Bank Regulation: Capital and Liquidity Requirements*

Jordan Pandolfo †

Abstract

The 2010 Dodd-Frank Act introduced a new set of capital and liquidity standards for U.S. commercial banks. Given the novelty of liquidity regulation, less work has focused on the joint role of capital and liquidity requirements in achieving policy objectives, as well as their interaction. To address this, I develop a quantitative general equilibrium model with a heterogeneous banking sector in which banks are subject to endogenous insolvency and liquidity default. Using panel microdata for U.S. commercial banks, I find that the Dodd-Frank Act led to a threefold reduction in bank default rates (from 0.93% to 0.23%) and was welfare improving. Further, I find significant policy interactions exist: capital requirements can reduce both insolvency and liquidity default. Given this feature, most of the welfare gains of the Dodd-Frank Act can be achieved just through the capital requirement component of the reform. I also solve for the jointly optimal policy and find that capital requirements should be increased and liquidity requirements decreased, relative to their Dodd-Frank levels.

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†Federal Deposit Insurance Corporation, email: jpandolfo@fdic.gov

1 Introduction

In 2010, the Third Basel Accord (Basel III) passed a new set of bank capital and liquidity standards which were implemented in the United States as a major component of the Dodd-Frank Act (DFA).[1] A key feature of the reform was the novel use of liquidity requirements. In the wake of the DFA's passage, a debate has emerged over the efficacy of these policies. In particular, proponents for increased regulation argue that these standards are necessary to reduce default risk and its associated costs; those opposing argue that the standards have severely restricted the ability of banks to act as financial intermediaries: efficiently channeling funds to profitable investments. More generally, the debate stems from ongoing questions about the new use of liquidity requirements in conjunction with capital requirements to achieve regulatory objectives.

In this paper, I ask, what was the impact of the Dodd-Frank Act on bank default risk as well as other relevant aggregates? Further, do significant interactions exist between capital and liquidity requirements? Lastly, what is the jointly optimal policy for both capital and liquidity requirements?

To answer these questions, I develop a general equilibrium model framework with a heterogeneous banking sector. Banks act as intermediaries between households and loan projects. The bank problem takes place in two stages and each stage corresponds to a unique type of default. In the first stage (Initial Stage), banks make an insolvency default decision which depends upon the available net worth of the bank.[2] Absent default, the bank chooses a portfolio of assets and debt liabilities. On the asset side, banks can originate loans and purchase government securities as well as cash. On the liability side, banks can borrow both stable deposits and runnable wholesale funding debt. In the second stage (Settlement Stage), the bank experiences a funding shock: some fraction of its wholesale funding is withdrawn. At this point, the bank makes a liquidity default decision. Absent default, the bank chooses how to liquidate assets to meet the withdrawal of its wholesale funding debt.

Banks have an increased risk of insolvency default when they operate with low levels of equity, and an increased risk of liquidity default when they operate with low levels of asset liquidity. Both equity and liquidity are regulated through the use of capital and liquidity requirements, respectively: capital requirements act as a lower bound on the ratio of equity-to-assets while liquidity requirements act as a lower bound on the ratio of liquid assets to wholesale funding debt.

These requirements can play a socially valuable role due to the existence of moral hazard from

[1] Capital requirements restrict the ability of banks to debt fund while liquidity requirements control the liquidity of bank assets.

[2] Banks are financially constrained in that they are unable to raise equity directly from households.

limited liability, deposit insurance and myopic bank managers. Because of the moral hazard, banks do not fully internalize their cost of default. Thus, if left unregulated, banks become excessively risky from the perspective of households. This is relevant to households because consumption is affected by bank activities through the net return on deposit savings, bank equity income and taxes related to the cost of deposit insurance. Ultimately, capital and liquidity requirements trade off a reduced cost of default (+) with reduced bank profitability and equity income (-).

I discipline the quantitative model with the use of panel microdata for the U.S. commercial banking sector known as U.S. Call Reports. A set of bank technology parameters are estimated directly through the use of bank income statements and debt inflow/outflow data. Further, I use the structure of the model to identify a remaining set of key parameters related to bank technology and preferences, utilizing observed default rates, regulatory ratios and portfolio shares within the banking sector. To check the validity of the model, I show that the parameterization captures key cross-sectional features in the data. Further, I find that bank portfolio shares and balance sheet levels adjust to increased regulation by a similar magnitude when compared to their data counterparts, before and after the implementation of the Dodd-Frank Act.

In evaluating the Dodd-Frank Act, I find that it led to a threefold reduction in total bank default risk, from 0.93% to 0.23% (annualized) and was welfare improving. Further, I find that policy interactions are quantitatively significant: capital requirements improve bank liquidity while liquidity requirements lead to a deterioration of bank equity. In the case of capital requirements, increased regulation causes a large substitution out of wholesale funding debt, leading to an improvement in bank liquidity ratios. In the case of liquidity requirements, increased regulation causes a large substitution into loans, increasing asset risk and lowering equity ratios. The main implication of the policy interactions is that capital requirements are effective in reducing both insolvency and liquidity default risk.

To examine the marginal contributions of the regulations, I decompose the Dodd-Frank Act with two separate policy experiments: one with just the reform to capital requirements (4% $\rightarrow$ 6%), and the other with just the reform to liquidity requirements (0% $\rightarrow$ 100%), holding all other regulations at their pre-DFA level. Doing this, I find that the capital requirement component of the Dodd-Frank Act can alone achieve 95% of the welfare gains of the total reform. Conversely, just implementing the liquidity requirement component of the reform would lead to an increase in total banking sector default risk and a household welfare loss.

In addition, I solve for the joint optimal policy and find that capital requirements should be raised to 6.75% and liquidity requirements lowered to 95%. This result seems counter-intuitive, given the harmful role of liquidity requirements in the marginal DFA experiment. The difference in outcomes is related to the level of capital requirements: when capital requirements are set low (at 4%), banks hold relatively large levels of wholesale funding debt which makes it costly (for the bank) to impose high liquidity requirements. Conversely, when capital requirements are set high (at 6.75%), banks hold a relatively small level of wholesale funding debt (due to the positive interaction of capital requirements) such that banks can easily hold enough liquid assets to cover the liquidity requirement.

Lastly, I examine the impact of unanticipated aggregate shocks to bank loan returns and withdrawals of debt funding. I find that a negative 1% net loan return shock leads to a threefold increase in insolvency default rates and an 8% decline in total lending in the preceding period. Also, a negative 10% withdrawal of wholesale funding debt within the banking sector leads to a 30% increase in liquidity default rates and a 0.5% decline in aggregate lending in the preceding period.

