+1}\right) = \left(\mathbb{E}_t\left(v_{t+1}^{1-\psi}\right)\right)^{\frac{1}{1-\psi}}$$

where d_t denotes dividend payouts at time t and u is an Epstein-Zin utility function with a risk aversion coefficient of ψ and an intertemporal elasticity of substitution of $1/\theta > 1$. We introduce curvature to the bank's objective function for two reasons: to deliver (a) dividend smoothing and, (b) to introduce risk-aversion, which leads to a leverage target (Fact 3). Both are features that we can observe in the data. We assume an IES higher than one so that, banks pay less dividends when expected returns are high.

State Variables. At t, a bank holds a stock of outstanding loans at market value b_t and a stock of liabilities l_t. On its books, a bank's outstanding loans are recorded as $\bar{b}_t$. Thus, $\bar{b}_t$ is the face value of the loans the bank is owed. We introduce distinct market and book value concepts in order to be able to speak to Facts 1 and 2. We explain the differences below in more detail below. Loans are long term, modeled as perpetuities that mature at rate δ. Long-term debt is needed to obtain slow-moving leverage. Decaying perpetuities are used to model long-term debt.

Loans are risky. Every period, a fraction$\varepsilon \in [0, 1]$ defaults. The distribution of ε has a c.d.f. $F\left(\varepsilon\right)$. The market value of the stock of loans b_t is the stock net of defaults. The stock of book loans, $\bar{b}_t$, is similar but does not account for ε. In other words, the assumption is that $\bar{b}_t$ denotes the beginning-of-period face value of loans without the recognition of losses. This is a novel feature of our model and critical to capture banks' ability to engage in evergreening and to avoid the recognition of losses immediately (see empirical evidence in Blattner, Farinha, and Rebelo (2017)).[38] The laws of motion for b_t and $\bar{b}_t$ are linked but are not identical, as we show below. The state variable for a bank is the triplet $\{b_t, l_t, \bar{b}_t\}$.

Loan creation. The loan market is simplified to keep the model tractable. At each period, a bank chooses a new flow of loans, I_t. Banks fund new loans I_t by issuing deposits. That is, borrowers that demanded this new loan receive deposits in exchange. Banks issue new deposits at the price $p(I_t, b_t, l_t)$. We employ a tractable form:

$$p(I_t, b_t, l_t) = 1 + \gamma \frac{I_t}{b_t - l_t}$$

Note that the price for deposits depends on the balance sheet of banks. Since $b_t - l_t$ is the bank's equity, the price depends on the ratio of newly issued loans relative to equity. This functional form introduces quadratic adjustment costs to the bank's portfolio in a simple way. As the bank issues more loans relative to its equity, it has to issue more liabilities. Likewise, as it sells more loans, it receives a worse price. These costs reflect the notion that banks specialize in assets that have asymmetric information problems between borrowers and lenders (e.g. Leland and Pyle (1977a); Diamond (1984b); Dang, Gorton, Holmström, and Ordonez (2017)). This functional form introduces adjustment costs while allowing us to reduce the dimension of the state space.. The combination of an adjustment cost and long-term loans induces slow-moving leverage for the bank. We assume that banks cannot issue new equity, so we will focus on the dividend/asset sale margin when we discuss the desire to recapitalize.

Laws of motion. From now on, we represent the problem recursively. We denote by x' the variables chosen at the end of period t. Note that x' is not necessarily the same as x at the beginning of $t+1$ because the bank cannot condition its choice of x' on the default shock. The law of motion for the evolution for loans is:

$$b' = \left(1 + r^b\right)(1 - \delta)\, b + I,$$

where $r^b < \delta$ denotes the rate banks have earned on their outstanding loans. This law of motion says that a bank enters the period with a pre-determined amount of loans b. Over the period, a fraction δ matures and new loans I are added. Between the end of period t and $t+1$, loans receive a default shock and only a fraction ε of loans survive. Therefore, by the begining of next period the bank inherits$\varepsilon b'$ loans.

The law of motion for liabilities is:

$$l' = \left(1 + r^l\right) l - \delta b + p(I, b, l)\, I + d,$$

[38] Evergreening as explained in Caballero, Hoshi, and Kashyap (2008) occurs when banks roll over a loan that won't be paid. The objective is to avoid registering losses. Since rolling over a loan does not require new funds, evergreening allows the bank to reduce it's accounting equity without a cost.

Liabilities increase as the bank pays interest on deposits, r^l. At the same time, the bank is paid in deposits when loans mature by δb. When the bank makes new loans, it issues $p(I, b, l)$ deposits per loan.

The law of motion for book values satisfies:

$$\bar{b}' = \left(1 + r^b\right)(1 - \delta)\,\bar{b} + I$$

The idea behind this law of motion is that the book value of loans does not recognize losses, and therefore it follows the same law of motion of the market value, but without $\varepsilon = 1$.

We define three convenient objects. The first is the real bank equity:

$$W \equiv b - l.$$

Second,real leverage:

$$\lambda \equiv \frac{b}{W}, \text{ and thus, } \lambda - 1 = \frac{l}{W}.$$

Third, the loans q, the ratio of real loans to the book value of loans:

$$q \equiv b/\bar{b}.$$

Regulation. We assume that the book value of loans is subject to a regulatory leverage constraint. We model the bank's capital requirement as, $l' \leq \kappa\left(\phi\bar{b}' - l'\right)$. Here, κ is a capital requirement and ϕ a risk-weight on loans. This formulation allows banks to adjust their portfolio at the beginning of the period. It also implies that some banks would violate the constraint if the constraint were written in real loan terms. We define $\rho \equiv \phi\kappa/(1+\kappa)$ and rewrite the constraint as: $l' \leq \rho\bar{b}'$.

Liquidation of a Bank. A bank is shut down for two reasons. First, if the bank enters a period with a leverage above $\bar{\lambda}$, the bank is liquidated. We interpret this as a market-based liquidation: the idea is that depositors discipline the bank by imposing a cap on leverage.[39] The second reason for liquidation is regulation. Regulatory liquidiation occurs when the regulatory capital constraint cannot be met for any (d, I). Notice that a bank is subject to random default shock so it cannot control the market value of its loans at the beginning of the following period.