For the remainder of the paper, Section 2 covers related literature and my corresponding contribution. Section 3 provides background on both the regulatory framework in which banks operate, as well as relevant empirical observations for the U.S. banking sector. Section 4 introduces the general equilibrium framework. Section 5 presents a definition of the equilibrium concept as well as a characterization of important equilibrium outcomes. Section 6 covers the model calibration. Section 7 covers key results with respect to the Dodd-Frank Act, policy interactions, optimal policy and aggregate shocks. Section 8 concludes the paper.

2 Related Literature

This model embeds a banking sector as an intermediary between households and lending projects in an incomplete market setting, and hence relates to a large literature in macro-financial frictions in which financial markets play a nontrivial role and can impact the real economy (see Bernanke and Gertler [1989], Bernanke et al. [1999] and Kiyotaki and Moore [1997]). Further, by incorporating insolvency and liquidity default within the bank problem, this paper relates to a broader literature which considers the interplay between bank capital structure and short-term liquidity needs (see Calomiris and Kahn [1991], Diamond and Dybvig [1983] and Diamond and Rajan [2001]).

A relatively new literature has stemmed from developing tractable general equilibrium banking model frameworks with which to quantify and evaluate policy, starting with Van den Heuvel [2008]. Given that capital adequacy was the key policy concern for international banking standards set by Basel I and Basel II, the primary focus of the literature was on capital regulation. Corbae and

D'Erasmo [2010] utilize a quantitative general equilibrium model with a heterogeneous banking sector in which banks differ in their market power and geographic location to generate key business cycle properties with respect to competition, equity ratios and entry/exit. My paper's formulation of the bank problem is most similar to their framework but differs along several dimensions: it considers a larger portfolio problem on the asset side (loans, securities and cash) as well as the liability side (deposits, wholesale funding and equity). Further, in my model, funding shocks from wholesale funding debt introduce an intra-period problem the bank must solve. Begenau [2020] develops a dynamic general equilibrium model where households have a preference for bank deposits and banks choose loan monitoring effort, affecting returns. Under the model calibration, optimal capital requirements are set uniformly at 12.4%. The gains from the heightened capital requirements come from cheaper funding costs (due to deposit scarcity) and increased monitoring effort by banks. Both Davydiuk [2017] and Faria-e Castro [2020] study the use of time-varying capital requirements and find that the implementation of a countercyclical capital buffer can generate welfare gains relative to a fixed capital requirement. Gertler et al. [2020] develop a model with banking panics and show that a countercyclical capital buffer is a critical component of successful macroprudential policy in that it reduces the variability of aggregate output with little cost to the average level.[3] Pancost and Robatto [2019] use a dynamic quantitative model in which nonfinancial firms, as well as households, hold deposits. Through general equilibrium effects, the nonfinancial firm holding of deposits mitigates the cost of heightened capital requirement, and they find an optimal capital requirement for U.S. banks of 18.7%. Mankart et al. [2015] look at the tradeoff between risk-weighted capital requirements and leverage requirements and find that stringent risk-weighted capital requirements have the adverse effect of increasing bank failure rates, due to the regulation's impact on the return of equity. Nguyen [2014] measures the optimal level of capital requirements in a dynamic general equilibrium model in which banks engage in risk-shifting due to bailout expectations. The financial sector has a real effect upon the growth of the economy, and the author finds the optimal level of Tier 1 capital requirements to be 8%. Begenau and Landvoigt [2017] and Harris et al. [2014] look at the impact of capital requirements imposed upon regulated, commercial banks in the presence of an unregulated shadow banking sector. Also, see Gertler et al. [2016] who include a wholesale/shadow banking sector in a model with banking panics and use this framework to help explain trends in the growth of shadow banking.

More recently, given the novel use of liquidity regulation in conjunction with capital regulation, new research has focused on the joint role of bank regulatory policy. Corbae and D'Erasmo [2018]

[3]Also, see Gertler and Karadi [2011] for a similar modeling environment which explores the use of monetary policy as a tool for macroprudential policy.

analyze the impact of heightened capital and liquidity requirements in a framework similar to Corbae and D'Erasmo [2010]. They find that increased liquidity regulation leads to an improvement in bank capital ratios; further, capital requirements are more effective in reducing the long run risk of an economic crisis. De Nicoló et al. [2014] examine the quantitative impact of bank capital and liquidity regulation on key aggregates and certain welfare criteria in a partial equilibrium setting. They find that capital requirements are effective in reducing bank default risk and there exists an inverted u-shaped relationship between capital regulation, aggregate lending and welfare. Further, they find that liquidity regulation unambiguously reduces welfare and lending, and destroys the marginal benefit of capital regulation. This occurs because liquidity regulation severely hampers the ability of banks to engage in maturity transformation. Covas and Driscoll [2014] develop a quantitative general equilibrium model with a heterogeneous banking sector in which bank deposits are runnable. They find capital and liquidity requirements complement one another in the sense that both regulations effectively penalize the holding of risky assets and incentive the holding of safe, liquid assets. Other papers which analyze the joint role of capital and liquidity regulation include Adrian and Boyarchenko [2013] and Van den Heuvel [2019]. In contributing to this literature, I develop a model which has a more comprehensive treatment of (i) the bank regulatory framework, by including multiple capital requirements, (ii) the bank portfolio problem, by capturing other key asset and debt items used by banks, as well as (iii) the nature of default risk, by incorporating both endogenous liquidity and insolvency default risk. I argue that including these features is essential in analyzing and quantifying the impact of capital and liquidity regulation.

This paper incorporates two underlying distortions which motivate welfare-improving gains from the use of both capital and liquidity requirements: moral hazard and a firesale externality. Moral hazard arises from the existence of limited liability default, deposit insurance and bank manager myopia. Due to deposit insurance, the riskiness of bank activities is not reflected in the price of bank debt, similar to Karaken and Wallace [1978]. This gives banks incentive to increase debt funding and default risk above levels which may be socially optimal. See also Diamond and Dybvig [1983] and Calomiris and Kahn [1991] for related theoretical work that discusses the benefits and costs associated with deposit insurance. This paper's notion of a firesale is similar to the seminal work of Schleifer and Vishny [1992] who show firesales occur when first-best users of productive assets are financially-constrained. Forced sale of the asset to less productive users leads to a lower valuation. More recently, Lorenzoni [2008] seeks to explain the existence of firesales in a macroeconomic setting where agents face collateral constraints. When collateral constraints bind, agents must liquidate some collateral on a spot market at a discounted price and do not internalize the pecuniary externality created by their liquidations. This leads to excessive borrowing in the competitive equilibrium. In this paper, banks hold wholesale funds which are subject to funding shocks, leading to an early withdrawal. Banks can settle with cash or the liquidation of securities on a spot market with a downward-sloping demand. If cash is scarce, banks are forced to liquidate securities. In the aggregate, this leads to larger liquidations and devaluations on the spot market and banks do not internalize their contribution to this effect. The two-stage modeling approach for this problem is most similar to Bianchi and Bigio [2019]. See also Bianchi [2011], Korinek and Dávila [2018] and Stein [2012] for relevant and related work.

3 Background

In this section, I provide some institutional detail on the regulatory environment for U.S. banks before then documenting empirical facts related to the banking sector, before and after the Dodd-Frank Act. These observations will be useful for disciplining the quantitative model, as well as providing support for key model assumptions.

Regulations. The Basel Committee on Banking Supervision (BCBS) was established in 1974 with the aim of promoting financial stability worldwide through enhanced bank supervision.[4] This led to the setting of international standards from the first and second Basel Capital Accords (Basel I and II) in 1988 and 2004, respectively. These standards were accepted and implemented in the United States, as well, albeit at different dates and subject some variation from the proposed Basel framework.[5] At that point in time, the primary focus was given to capital requirements. Specifically, banks were required to hold risk-weighted Tier 1 and total capital ratios of 4% and 8%, respectively, as well as a Tier 1 leverage capital ratio of 4%.[6] Further, banks were subject to capital requirements which required a certain fraction of Tier 1 capital to consist of common equity (known as CET1 requirements). After the global banking crisis, the 2010 Basel III introduced significant, new capital standards, as well as liquidity standards. In the same year, these reforms were finalized in the United States via the passage of the Dodd-Frank Act (DFA) although implementation was gradually phased in for various components of the reform.

For capital standards, Basel III introduced new ratio requirements[7] but also introduced two

[4]See Barth and Miller [2018] for a detailed exploration of how the regulatory standards have changed.

[5]For example, the U.S. implementation of Basel I went into effect in 1992 Q4 whereas the implementation of Basel II went into effect in 1998 Q2.

[6]Risk weights penalize assets which are perceived as more risky. In this way, high risk assets increase the necessary capital to meet the set requirement. Alternatively, the leverage ratio applies no weights to bank assets.

[7]It maintained the risk-weighted tier 1 capital ratio and risk-weighted total capital ratio requirements, but also

discretionary measures: the countercyclical capital buffer (CCyB) and the capital surcharge. Both measures are additive to the preexisting total requirement of 8%, as Figure 11, in the Appendix, depicts. The CCyB allows regulators to uniformly increase capital requirements for all banks during periods of high credit growth. Alternatively, the capital surcharge is targeted at individual banks and based upon bank-level characteristics. The overarching aim of these two measures is to address systemic risk concerns. Given that this paper uses a stationary model environment, the key policy focus for capital requirements will be the risk-weighted and leverage measures alone.[8]

For liquidity standards, Basel III introduced two new measures: the net stable funding ratio (NSFR) and the liquidity coverage ratio (LCR). These measures were introduced as a means of increasing the maturity of bank liabilities with the primary concern being the vulnerability of short-term liabilities to rollover risk and/or runs.[9] This paper's notion of liquidity requirement is most similar to the LCR, which I now give focus to.[10][11] The LCR is the ratio of high-quality liquid assets (HQLA) over expected total net cash outflows over 30 calendar days. Informally, the constraint states

$$\frac{\text{HQLA}}{\text{Expected Net Cash Outflows in 30 Days}} \geq 100\%$$

which means banks must be able to meet all expected net cash outflows with highly liquid assets, alone. Similar to capital risk-weights, high-quality liquid assets are defined by various levels of liquidity with the top level comprised of excess reserves and securities issued or guaranteed by the U.S. government. Currently, bank HQLA is primarily composed of excess reserves, treasury securities and Agency MBS (see Ihrig et al. [2017]).

Bank Data. Bank data is primarily obtained from FFIEC forms 041 and 051 (Consolidated Reports of Condition and Income for a Bank) as well as form FR Y-9C (Consolidated Financial Statements for Bank Holding Companies). Each report is quarterly in frequency and provides detailed information about the balance sheet, income statement and off-balance sheet items (such as derivatives contracts).

Figure 1 provides the aggregate portfolio of the U.S. banking sector between 2001 and 2010. Bank assets are categorized as loans, securities, cash or other.[12] Further, bank liabilities are

introduced a new leverage requirement (called the Supplementary Leverage Ratio, SLR) which accounts for on- and off-balance sheet items without risk-weighting.

[8]Future extensions of this work will include aggregate uncertainty and the use of the countercyclical capital buffer.

[9]See Copeland et al. [2014] and Gorton and Metrick [2012] for an in-depth review of run risk in repo markets, a primary source of wholesale funding for banks.

[10]See BCBS [2013] for Basel documentation on the LCR.

[11]For more information on the NSFR, see BCBS [2014].

[12]The securities category primarily consists of mortgage-backed securities, asset-backed securities and fixed-income

categorized as deposits, wholesale funding, equity or other.[13] Wholesale funding is broadly defined as uninsured, short maturity debt which consists primarily of repurchase agreements (repo), federal funds loans and large time deposits (i.e. deposits which exceed the coverage limits of deposit insurance). The main observation taken from the aggregate bank portfolio is that, while the loan-deposit business model is still at the core of commercial banking, banks hold a variety of other assets and liabilities. Accounting for these balance sheet items will be relevant when considering bank default risk and the impact of regulatory requirements.

Assets		Liabilities	
loans	58%	deposits	53%
securities	18%	wholesale	16%
cash	5%	other	21%
other	19%	equity	10%

Figure 1: Average Bank Balance Sheet

A critical feature of the balance sheet is bank reliance on wholesale funding debt. Due to its short maturity, wholesale funding debt is potentially unstable and a source of liquidity risk (i.e. subject to sudden large withdrawals). In fact, reliance on wholesale funding and the subsequent contraction in that market during the financial crisis of 2007-2008 is considered the pivotal event which prompted the liquidity regulation component of Basel III and the Dodd-Frank Act.[14] This *runnable* feature of wholesale funding is in stark contrast to deposits which, despite their short maturity, are a stable source of debt funding for banks. A significant factor is the provision of deposit insurance: due to insurance guarantees, (covered) depositors are not exposed to counterparty risk and therefore do not withdraw funds when observing a deterioration of financial conditions, at the bank or in the broader banking sector. In contrast to deposits, wholesale funding creditors do not receive the same level of insurance coverage as depositors and are therefore exposed to more counterparty risk. This risk exposure can in fact show up in the cost of wholesale debt funding: Figure 12, in the Appendix, plots the annualized interest rate cost of wholesale funds, which are consistently higher than that of deposits.