We define the liquidation set. Let Γ^r be the set of states of regulatory defaults, i.e. the states $\left\{b, l, \bar{b}\right\}$ such that $l' \leq \rho\bar{b}'$ for any choice $\{d, I\}$. Let Γ^m be the states where $\lambda \equiv b/(b-l) \geq \bar{\lambda}$. Obviously, the full set of liquidation states is $\Gamma = \Gamma^m \cup \Gamma^r$. In the case of entering either liquidation state, the bank values its wealth according to:

[39] This constraint is also a technical condition to prevent Ponzi schemes.

$$V^o = \frac{U(\eta W)}{(1-\beta)},$$

where η is a scalar denoting the fraction of wealth that is left after liquidation. Note that we can set $\eta = 0$ without loss of generality because we assumed an IES above 1 so utility is bounded below. Setting up the problem this way makes the bank's problem scale invariant, which is a useful normalization: combined with the functional form for $p(I, b, l)$, we can factor out the bank's wealth.

Problem 1 *[Bank's Problem] The bank's policy functions are the solutions to the following profit-maximization problem:*

$$V\left(b, l, \bar{b}\right) = \max_{\{d,I\}} U(d) + \beta \mathbb{E}\left[V\left(\varepsilon b', l', \bar{b}'\right)\right]$$

subject to:

$$\begin{aligned}
b' &= \left(1+r^b\right)(1-\delta) b + I \\
\bar{b}' &= \left(1+r^b\right)(1-\delta) \bar{b} + I \\
l' &= \left(1+r^l\right) l - \delta b + p(I, b, l) I + d \\
l' &\leq \rho \bar{b}'
\end{aligned}$$

and

$$V\left(b, l, \bar{b}\right) = V^o \text{ if } \left\{b, l, \bar{b}\right\} \in \Gamma.$$

3.2 Analysis

Next, we show how the assumptions generate a model that is easy to characterize. One proposition summarizes the result:

Proposition 1 *[Bank's Problem] For a given combination of leverage λ and market to book value of loans q, the value function is homothethic in wealth W. In particular, the value function and the optimal decision rules are given by:*

$$V\left(b, l, \bar{b}\right) = \bar{V}(\lambda, q) W^{1-\sigma}$$

and

$$d = cW \text{ and } I = \iota W,$$

where $\{\bar{V}, \iota, c\}$ *solve the following Bellman equation:*

$$\bar{V}(\lambda, q) = \max_{\{c,\iota\}} U(c) + \beta U\left(\mathbb{CE}_t\left[U^{-1}\left(\bar{V}\left(\frac{\varepsilon}{\frac{1}{\lambda'} - (1-\varepsilon)}, \varepsilon q'\right)\Omega(\varepsilon)^{1-\theta}\right)\right]\right) \tag{2}$$

subject to:

(a) the law of motion for leverage:

$$\lambda' = \frac{\left(1+r^b\right)(1-\delta)+\iota}{\Omega(1)}\lambda, \tag{3}$$

(b) the law of motion for the market to book ratio of loans:

$$q' = \frac{\left(1+r^b\right)(1-\delta)+\iota}{\left(1+r^b\right)(1-\delta)\frac{1}{q}+\iota},$$

(c) the return on loans:

$$R^a(\varepsilon) \equiv \varepsilon\left(1+r^b\right)(1-\delta)+\delta,$$

(d) the normalized loan price:

$$\bar{p}(\iota, \lambda) = 1 + \gamma\iota\lambda, \tag{4}$$

(e) the portfolio return:

$$\Omega(\varepsilon) \equiv \left[\left(1+r^b\right)(1-\delta)+\iota\right]\lambda\left(\frac{1}{\lambda'} - (1-\varepsilon)\right), \tag{5}$$

(f) the regulatory constraint:

$$\frac{1}{\lambda'} \geq 1 - \frac{\rho}{q'} \text{ for } q' \geq \rho, \tag{6}$$

(g) liquidation states:

$$\bar{V}(\lambda, q) = \frac{U(\eta)}{(1-\beta)} \text{ if } (\lambda, q) \in \Gamma. \tag{7}$$

(See the proof in the Appendix.) The proposition merits a discussion: first, we factored out bank equity from the objective and transformed the problem into a scale-free problem. The normalized problem has two state variables: $\lambda = b/W$ (real leverage), and $q = b/\bar{b}$ (the Tobin q for loans). The Bellman equation $\bar{V}(\lambda, q)$ is a standard consumption-portfolio problem augmented by regulatory and market-solvency constraints, and a price impact for selling or buying loans. Constraints (a) and (b) are the laws of motion for the state variables. Equation (c) is the definition of the return on loans for a given default shock ε. Equation (d) is the price equation per unit of equity. The term $\Omega(\varepsilon)$ in (e) and ((2)) measure the growth of the bank's equity, given a default shock, leverage and policy variables. The inequality (f) and the condition in (g) are the regulatory constraint and liquidation values re-written in terms of the controls $\{\lambda', q'\}$ and the state variables $\{\lambda, q\}$. Once the normalized problem is solved, we can recover the original policy functions and laws of motion.

Model Properties. The problem has many desirable properties that allow the model to reproduce facts 1-4. The presence of a price impact on the value of loans (4) implies that banks cannot adjust their portfolio immediately. Leverage λ is a double-edged sword. On the one hand, it enhances returns. This feature is captured by equation (5): leverage increases expected levered returns inside $\Omega(\varepsilon)$. On the other hand, leverage exposes the bank to the risk of liquidation: for a given choice of λ', a bad draw of ε increases leverage at the beginning of next period, $\frac{\varepsilon}{\frac{1}{\lambda'}-(1-\varepsilon)}$, which is decreasing in ε. Moreover, the default set $\Gamma(\lambda, q)$ is decreasing in λ: higher leverage makes it more likely to violate the cap $\bar{\lambda}$, and the regulatory constraint is tighter for higher λ—see Figure 11.

Even if a single shock doesn't force liquidation, leverage is not adjusted automatically, so a series of negative shocks can induce greater leverage and lead to liquidation (e.g. see the law of motion (3)). The combination of a concave objective and the risk of default leads to a target level for leverage.

Regulatory constraints enter the problem in a novel way. Focussing on the constraint in equation (6), the coefficient $\rho < 1$ makes the constraint set convex and generates a trade-off between dividend payouts and growth in loans. The greater q (i.e. the closer it is to 1), the tighter the constraint, as it means that loan book values are very close to their market value. When q is closer to 0 and conditional on λ, the constraint becomes less binding. The following graph shows the regulatory constraint in the (λ', q') space:

3.3 Construction of Model Return Shock Impulse Responses

In this section, we construct a pricing equation for bank stocks and map the underlying default shocks to a return shock. The idea is to produce the model analogue to the impulse responses we used to identify the behavior of bank variables in the data. Towards that goal, consider a representative outside investor that discounts the dividend of the bank with a constant rate μ. In spirit of our analysis, we abstract from aggregate shocks. Furthermore, we assume that the investor observes ε. This information is captured in market but not in book values. This assumption is consistent with the fact that market-to-book values in the model, as in the data, have predictive power, as we demonstrated in Section (2).

The investor values a share of bank stock according to:

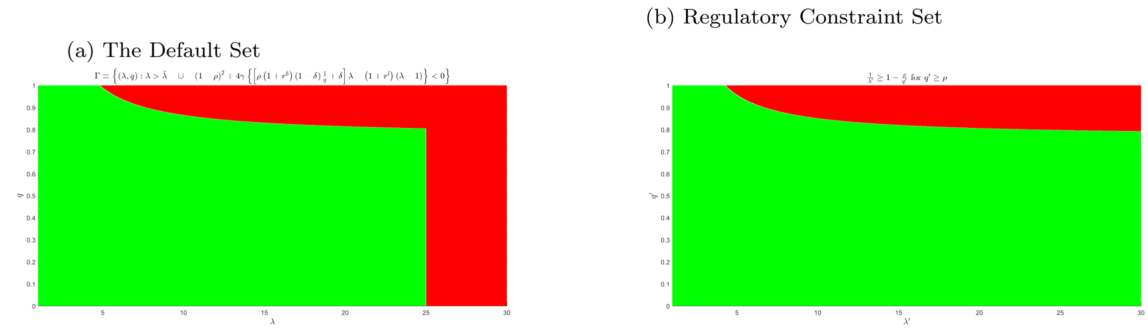


Figure 11: Constraint Sets.
Note: The figure shows in red the regions of the state space (λ, q) where the bank is forced to default.

$$S\left(b, l, \bar{b}\right) = d + \mu \mathbb{E}\left[S\left(\varepsilon b', l', \bar{b}'\right)\right].$$

Now, this value function can also be written recursively:

$$S\left(b, l, \bar{b}\right) \equiv s\left(\lambda, q\right) W = c\left(\lambda, q\right) W + \mu \mathbb{E}\left[s\left(\lambda', q'\right) \Omega\left(\varepsilon\right)\right] W.$$

We interpret $S\left(b, l, \bar{b}\right)$ as the market capitalization of a bank. The expected return on bank shares can be defined as:

$$\bar{R} \equiv \frac{d + \mathbb{E}\left[S\left(\varepsilon b', l', \bar{b}'\right)\right]}{S\left(b, l, \bar{b}\right)} = \frac{c\left(\lambda, q\right) + \mathbb{E}\left[s\left(\lambda', q'\right) \Omega\left(\varepsilon\right)\right]}{s\left(\lambda, q\right)}.$$

Realized returns for a given bank are given by:

$$R\left(\varepsilon\right) = \frac{c\left(\lambda, q\right) + s\left(\lambda', q'\right) \Omega\left(\varepsilon\right)}{s\left(\lambda, q\right)}.$$

The model analogue to the return shocks in section (2) is then given by:

$$\Delta R\left(\varepsilon\right) = R\left(\varepsilon\right) - \bar{R} = \frac{s\left(\lambda', q'\right)}{s\left(\lambda, q\right)} \Omega\left(\varepsilon\right) - \mathbb{E}\left[\frac{s\left(\lambda', q'\right)}{s\left(\lambda, q\right)} \Omega\left(\varepsilon\right)\right].$$

which is a mean-zero random variable by construction. In the following section, we report the impulse responses of bank variables to changes in $\Delta R\left(\varepsilon'\right)$. These are precisely the analogue of the impulse responses in Section (2). Before we get to that, we present a numerical example of the solution to the problem of banks and investors.

3.4 Calibration and Estimation

Calibration. The time period of the model is a quarter because that is the available frequency. The values of all parameters are listed in Table 4. In summary, we need to assign values to 14 parameters. The set of parameters $\left\{r^b, r^l, \delta, \phi, \kappa, \beta, \sigma, \psi, \bar{\lambda}, \mu\right\}$ and the distribution of default shocks F are calibrated directly. We estimate two values for the adjustment costs γ: one for the pre-crisis level and one for the post-crisis level $\{\gamma^{pre}, \gamma^{crisis}\}$ using a GMM method that matches the impulse responses to return shocks.

The returns on bank liabilities r^l and bank assets r^b are respectively set to 1.5% and 1.0% to yield corresponding annualized returns of 6% and 4%. We set the capital constraint to $\kappa = 9$ to have a capital adequacy ratio in line with Basel regulation. We set $\phi = 0.85$ to fit the risk-weights of loans, also in line with Basel regulation.[40] We set δ to 0.04 to obtain an average loan maturity of 3 years. The parameter η is set to 0, because the model is not sensitive to small numbers of this parameter.

We calibrate other parameters to match other moments. In particular, we target: the distribution of cross-setional return-shocks, the average market-based leverage of banks, and the average dividend-rate of banks. Let's explain why these moments inform us about all of these parameters. With IES identical to 1, the bank's dividend rate per unit of wealth is given by $1 - \beta$. If we solve for the equilibrium price of banks, the price/dividend rate is related to β and μ. We set the inverse IES $\sigma = 0.5$. We set the risk aversion coefficient $\psi = 0$ to target the average leverage observed in the data. To calibrate F we assume that $\ln(1-\varepsilon)$ is distributed lognormal, and set the mean and standard deviation of the default shock to target a mean of 3.46% and standard deviation of 1.67% for the returns of the banks during 1990 Q3 to 2006 Q4.