Given the stability and cost advantage of deposit funding, it seems counter-intuitive that banks hold such large stocks of wholesale funding debt. Empirical and industry evidence support the

government liabilities (such as U.S. treasuries). The other assets includes trading assets, intangible assets, fixed assets, investments in unconsolidated subsidiaries, reverse repos and federal funds sold.

[13] Other liabilities include trading liabilities as well as other longer maturity debt.

[14] See BCBS [2014] and BCBS [2013].

narrative that banks utilize wholesale funding as a quick means for asset-funding, relative to traditional deposits which are often sticky or price inelastic (see Choi and Choi [2020] and Baklanova et al. [2015]). In this sense, banks have a direct preference for debt funding with deposits but rely upon wholesale funding debt in response to certain market frictions.

One of the key modeling assumptions in this paper is the presence of deposit borrowing constraints. These constraints limit the available level of deposit funding and motivate the use of wholesale funding debt. A result of this assumption is that larger banks rely more upon wholesale funding debt, and I find empirical evidence to support this relationship. In particular, I use Call Report data to regress wholesale funding use (in terms of portfolio shares) against size, time fixed effects and a control variable for different bank business lines. The results are listed in Table 10 in the Appendix.[15] The results show that there exists a strong positive relationship between bank size and wholesale funding usage, particularly before the passage of the Dodd-Frank Act. Specifically, for each \$1 billion in total bank assets, the wholesale funding liability share of the bank portfolio increases by 0.19%.

Empirical Dodd-Frank Trends. In the remainder of this section, I briefly document balance sheet trends for the U.S. banking sector, before and after the finalization of the Dodd-Frank Act.[16] These observations will prove helpful in evaluating both the quantitative performance of the model as well as the main mechanisms by which capital and liquidity regulation affect outcomes. Figure 2 plots aggregate bank lending and wholesale funding usage relative to a pre-Dodd-Frank trend. As of 2020, and looking at the average of actual and pre-trend differences, total bank lending has dropped by 8.5% whereas total wholesale funding usage has dropped by 48.1%.[17] While external factors, other than the Dodd-Frank Act, clearly affect these levels, this paper will predict similar drops in response to more stringent bank regulation.

[15] In the regression, *Wholesale Share* units are in basis points. *Size* is total assets (RCON 2170) and in \$ billion. *Income Ratio* is the ratio of non-interest income (RIAD 4079) to interest income (RIAD 4107) in fractional form.

[16] I focus on 2010 as a cutoff year for two main reasons. First, the passage of the bill alone has an effect on bank behavior and, more importantly, the timing of the DFA's implementation was fairly complicated, making it difficult to select one particular cutoff year.

[17] The pre-trend annualized growth rates for loans and wholesale funding were 4.9% and 4.5%, respectively.

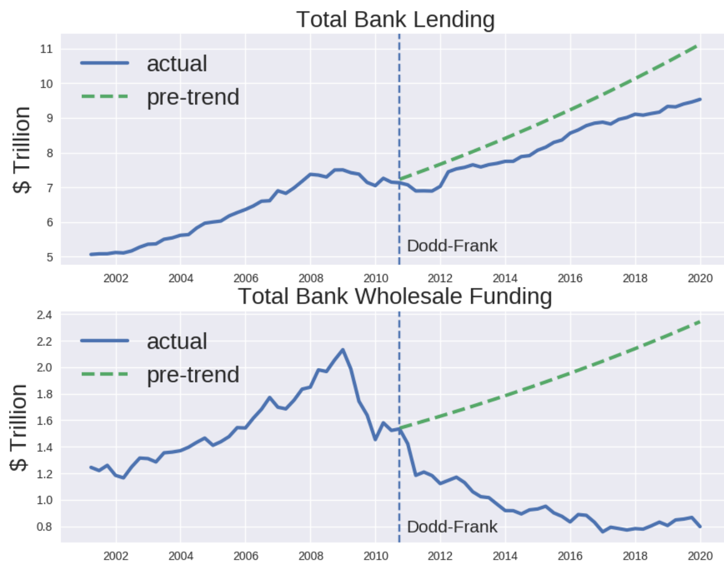

Figure 2: U.S. Banking Aggregates, Pre- and Post-DFA

Figure 14, in the appendix, shows a similar drop of 9.8% for the total balance sheet size of the U.S. commercial banking sector. Lastly, Figures 15 and 16, in the Appendix, plot the portfolio shares of total banking sector assets and liabilities, over time, and since the early 2000s.

Lastly I document some empirical features of bank capital ratios. Figure 13, in the Appendix, plots the pre- and post-Dodd-Frank distribution of capital/equity ratios for the U.S. banking sector. Two important facts related to capital regulation emerge. First, most banks do not have binding capital requirements and instead hold capital ratios in excess of the minimum. Second, while capital requirements seldom bind, they appear to influence capital ratios. For example, banks aware of their capital requirement and the penalties associated with breaking it will hold excess capital as a precautionary move. From Figure 17, in the Appendix, it is also clear that larger banks hold lower risk-weighted equity/capital ratios. Corbae and D'Erasmo [2018] document that larger banks have less volatility in their debt funding, relative to small banks, and for this reason they hold smaller equity buffers. In the calibration section of this paper, I find similar evidence for this feature with respect to deposits, but the presence of wholesale funding debt can be a potentially confounding source for that narrative.

To summarize, while the traditional loan-deposit model is still at the core of U.S. commercial bank activities, banks hold a variety of other financial objects, on the asset and liability side of the balance sheet. In addition to loans, banks hold significant quantities of fixed-income securities as well as cash. Further, apart from deposits, banks rely upon wholesale funding as a source of debt funding. Although it demands higher interest expense and is a source of liquidity risk, wholesale funding usage is motivated by the well-documented existence of various market frictions which prevent the bank from total reliance on deposits. In this paper, I use deposit borrowing constraints to motivate the use of wholesale funding debt. I also document that post-Dodd-Frank bank aggregates (such as lending, wholesale funding and balance sheet size) have all declined, and that capital/equity ratios have increased in a response to the more stringent regulation.