We estimate the adjustment cost parameters to match the impulse responses of the model.[41] We generate data from the model by simulating the paths of banks and running the same specification as in Section (2), using λ as the dependent variable. We then compute the distance between the coefficients estimated from the model and those from the empirical section, using as weights a diagonal matrix that contains the estimated variances of the coefficients—see **Christiano Eichenbaum Evans (2005)** for more details on this procedure. We select the values of $\{\gamma^{pre}, \gamma^{crisis}\}$ that minimize this distance.

[40] Basel regulation features various capital requirements that banks simultaneously need to satisfy, some of which feature different risk weights when computing the value of banks' assets. We see 85% percent as appropriate given these different requirements. Notice that implicitly we are applying the same risk weights to loans and reserves, which is sensible in our model because both reserves and loans are risk free. Below, we discuss an extension of the model with risky loans.

[41] Since the model features growth, we simulate the paths for 100,000 banks for 200 periods for the pre-crisis regime to guarantee that the cross-sectional distribution of the state variables is stationary. We then keep the same number of quarters for which we have data before and after the change in the adjustment cost.

Table 2: Parametrization

Parameter	Description	Target	Model	Data 1990 Q3 - 2006 Q4
$\beta = 0.99$	Discount factor	Average dividend rate	1.97%	0.63%
$\psi = 0$	Risk aversion	Average leverage rate	5.33	8.68

Parameter	Description	Target
$\sigma = 0.5$	Inverse IES	Literature
$r^b = 0.015$	Loan yield	BHC data: interest income / loans
$r^l = 0.010$	Bank debt yield	BHC data: interest expense / debt
$\delta = 0.04$	Loan maturity	BHC data: average loan maturity
$\bar{\lambda} = 25$	Leverage cap	BHC data: maximum leverage
$\phi = 0.85$	Risk weight on loans	FR-Y-9C instructions
$\kappa = 9$	Leverage constraint	FR-Y-9C instructions
$\gamma^{pre} = 0.14$	Adjustment cost pre crisis	Impulse response functions
$\gamma^{crisis} = 0.17$	Adjustment cost post crisis	

Bank Behavior. Figure 12 presents the numerical solution to the bank's problem and the investor's valuation using the calibration described above. The figure reports the bank value $\bar{V}$, the stock price s, the dividend rate c, and the loan issuance rate ι. These objects are normalized to a unit level of W. The plots are functions of leverage λ and the ratio of market to book value of loans q.

The key objective is to understand the shape of the value function$\bar{V}$. First, there are regions of the state space where the bank value and stock price drop to zero. These are the areas where the bank is forced to liquidate because leverage is above the threshold $\bar{\lambda}$, or because the regulatory constraint cannot be met for any choice of c and ι. Outside of the liquidation set Γ, the value function is non-monotone. Let's think about why. First, observe that as q increases the capital requirement of the bank becomes more restrictive. This is because the book value approaches the actual value of loans, tightening the regulatory constraint. As a consequence the value of a bank decreases with q. Second, the value is non-monotone in leverage. The reason is that the value of the bank inherits the standard trade-off between risk and return. The bank cannot control its leverage perfectly over time due to the combination of default shocks and adjustment costs. As leverage increases, the bank can increase its immediate return by exploiting the arbitrage between borrowing and lending rates. However, excessive leverage puts the bank at risk of increasing leverage in excess (as implied by equation (3)), inducing liquidation.In order to reduce the risk of liquidation, the bank chooses a leverage target well below $\bar{\lambda}$.

The value of bank shares closely resembles the value function at a different scale. The scale and shapes are different because the outside investor values cash-flows linearly, whereas the bank's utility has curvature. The important thing to note here is that the value of bank shares will capture changes in real leverage for a given value of book loans. Thus, changes

Figure 12: Behavior of Bank Variables as a Function of the State Variables: Leverage and Market-to-Book Value of Loans
Note: The figure shows the value function of the bank, the stock value, the optimal dividend payout and lending rates of banks as functions of the individual bank state variables (λ, q).

in this model will convey information on the future behavior of the bank, consistent with Fact 1.

Portfolio Adjustments Before and After after a Loan Liquidity Crisis. Now we use our model with the goal of reproducing the impulse responses to return shocks that we observe in the data. We present these impulse responses overlaying the responses of banks under two scenarios. Namely, we compare the responses to a negative realization of $R(\varepsilon)$ for high and low values of γ. We interpret a low γ as a "tranquil" regime where the price of loans is less sensitive than in the alternative regime. In the alternative regime, the "liquidity crisis" regime, γ takes a higher value so that the price impact is higher. Under this interpretation, the common loan default shock to banks makes it harder for individual banks to sell their loans to achieve their leverage target. An alternative interpretation would be that adjustment costs are asymmetric (namely, selling loans is harder than originating them), and banks were trying to expand pre-crisis and delever post-crisis. The crucial assumption for the model is that balance sheet adjustments on the margin were harder post-crisis than pre-crisis.

The blue curves in Figure (13) are the responses under the pre-crisis regime, the red curves are under the post-crisis regime, and black lines reproduce the responses found in the data. The top panel reports the impulse responses of market leverage λ and book leverage, computed as the ratio of book assets to book equity and given by $\frac{1}{1-q+\frac{q}{\lambda}}$. The bottom panel reports the impulse responses of the market-to-book ratio of loans q, the dividend rate c, and the issuance rate ι, following a negative 1% return shock.

Upon the shock, the market leverage of the bank, measured as the ratio of assets to market capitalization, experiences an increase on impact. This is because market prices move faster than assets (due to adjustment costs). Market based leverage will remain above trend even after 10 periods, i.e. 2.5 years. The top right panel shows the impulse response function of book leverage computed as the ratio of book assets to book equity. The accounting measure of assets incorporates the default loss information only slowly while book equity remains relatively constant. Thus, book leverage falls following a return shock. The response is larger post-crisis because the fall in the assets (i.e. loans) is more pronounced. These two impulse response functions show that this model is capable of replicating the behavior of book and market leverage of the Great Recession. As in the

Figure 13: Model Impulse Responses (in percent) to a Default Shock

Note: The figure shows the impulse responses to return shocks in the model and in the data. The blue line corresponds to the pre-crisis data analogue whereas the red line is the post-crisis analouge. The black line reports the responses estimated in the data.

data, market leverage increases whereas book leverage falls, i.e. market leverage is counter-cyclical while book leverage is pro-cyclical.

The bottom panel shows the impulse response function for the rate of new loan issuance (top left), dividends (top right), and the two state variables: the market-to-book ratio and leverage. While the lending rate falls equally sharp pre- and post crisis, dividends are only slighltly reduced pre-crisis while post-crisis dividends are drastically reduced, equivalent to more equity issuance.

3.5 Assesment: Matching the Facts

We now evaluate the extent to which the model can match the key facts of the paper.

Fact 1 notes the divergence of book and market values, and that market values capture information not captured by the books. The divergence of book and market values as denoted by q is shown in the impulse responses: book and market leverage react very differently to the default shock. The value function shows that the market value of a bank depends on leverage and q, demonstrating the fact that market values capture important information that is not captured by the books.

Fact 2 speaks to which constraints banks are strictly up against. In the model, banks are typically not up against the regulatory constraint nor the market constraint on leverage, consistent with the data. However, banks' decisions take into account the possibility and ensuing consequences of hitting these constraints. This pushes banks to limit their leverage akin to a precautionary savings motive as does the risk aversion in their utility function. In the model, this induces a target leverage, consistent with the data.

Fact 3 speaks to what determines banks' leverage choice. With enough curvature in the problem (e.g. risk aversion and adjustment costs), as well as long term loans, we can deliver on a leverage target and slow moving leverage as in the data.

Fact 4 notes the difference in the impulse responses pre- and post-crisis. In both the model and the data, the pre-crisis impulse response shows banks responding to a negative shock by contracting their balance sheet, with little response on the equity adjustment side.

Post-crisis, banks also respond to the negative shock by raising more equity, a fact again captured by the model.[42]

Assessment. In short, the model does a good job at fitting the four stylized facts. The model also reveals important additional insights. Within the model, adjustment costs serve as an amplification mechanism for shocks: the bank does not only face the direct losses from default, but also faces additional losses due to adjustment costs as it tries to return to its target leverage. This also suggests that, although book accounting means that the books are slow to reflect the true equity of banks, this regulatory slack may be beneficial: immediate adjustment can be very costly. Thus allowing banks to smooth out the necessary adjustment over time can limit their losses. Although we have not incorporated general equilibrium effects into the model, it is easy to see how there could be contagion in this model: fire sales by one bank could lower the price at which loans can be sold, thus entering the objective of other banks through γ and making adjustment even more costly. The adjustment costs also provide one mechanism for persistence: banks do not immediately adjust their leverage, so the credit crunch persists until banks return to their target leverage.

4 Conclusion

This paper summarizes four salient facts about the behavior of banks during the US the financial crisis of 2008. We wrote the paper without a knowing what to expect, we learned from these facts and propose directions for better banking models. We describe the contrast between the collapse in bank market-value equity and the modest decline in bank book-equity which was offset by equity issuances. We also described the large cross-sectional variation in market-to-book ratios and scant evidence of binding regulatory capital. Both observations pose challenges to current workhorse models. We then present dynamic impulse-response functions to individual bank returns to gather information on how banks react to shocks that raise their market leverage: Our empirical findings suggest a theory where banks target market leverage, but where adjustments to that target are gradual. A comparison between pre- and post-crisis responses suggest that, in contrast to the pre-crisis period, in the post-crisis banks relied more on retained earnings than on assets sales to readjust their targets for market leverage.

We then present a heterogeneous-bank model that distinguishes book from market values. In our model, both measures of equity matter for banking decisions. An novel feature is that banks have the ability to delay the acknowledgement of loan losses on their books.

[42] In the data we also examined the breakdown between raising equity through new issuances vs. through lower dividends (retained earnings). In the model, we abstract from this distinction for simplicity.

The model produces an endogenous target for leverage and features ad-hoc adjustment costs to the resale of assets. At steady state, the model reproduces the impulse responses that we estimated from the cross-section in the data. When we interpret the crisis as a period of greater adjustment costs, the model is able to reproduce the shift in the method of adjustment of market equity that we see in the data.

Of course, the model is not amenable for policy analysis. Indeed, the model has many reduced form assumptions and is studied in partial equilibrium. However, our model is useful because it can reproduce the four empirical facts we underscore in the paper. Oure hope is that we can use this model to search for the microfoundations that can deliver similar reduced form dynamics and, therefore, can also reproduce the empirical facts. After all, science is made one little step at a time.

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A Robustness

We formalize the determinants of Tobin's Q in regressions. We saw suggestive evidence for the relationship in Figures 4. We maintain a consistent sample throughout the analysis: the regressors are trimmed to drop any extreme outliers as in the graphical analysis, and any observation that is not used in one of the specifications is not used in any of the specifications. The results are reported in Table 3. The regressions bear out the same conclusions: return on book equity one year ahead remains statistically significant predictor of Tobin's Q up to two years.[43] A Oaxaca decomposition using the the sample for this table and the variables in the final column suggest that between 40% and 45% of the difference in logged Tobin's Q can be explained just with these variables. To summarize market capitalization during the crisis was reflecting cross-sectional information not contained in the books. The next section cross-sectional differences in market values lead to differentiated behavior of banks. We ask what does this tell us about the constraints faced by banks, and what does it mean for macro models?

[43] A careful treatment of this analysis would note that the regressors which we truly want is expected future profits, and realized future profits are in fact expected profits measured with noise. The lower coefficients on future profits, compared to current profits, thus represent not just time discounting, but also the extent to which variation in future profits was anticipated, conditional on the other regressors.