4 Model

There are five principal agents: banks, money market lenders, outside securities investors, government and households. Figure 19, in the Appendix, presents a simple illustration of the model and the way in which agents interact with one another.

Banks. Banks are chartered firms endowed with an intermediation technology. A bank charter includes deposit insurance and a set of regulatory requirements that the bank must satisfy. The intermediation technology affects both the cost of lending and issuing debt. Banks operate with the objective of maximizing the expected, discounted present value of their dividend stream to equity owners. The bank problem takes places in two stages: the Initial Stage and the Settlement Stage. At the beginning of each stage, the bank is subject to a distinct type of default decision, and given the decision to operate, makes portfolio choices which affect its balance sheet. I define *insolvency default* in the Initial Stage as the event in which a bank's net worth is critically low and *liquidity default* in the Settlement Stage as the event in which the bank cannot make contractual payments.

At the beginning of the Initial Stage, banks enter with a fixed index $j \in \{1, 2, ..., J\}$ which determines parameters related to the bank's intermediation technology. This shows up in the deposit borrowing constraint $\bar{d}_j$ the bank enters the period with, where $\bar{d}_j$ follows a j-dependent first-order process with a fixed and stochastic component. Lastly, the bank enters the period with initial net worth n_b which is the return on old assets less the cost of repaying old debt, and this is the initial source of funding or cash-on-hand for the bank. At this point, the bank makes an insolvency default decision, where it can exit with limited liability or continue to operate. Figure 3 shows the timeline of the bank problem during the Initial Stage.

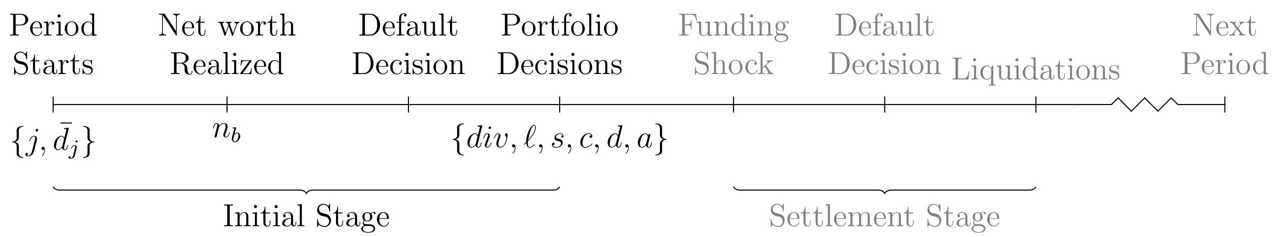

Figure 3: Timeline of Initial Stage

Given the bank chooses to operate in the Initial Stage, it then makes decisions over its portfolio. On the asset side, banks originate loans ℓ and purchase both government securities s and cash c.[18] Loans are the only source of risk on the asset side of the balance sheet, generating interest returns i_ℓ which follows an iid exogenous process. In originating loans, banks pay the principal plus a convex origination cost $\theta_j \frac{\ell^2}{2}$ which is j-dependent. Both securities and cash are risk-free: securities with interest return i_s and cash with no interest return $i_c = 0$. While cash is return-dominated by government securities, it has settlement properties which give the bank incentive to hold positive balances; a point which will be made clear when describing the Settlement Stage of the bank problem.

On the liability side, banks can hold two types of debt: insured deposits d at interest R^d as well as collateralized wholesale funding a at interest R^a. While deposits are treated as risk-free by creditors (due to deposit insurance), wholesale funding debt is uninsured and its interest cost, therefore, reflects the underlying default risk of the bank. Lastly, the bank chooses dividend distributions div to equity owners. Figure 4 illustrates the bank balance sheet.

Assets	Liabilities
loans ℓ	deposits d
securities s	wholesale a
cash c	equity

Figure 4: Bank Balance Sheet

In the Initial Stage, banks face a set of market constraints, regulatory constraints as well as non-negativity constraints on its balance sheet items. Of market constraints, the banks must satisfy a budget constraint

$$div + \ell + \theta_j \frac{\ell^2}{2} + s + c = n_b + a + d \tag{1}$$

[18]Government securities are used as synonymous with *bonds*.

where on the RHS, the bank funds assets and dividends with net worth and debt funding. Wholesale funding debt requires securities as collateral such that the bank must satisfy

$$s \geq (1+h)a \tag{2}$$

where h is a collateral haircut.[19] Given the deposit borrowing constraint $\bar{d}_j$, bank deposit issuance is bounded above such that $d \leq \bar{d}_j$.[20] Lastly, there exists a financial friction for the bank in terms of equity issuance. In particular, I assume banks face a non-negativity constraint on dividends $div \geq 0$ such that bank funding must be financed through retained earnings or debt.

Of regulatory constraints, the bank faces two capital requirements and one liquidity requirement. The first capital requirement is the leverage requirement

$$\frac{\ell + s + c - [a+d]}{\ell + s + c} \geq \phi^{lev} \tag{3}$$

which dictates the the ratio of equity to assets must be at or above the fraction ϕ^{lev}. In addition, the bank must satisfy a risk-weighted capital requirement

$$\frac{\ell + s + c - [a+d]}{\ell} \geq \phi^{cr} \tag{4}$$

which effectively penalizes the bank for holding risky loans, relative to its equity base. Lastly, the liquidity requirement sets a lower bound on the ratio of liquid assets to wholesale debt funding

$$\frac{c + (1-h^s)s}{a} \geq \phi^{lr} \tag{5}$$

where h^s is a regulatory haircut which penalizes the holding of securities as liquidity relative to cash.

At the beginning of the Settlement Stage, banks receive a wholesale funding shock $\delta' \in [0,1]$ where the fraction δ' of wholesale debt is withdrawn.[21] At this point, the bank makes its liquidity default decision. If the bank chooses to operate, it determines how to settle the funding withdrawal, with either cash or security liquidations.[22] Figure 5 shows the timeline of the bank problem during

[19]While wholesale funding is not insured like deposits, lenders are first in line to receive collateral in the event of default.

[20]This constraint affects the bank's cost of debt funding in the sense that for debt levels in excess of $\bar{d}_j$, the bank must rely upon wholesale funding which requires collateral and a different interest return.

[21]δ' is an iid exogenous process with transition Π_δ.