Table 3: OLS regression estimates of the effects of predictors on logged Tobin's Q

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post	-1.164***	-0.720***	-1.542***	-0.786***	-0.890***	-1.219***	-0.559***	-0.783***
	(0.0409)	(0.0640)	(0.0741)	(0.0579)	(0.0578)	(0.0528)	(0.0875)	(0.0894)
Delinquency		-0.780***					-0.691***	-0.682***
		(0.207)					(0.149)	(0.148)
Post*Delinq		-1.087***					-0.294	-0.273
		(0.279)					(0.257)	(0.250)
Dividend Rate			10.93***					-0.614
			(2.533)					(1.828)
Post*DivRate			47.04***					32.32***
			(5.897)					(5.184)
ROE				17.91***			13.61***	13.67***
				(1.413)			(2.246)	(2.253)
Post*ROE				1.348			-1.424	-5.221
				(2.425)			(3.049)	(2.980)
F4ROE					16.88***		6.184**	6.265**
					(1.238)		(1.997)	(2.022)
Post*F4ROE					-0.755		-1.240	-2.181
					(2.502)		(3.252)	(3.017)
F8ROE						4.663***	-0.310	-0.279
						(1.045)	(0.532)	(0.547)
Post*F8ROE						6.466**	1.990	1.143
						(2.268)	(2.013)	(1.815)
Constant	0.674***	0.743***	0.560***	0.115*	0.224***	0.589***	0.152***	0.153***
	(0.0170)	(0.0281)	(0.0338)	(0.0450)	(0.0371)	(0.0261)	(0.0417)	(0.0420)
Observations	590	590	590	590	590	590	590	590
R^2	0.564	0.659	0.669	0.727	0.678	0.616	0.768	0.790

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

B Appendix to Model Section

B.1 Proof of Proposition 1

Preliminary Definitions. Define the following gross rates of return:

$$R^l \equiv \left(1+r^l\right) \text{ and } R^b \equiv \left(1+r^b\right).$$

Also, define the net investment rate of the bank as:

$$\iota \equiv I/b.$$

Finally, express the dividend to wealth ratio as:

$$c \equiv d/W.$$

We present some observations that aid the proof of the proposition.

Observation 1: homogeneity of p. Observe that:

$$\begin{aligned} p\left(I,b,l\right) &= \alpha+\gamma\frac{I}{b-l} \\ &= \alpha+\gamma\frac{I}{W} \\ &= \alpha+\gamma\iota\lambda. \end{aligned}$$

Thus, we can express $p\left(I,b,l\right)$ as:

$$\bar{p}\left(\iota,\lambda\right)=\alpha+\gamma\iota\lambda,$$

which is a function independent of the size of the bank, and only depends on the composition of its assets and its investment rate.

Observation 2: homogeneity of regulatory constraint. We want to express the capital requirement recursively. First, notice that we can express the regulatory constraint as:

$$l' \leq \frac{\kappa}{1+\kappa}\phi\bar{b}'.$$

Let $\rho \equiv \phi\kappa/\left(1+\kappa\right)$. Then, this constraint is equivalent to:

$$\frac{l'}{W} \leq \rho\frac{\bar{b}'}{b}\frac{b}{W}.$$

From here, we employ the laws of motion for l' and b' to obtain:

$$
\begin{aligned}
R^{l}\left(\lambda-1\right)-\delta\lambda+\bar{p}\left(\iota,\lambda\right)\iota\lambda+c &\leq \rho\frac{R^{b}\left(1-\delta\right)\bar{b}+I}{b}\lambda \\
&= \rho\left(R^{b}\left(1-\delta\right)q^{-1}+\iota\right)\lambda.
\end{aligned}
$$

We can re-arrange the constraint so that parameters are left on the right side:

$$
\left(\bar{p}\left(\iota,\lambda\right)-\rho\right)\iota\lambda+c\leq\left(\rho R^{b}\left(1-\delta\right)q^{-1}+\delta\right)\lambda-R^{l}\left(\lambda-1\right).
$$

The boundary falls in a constrained region. If we open up the expression for $\bar{p}$, we obtain:

$$
\left(\alpha-\rho\right)\iota\lambda+\gamma\left(\iota\lambda\right)^{2}+c\leq\left(\rho R^{b}\left(1-\delta\right)q^{-1}+\delta\right)\lambda-R^{l}\left(\lambda-1\right).
$$

So long as $\rho<1$, the constraint set is convex, for any $\left(\lambda,q\right)$. Note again that the constraint is independent of W.

Observation 3: growth independence. Next, we construct W' as a linear function of wealth:

$$
\begin{aligned}
W' &= \varepsilon b'-l' \\
&= \varepsilon\left(R^{b}\left(1-\delta\right)b+I\right)-\left(R^{l}l-\delta b+p\left(I,b,l\right)I+d\right) \\
&= \left(\delta+R^{b}\left(1-\delta\right)\varepsilon\right)b-R^{l}l-d+\left(\varepsilon-p\left(I,b,l\right)\right)I \\
&= R^{a}\left(\varepsilon\right)b-R^{l}l-d+\left(\varepsilon-p\left(I,b,l\right)\right)I
\end{aligned}
$$

where we defined:

$$
R^{a}\left(\varepsilon\right)\equiv\varepsilon R^{b}\left(1-\delta\right)+\delta.
$$

Now, we factor W from the expression above to obtain:

$$
\begin{aligned}
&= \left[R^{a}\left(\varepsilon\right)\lambda-R^{l}\left(\lambda-1\right)-c+\left(\varepsilon-\bar{p}\left(\iota,\lambda\right)\right)\iota\lambda\right]W \\
&= \Omega\left(\varepsilon\right)W.
\end{aligned}
$$

Here, we implicitly defined:

$$
\Omega\left(\varepsilon\right)\equiv R^{a}\left(\varepsilon\right)\lambda-R^{l}\left(\lambda-1\right)-c+\left(\varepsilon-\bar{p}\left(\iota,\lambda\right)\right)\iota\lambda.
$$

Observation 5: recursive leverage. Next, from the law of motion of b we obtain a recursive expression for the the law of motion of leverage, λ given any choice of ι and $c:$

$$
\begin{aligned}
\lambda' &= \varepsilon \frac{b'}{W'} \\
&= \varepsilon \frac{\left(R^b (1-\delta) + \iota\right) b}{W'} \\
&= \varepsilon \left(R^b (1-\delta) + \iota\right) \lambda \frac{W}{W'}.
\end{aligned}
$$

But recall that: $W' = \Omega(\varepsilon) W$. Thererfore:

$$
\lambda' = \varepsilon \frac{R^b (1-\delta) + \iota}{\Omega(\varepsilon)} \lambda.
$$

Observation 6: recursive expression for q. Next, we show how to write q in a recursive way:

$$
\begin{aligned}
(q')^{-1} = \frac{\bar{b}'}{\varepsilon b'} &= \frac{R^b(1-\delta)\bar{b} + I}{\varepsilon \left(R^b(1-\delta)b + I\right)} = \frac{(R^b(1-\delta)\lambda q^{-1} + \iota\lambda)W}{\varepsilon \left(R^b(1-\delta)\lambda + \iota\lambda\right) W}. \\
&= \frac{R^b(1-\delta)q^{-1} + \iota}{\varepsilon \left(R^b(1-\delta) + \iota\right)}.
\end{aligned}
$$

Observation 7: homogeneity of the value function. We guess and verify that:

$$
V\left(b, l, \bar{b}\right) = \bar{V}(\lambda, q) W^{1-\gamma}
$$

for U given by CRRA utility. Where, clearly, we are using that:

$$
\begin{aligned}
b &= \lambda W \\
l &= (\lambda - 1) W \\
\bar{b} &= q^{-1} \lambda W.
\end{aligned}
$$

Next, we work with our guess for the value function:

$$
\bar{V}(\lambda, q) W^{1-\gamma} = \max_{\{d,I\}} U\left(\frac{d}{W}\right) W^{1-\gamma} + \beta \mathbb{E}\left[V\left(\varepsilon b', l', \bar{b}'\right)\right]
$$

subject to:

$$
\begin{aligned}
b' &= R^b (1-\delta) b + I \\
\bar{b}' &= R^b (1-\delta) \bar{b} + I \\
l' &= R^l l - \delta b + p(I, b, l) I + d \\
l' &\leq \kappa \left(\phi \bar{b}' - l'\right).
\end{aligned}
$$

First, we transform the constraint set. We use the law of motion for wealth, to express every equation in terms of past wealth and current decieions.

$$W' = \Omega(\varepsilon, c, \iota, \lambda) W.$$

Then, dividing both sides by W and using the W', the law of motion for loans, becomes the law of motion from leverage:

$$\lambda'(\varepsilon, \lambda) = \frac{\varepsilon \left(R^b (1-\delta) + \iota\right) \lambda}{\Omega(\varepsilon, c, \iota)}.$$

Since we know also that:

$$(q')^{-1} = \frac{R^b(1-\delta)q^{-1} + \iota}{\varepsilon\left(R^b(1-\delta) + \iota\right)},$$

once we know λ' and q' and W', we know $b', \bar{b}', l'$ and the first equations are satisfied.

Second, we divide both sides of the regulatory constraint, again to obtain::

$$(\alpha - \rho) \iota\lambda + \gamma (\iota\lambda)^2 + c \leq \left(\rho R^b (1-\delta) q^{-1} + \delta\right) \lambda - R^l (\lambda - 1).$$

If the conjecture is right, we can replace the law of motion into the objective and obtain:

$$
\begin{aligned}
\bar{V}(\lambda, q) W^{1-\gamma} &= \max_{\{c,\iota\}} U(c) W^{1-\gamma} ... \\
&+ \beta \mathbb{E}\left[(1-\pi) \bar{V}(\lambda'(\varepsilon, \lambda), q') \Omega^{1-\gamma}(\varepsilon, c, \iota, \lambda) + \pi \bar{V}(\lambda'(\varepsilon, \lambda), 1) \Omega^{1-\gamma}(\varepsilon, c, \iota, \lambda)\right] W^{1-\gamma}.
\end{aligned}
$$

This shows that the objective is indeed homothetic in wealth. Hence, we have to solve the following:

$$\bar{V}(\lambda, q) = \max_{\{c,\iota\}} U(c) + \beta \mathbb{E} \left[\begin{array}{c} \pi \left[\bar{V}(\lambda'(\varepsilon, \lambda), 1) - V(\lambda'(\varepsilon, \lambda), q')\right] \Omega^{1-\gamma}(\varepsilon, c, \iota; \lambda) \\ + \bar{V}(\lambda'(\varepsilon, \lambda), q') \Omega^{1-\gamma}(\varepsilon, c, \iota; \lambda) \mathbb{I}\left[\lambda'(\varepsilon, \lambda) < \bar{\lambda}\right] + V^o \mathbb{I}\left[\lambda'(\varepsilon, \lambda) \geq \bar{\lambda}\right] \end{array} \right].$$

subject to the conditions we described above:

(a) Law of motion for leverage:

$$\lambda'(\varepsilon,\lambda) = \frac{\varepsilon\left(R^b(1-\delta)+\iota\right)\lambda}{\Omega(\varepsilon,c,\iota)}.$$

(b) Law of motion for books:

$$(q')^{-1} = \frac{R^b(1-\delta)q^{-1}+\iota}{\varepsilon\left(R^b(1-\delta)+\iota\right)}.$$

(c) Asset returns:

$$R^a(\varepsilon) = \left(\varepsilon R^b(1-\delta)+\delta\right)$$

(d) Loan price:

$$\bar{p}(\iota,\lambda) = \alpha + \gamma\iota\lambda$$

(e) Portfolio returns:

$$\Omega(\varepsilon,c,\iota;\lambda) = \left[R^a(\varepsilon)\lambda - R^l(\lambda-1) - c + (\varepsilon - \bar{p}(\iota,\lambda))\iota\lambda\right].$$

(f) Regulatory constraint:

$$(\alpha-\rho)\iota\lambda + \gamma(\iota\lambda)^2 + c \leq \left(\rho R^b(1-\delta)q^{-1}+\delta\right)\lambda - R^l(\lambda-1).$$

This verifies the proposition.

B.2 Extension with Equity injections

Equity Injections. Now assume that banks can issue equity in a follow-on offering. As occurs in practice, we let this issuances be large and unfrequent. In particular, a public offering is a binary decision to issue an amount increase the amount of shares by $e/(1-e)$. This implies that the initial share-holders lose $(1-e)$ of the shares of the bank. The cash inflow is:

$$f = s(\lambda,q)We.$$

This cash infusion allows the bank's leverage to decrease from λ to $\lambda^i(\lambda,q,e)$ that solves the equation:

$$\lambda^i = \frac{\lambda W}{\lambda W - (\lambda-1)W + s(\lambda^i,q)We} = \frac{\lambda}{1+s(\lambda^i,q)e}.$$

Thus, from the perspective of the inside investor, upon an issuance the bank bank's value switches to:

$$\bar{V}\left(\frac{\lambda}{1+s\left(\lambda^{i},q\right)e},q\right)(1-e)^{1-\gamma}.$$

Thus, the bank's value function with the option to issue equity switches to:

$$\bar{V}(\lambda,q)=\max_{\{c,\iota\}}U(c)+\beta\mathbb{E}\left[\max\left\{\bar{V}\left(\lambda'(\varepsilon,\lambda),q\right),\bar{V}\left(\lambda^{i},q\right)(1-e)^{1-\gamma}\right\}\Omega^{1-\gamma}(\varepsilon,c,\iota;\lambda)\right].$$

B.3 Calibration

The time period of the model is a quarter because that is the available frequency of the Call Rerports is .