[22]It is assumed that loans are too illiquid such that the bank must rely solely upon cash and securities in the Settlement Stage.

the Settlement Stage.

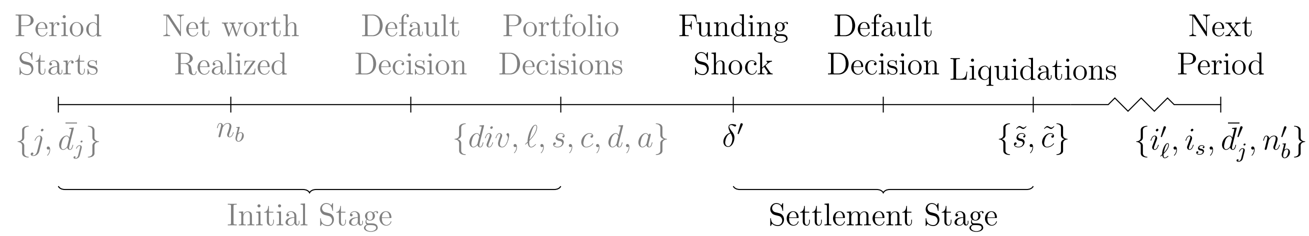

Figure 5: Timeline of Settlement Stage

The bank can settle the funding withdrawal with cash $\tilde{c} \leq c$ or security liquidations $\tilde{s} \leq s$ at the price p^*, where the Settlement Stage decisions $(\tilde{c}, \tilde{s})$ are constrained by portfolio decisions from the Initial Stage. The bank must satisfy the funding constraint

$$\delta' a = p^* \tilde{s} + \tilde{c} \tag{6}$$

where the bank is forced into liquidity default if its total available liquidity (i.e. $p^* s + c$) is insufficient to cover the wholesale funding withdrawal. Given these settlement decisions, the bank enters the following period subject to a law of motion on bank net worth

$$\begin{aligned} n'_b =& \text{Return on Assets} - \text{Cost of Debt} - \text{Corporate Income Tax} \\ =& (1 + i'_\ell)\ell + (1 + i_s)[s - \tilde{s}] + [c - \tilde{c}] - R^d d - R^a(1 - \delta')a - \bar{\tau}(\text{earnings}) \end{aligned} \tag{7}$$

where $\bar{\tau}(\text{earnings}) = \tau \max\{0, \text{earnings}\}$ is a one-sided tax function on earnings, at the rate $\tau \in \mathbb{R}$, where earnings are defined as $i'_\ell \ell + i_s(s - \tilde{s}) - r^d d - r^a(1 - \delta')a$.[23] Thus, the bank is tax-exempt during a period in which it experiences negative earnings.

Initial Stage Dynamic Program. In the Initial Stage, a bank's state is determined by its networth n_b as well as intermediation type j and deposit borrowing constraint $\bar{d}_j$. I define bank

[23] This is standard within the corporate finance literature. See Hennessy and Whited [2007] and De Nicoló et al. [2014].

portfolio choices with the vector $\mathbf{y} = \big(div, \ell, s, c, d, a\big)$ such that the bank solves

$$V^b(n_b; j,\bar{d}_j) = \underset{\mathbf{y}}{max} \quad div + E_{\delta'}\Bigg[\underbrace{max\{0, \overbrace{\tilde{V}^b(\mathbf{y}; j, \bar{d}_j, \delta')}^{\text{Value if operate}}\}}_{\text{liquidity default}}\Bigg] \tag{8}$$

$$\begin{aligned} s.t. \quad & \text{market constraints} \\ & \text{regulatory constraints} \\ & \text{non-negativity constraints} \end{aligned}$$

where $\tilde{V}^b$ represents the bank dynamic program in the Settlement Stage and the max operator captures the limited liability default decision the bank makes in the Settlement Stage.

Settlement Stage Dynamic Program. In the Settlement Stage, a bank's state is determined by the portfolio decisions $\mathbf{y}$ from the Initial Stage, its intermediation type j, deposit borrowing constraint $\bar{d}_j$ and the wholesale funding shock δ'. Given no liquidity default, the bank chooses cash settlement and security liquidations to solve

$$\tilde{V}^b(\mathbf{y}; j, \bar{d}_j, \delta') = \underset{\tilde{s},\tilde{c}}{max} \quad \boldsymbol{\gamma}\beta E_{i'_\ell,\bar{d}'_j}\Bigg[\underbrace{max\{0, \overbrace{V^b(n'_b; j, \bar{d}'_j)}^{\text{Value if operate}}\}}_{\text{insolvency default}}\Bigg] \tag{9}$$

$$\begin{aligned} s.t. \quad & \delta' a = p^* \tilde{s} + \tilde{c} \\ s.t. \quad & \tilde{c} \in [0, c] \quad \text{and} \quad \tilde{s} \in [0, s] \\ s.t. \quad & n'_b \text{ law of motion} \end{aligned}$$

where the bank discounts the future at the rate $\gamma\beta \leq \beta$ where β is the household discount factor. The bank's impatience, represented by γ, is important in determining how the bank assesses the cost of default (i.e. foregone dividends) and therefore chooses adequate levels of both equity and liquidity on its balance sheet.[24]

Money Market Lenders. There exists a unit mass of money market lenders which cannot issue debt and solely invest in collateralized wholesale funding to the banking sector. Lenders' objective is to maximize the expected, discounted present value of their dividend stream to equity owners, and they discount the future at a rate β with linear preferences. Each period they choose dividends

[24] This discounting assumption is similar to Acharya and Thakor [2016] and Corbae and D'Erasmo [2018]. See Rajan [1994], Stein [1988] and Minnick and Rosenthal [2014] that provide foundations for such behavior of financial intermediaries.

div_m and wholesale lending a_m. Wholesale loans are collateralized by bank securities with a haircut h. Money market lenders lend to a (share-weighted) mutual fund of banks such that they do not account for individual bank counterparty risk. Figure 6 gives a simplified illustration of the payoff structure for a bank-level wholesale loan.

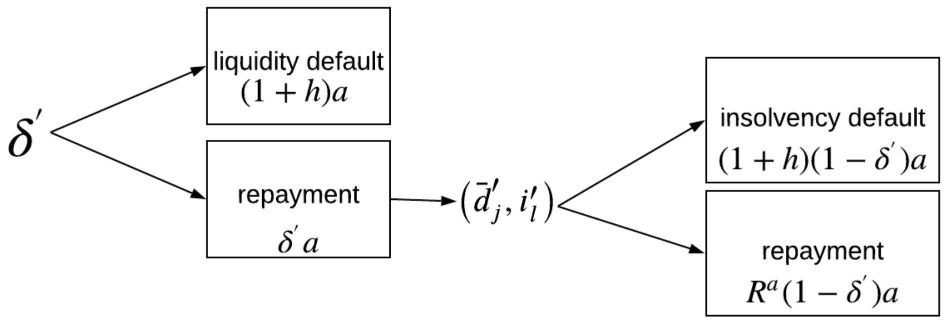

Figure 6: Sequence of Events for Bank-Level Wholesale Loan

Some fraction δ' of the loan is withdrawn early during the Settlement Stage. The bank either experiences a liquidity default (in which case the money market lenders seize the collateral) or meets the withdrawal. At the beginning of the next period, the bank then realizes a new deposit capacity constraint and return on its loans. The bank either enters insolvency default (in which case the money market lenders seize the remaining collateral) or its repays, at the contracted rate R^a. Refer to Appendix A.3 for a more explicit statement of the money market lenders problem.

Outside Securities Investors. When banks liquidate securities in the Settlement Stage, they do so on a secondary spot market populated by outside investors who have limited demand for the securities at the price p^*. This market is represented by the inverse demand function

$$p^*(s) = \alpha(\omega^s + s)^{\alpha-1} \tag{10}$$

where ω^s represents an endowment for outside investors and $\alpha \in (0,1)$ affects demand elasticity.[25]

Government and Deposit Insurance. The government receives fiscal revenues from the corporate income tax τ set on bank earnings, as well as the lump sum transfer T for households. In terms of expenses, the government must services its debt as well as fund deposit insurance. Each period, the government operates a balanced budget through setting the lump sum transfer T. When banks enter default, the government seizes control of its assets (net of collateral claims

[25]Refer to Appendix A.3 for a simple representation of the security investor's problem which would generate such a demand function.

from the money market) and liquidates them with a fraction $(1-\xi)$ lost in the process. In this sense, bankruptcy imposes a real cost on the economy which banks do not internalize. With the remaining assets, the government first repays wholesale debt and then deposits. Any residual debt obligations for deposits are financed through the deposit insurance fund. Refer to the Appendix for a more explicit statement on the aggregate cost of deposit insurance. In practice, coverage limits exist for deposit insurance such that a significant stock of bank deposits are uninsured. Within the model, I make a simplification by assuming that all household deposits are insured.

Entry and Exit. Each period banks make insolvency and liquidity default decisions. It is assumed that when a bank exits, it is replaced by an identical bank in terms of its Initial Stage state from the previous period $(n_b, j, \bar{d}_j)$ where n_b represents an initial equity injection, raised from households.

Households. There exists a unit mass of households. Households do not face aggregate or idiosyncratic risk. Each period, households enter with networth n_h and choose consumption c_h, deposits d_h and equity shares (e_b, e_m) in both the banking and money market sector. Deposits are their sole form of saving. Further, equity ownership comes at a price (p_b, p_m) and pays period dividends (Div_b, Div_m). Households solve

$$\begin{aligned} V^h(n_h) = & \max_{c_h, d_h, \{e_i\}} \quad u(c_h) + \beta V^h(n'_h) \\ & s.t. \quad c_h + d_h + \sum_{i\in\{b,m\}} e_i p_i = n_h \\ & s.t. \quad n'_h = (1+r^d)d_h + \sum_{i\in\{b,m\}} e_i(p_i + Div_i) + T + \omega \end{aligned} \tag{11}$$

where ω is the household endowment and T the lump sum government transfer.

5 Equilibrium and Characterization

In this section, I present the formal definition of the equilibrium concept along with a characterization of equilibrium outcomes of the model, at the bank-level. In addition, I review qualitative outcomes within the bank problem as well in the aggregate which occur in equilibrium and under reasonable parameterizations of the model. This is meant for instructive purposes to illustrate some of the key mechanisms of the model.

Definition. Given the idiosyncratic exogenous processes $\left\{i_l, \delta, \{\bar{d}_j\}_{j=1}^J\right\}$, a stationary recursive competitive equilibrium is defined as a set of prices $\{R^d, R^a, p_b, p_m, p^*\}$, initial stage bank policy functions $\mathbf{g_b}(n_b, j, \bar{d}_j) = \{\ell(n_b, j, \bar{d}_j), s(n_b, j, \bar{d}_j), c(n_b, j, \bar{d}_j), d(n_b, j, \bar{d}_j), a(n_b, j, \bar{d}_j), div(n_b, j, \bar{d}_j)\}$, settlement stage bank policy functions $\tilde{\mathbf{g_b}}(\mathbf{y}, \delta', j, \bar{d}_j) = \{\tilde{c}(\mathbf{y}, \delta', j, \bar{d}_j), \tilde{s}(\mathbf{y}, \delta', j, \bar{d}_j)\}$, household policy functions $\mathbf{g_h}(n_h) = \{c_h(n_h), d_h(n_h), e_b(n_h), e_m(n_h)\}$, aggregate wholesale lending a_m, aggregate security liquidations s_o and marginal bank distributions $\{\lambda^j(n_b, \bar{d}_j)\}_{j=1}^{J}$ such that

1. $V^h(n_h)$ and $\mathbf{g_h}(n_h)$ solve the household problem,
2. $V^b(n_b, j, \bar{d}_j)$, $\tilde{V}^b(\mathbf{y}, \delta', j, \bar{d}_j)$, $\mathbf{g_b}(n_b, j, \bar{d}_j)$ and $\tilde{\mathbf{g_b}}(\mathbf{y}, \delta', j, \bar{d}_j)$ solve the bank problem,
3. Money market lenders solve their problem
4. Outside securities investors solve their problem
5. The marginal distribution of banks follows law of motion

$$\lambda^j = \Gamma^j(\lambda^j) \qquad \forall j = 1, 2, ..., J$$

   for transition function Γ^j and is consistent with firm/household maximization

6. Market clearing

   (a) $e_b = e_m = 1$ (Equity Shares)

   (b) $\int_{N_b} \sum_j \sum_{\bar{d}_j} d(n_b, j, \bar{d}_j) d\lambda^j(n_b, \bar{d}_j) = d_h(n_h)$ (Deposits)

   (c) $\int_{N_b} \sum_j \sum_{\bar{d}_j} a(n_b, j, \bar{d}_j) d\lambda^j(n_b, \bar{d}_j) = a_m$ (Wholesale Funds)

   (d) $\int_{N_b} \sum_j \sum_{\bar{d}_j} \left[\sum_{\delta'} \pi_{\delta'} \tilde{s}(\mathbf{y}, \delta', j, \bar{d}_j)\right] d\lambda^j(n_b, \bar{d}_j) = s_o$ (Secondary Securities)

Characterizing Equilibrium. In equilibrium, banks have incentives to hold an interior portfolio for both loans and securities due to the risk-return tradeoff between the two assets and concavity in the value function, which arises from the convex cost of loan origination. Unlike loans and securities, cash does not generate interest income and thus is return-dominated by the other two assets. Nonetheless, banks have precautionary reasons to hold positive cash balances due to the settlement properties of cash in the Settlement Stage. This leads to the following proposition.