Overall Strategy. The values of all parameters are listed in Table 4. In summary, we need to assign values to xxx parameters. There are three sets of parameters. The first set of parameters, $\left\{r^{b},r^{l},\delta,\phi,\kappa\right\}$, is calibrated directly. The second set $\{\beta,\sigma,\pi,\bar{\lambda},F\}$[44] are calibrated by matching moments of an auxiliary model that for produces a direct map from model parameters to data moments. Finally, we will estimate two values for the adjustment costs, γ, one for the pre-crisis level and one for the post-crisis level $\{\gamma^{pre},\gamma^{crisis}\}$.

Externally Calibrated Parameters $\left\{r^{b},r^{l},\delta,\phi,\kappa,\eta\right\}$. The returns on bank liabilities r^{l} and bank assets r^{b} are respectively set to 0.015 and 0.01 to yield corresponding annualize returns of 6 and 4 percent. We set the capital constraint to $\kappa=xxx$ to have a capital adequacy ratio of xxx percent, in line with Basel regulation. We set $\phi$to fit the risk-weights of loans, also in line with Basel regulation.[45] We set δ to xxx to obtain an average maturity of loans of 4.4 years as . The parameters η es set to 0.5 as done by the literature on bankruptcy. Notice that in our model, the bank closes despite being solvent.

Paremters Calibrated with an Auxiliary Model $\{\beta,\sigma,\pi,\bar{\lambda},F\}$. We use the following auxiliary model to calibrate $\{\beta,\sigma,\pi,\bar{\lambda},F\}$. The auxiliary model is simply the model when $\gamma=0$ and where $\kappa=\infty$. That is, we calibrate this set of parameters assuming that the model doesn't have adjustment costs or capital requirements. This auxiliary model because it doesn't produce ex-ante heterogeneity. Thus, it does not produce a distribution of state variables. This is helpful because as long as the moments produced by the full blown

[44]Recall that F is the distribution of ϵ shocks.

[45]Basel regulation features various capital requirements that banks simultaneously need to satisfy, some of which feature different risk weights when computing the value of banks' assets. We see xxx percent as appropriate given these different requirements. Notice that implicitly we are applying the same risk weights to loans and reserves, which is sensible in our model because both reserves and loans are risk free. Below, we discuss an extension of the model with risky loans.

model are not far, this auxiliary model provides a good approximation to the model with bank heterogeneity. We adopt this approach because it would be numerically unfeasiable to target moments to pin down $\{\beta, \sigma, \pi, \bar{\lambda}, F\}$ and jointly estimate values for $\{\gamma^{pre}, \gamma^{crisis}\}$. Next, we explain how we calibrate this set. We use the following moments, the distribution of cross-setional return-shocks, the average market-based leverage of banks, the average dividend-rate of banks, the average failure rate, and the average Tobin's Q. Let's explain why these moments inform us about all of these parameters. With IES identical to 1, the bank's dividend rate per unit of wealth is given by β. If we solve for the equilibrium price of banks, the price/dividend rate is related to β and mu. . To calibrate F, we obtain a direct map from the distribution of shocks ϵ to the distribution of return shocks.

Estimation of $\{\gamma^{pre}, \gamma^{crisis}\}$. This is the GMM step.

Table 4: PARAMETRIZATION

Parameter	Description	Target
$r^b = 0.015$	Loan yield	BHC data: interest income / loans
$r^l = 0.010$	Bank debt yield	BHC data: interest expense / debt
$\beta = 0.99$	Discount factor	Average dividend rate
$\sigma = 0.5$	Risk aversion parameter	Dividend elasticity to return shock
$\delta = 0.04$	Loan maturity	BHC data: 3 year average loan mat
$\gamma^B = 0.15$	Loan issuance cost	
$\gamma^L = 0.50$	Loan selling costs	Pre and Post crisis elasticities Target Leverage
$\bar{\lambda} = 15$	Maximum leverage	
$\pi = 0$	Audit Probability	# of regulatory liquidations
$\phi = 0.85$	Risk weight on loans	FR-Y-9C instructions
$\kappa = 9$	Leverage constraint	FR-Y-9C instructions

B.4 Computational Algorithm

We solve the model using value function iteration over a discretized state space. The endogenous state variables are λ (leverage) and q^{-1} (the ratio of book to market), on 50 nodes for λ and 30 nodes for q^{-1}. The exogenous state variable ε follows a log normal distribution, and is discretized over 20 nodes. We also discretize the control variables c and i using 29 and 49 grid points respectively. The periodic utility is

$$U(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma}.$$

Given the parameter (see section B.3) and prices (i.e. the interest rate on loans and deposits), the bank solves its optimization problem. The following computational algorithm solves the bank's problem by updating the value function of the bank until a fixed point is reached.

1. Use the value function from the last iteration (or a guess if it is the first). Interpolate the value function using a third degree polynomial.
2. For each value of the state variables, check whether the constraints are not violated.
3. Conditional on a given endogenous state variable combination
   (a) for each possible value of the control variables c and i
      i. Update the values of the state variables λ', $q^{-1\prime}$, as well as Ω'.
      ii. Evaluate the value function polynomial at the updated state variable and Ω' as in the Bellman equation 2 in Section 3.
      iii. Compute the new value function, using the Bellman equation. \lambda
   (b) Find the value of the control variables c and i that maximize the value function for a given state variable combination.
4. The resulting updated value function is compared to the initial value function. Until convergence is reached, repeat steps 1-4.

We use the resulting value function and policies in order to compute our variables of interests. To compute an invariant distribution of banks, we simulate a 25 year series of loan default shocks (100 quarters) 10000 times.