Proposition 1. *Given that $R^a(1-p_s^*)+i_s > 0$, banks will liquidate available cash in the balancing period, relative to securities; that is,*

$$\begin{aligned}\tilde{c} =& min\{c, \delta' a\} \\ \tilde{s} =& max\{\delta' a - \tilde{c}, 0\}\end{aligned} \tag{12}$$

In an environment when banks are not subject to early withdrawals of wholesale funding, it would optimal to hold no cash balances. Alternatively, when early withdrawals of wholesale funding exist and security liquidations are costly (proxied by the Settlement Stage rate of return $\frac{i_s}{p^*}$), cash provides value as a means of settlement.

On the liability side, banks also have cause to hold positive balances of both insured deposits and wholesale funding debt. In particular, a pecking order for debt preference emerges by which banks rely solely upon deposit funding until they hit their period deposit constraint $\bar{d}_j$. Figure 7 illustrates bank debt policy functions.

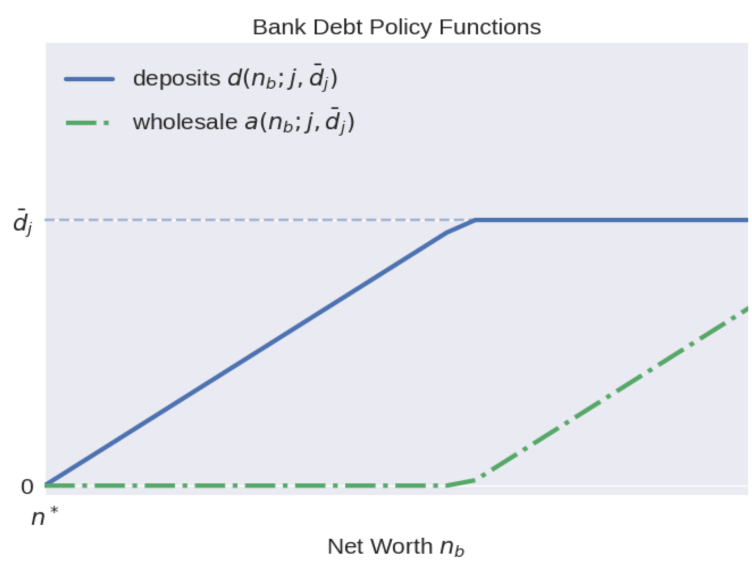

Figure 7

There are three key features which make deposits more attractive than wholesale funding. First, wholesale funds are collateralized; thus, each unit of wholesale debt requires additional securities which must be raised as collateral against it. Second, wholesale funding is subject to funding shocks in the Settlement Stage which drives liquidity default risk in the model. Third, wholesale funds are uninsured; thus, money market lenders account for bank default risk and this is reflected in its price R^a. Conversely, deposits are unsecured, stable and treated as risk-free.[26]

Given the linearity of the money market lenders problem, they are the marginal investor for wholesale funds and determine the price of wholesale debt in the competitive equilibrium.

Proposition 2. *In the competitive equilibrium, money market lenders price wholesale debt according to*

$$R^a = \frac{\frac{1}{\beta} - (1+h)\tilde{Def}^{liq} - E[(1-\tilde{Def}^{liq})\delta'] - (1+h)E[(1-\tilde{Def}^{liq})(1-\delta')\tilde{Def}^{In}]}{E[(1-\tilde{Def}^{liq})(1-\delta')(1-\tilde{Def}^{In})]} \tag{13}$$

where $\tilde{Def}^{liq}$ *and* $\tilde{Def}^{In}$ *are liquidity and insolvency bank default rates, weighted by the market share of each bank type and the joint distribution* $\lambda^j(n_b, \bar{d}_j)$*.*

Notice that if banks were not subject to early withdrawal shocks and never defaulted (liquidity or insolvency), then equation 13 would reduce to the inverse of the household discount factor.

Lastly, I review some of the key mechanisms of capital and liquidity requirements in affecting default outcomes in equilibrium.[27] Both capital and liquidity requirements target particular balance sheet objects and, to some extent, mechanically reduce the corresponding default risk. First, capital requirements target bank equity ratios as a means of reducing insolvency default risk. Given a default threshold n^*, insolvency default is defined as the event in which $n_b \leq n^*$, and the probability of insolvency default can be expressed

$$\begin{aligned} prob(n_b \leq n^*) =& prob(R^A A \leq R^D D + n^*) \\ =& prob(R^A \leq R^D(1-e) + \frac{n^*}{A}) \end{aligned}$$

where $R^A A$ is the return on assets, $R^D D$ is the cost of debt and e is the bank equity ratio $e = \frac{A-D}{A}$. Thus, higher equity ratios reduce insolvency default and capital requirements act as a lower bound

[26] In practice, deposits are not insured past certain coverage limits and this can affect the pricing and withdrawal behavior of bank deposits. While I attempt to properly account for these differences in the data counterparts of the model, the model itself abstracts from those differences for tractability reasons.

[27] While I do not present analytic results, these qualitative features occur in equilibrium, under any reasonable parameterization of the model.

on equity ratios. In this way, capital requirements target and reduce insolvency default risk. In a similar fashion, liquidity requirements target bank liquidity ratios as a means of reducing liquidity default risk. Given liquidity default is defined as the event in which $c + p^*s < \delta' a$, the probability of liquidity default can be expressed as

$$prob(c + p^*s < \delta' a) = prob(\delta' > \frac{c + p^*s}{a})$$

where $\frac{c+p^*s}{a}$ is similar to the bank liquidity ratio $\frac{c+(1-h^s)s}{a}$. Thus, higher liquidity ratios reduce liquidity default and liquidity requirements act as a lower bound on liquidity ratios. In this way, both capital and liquidity requirements reduce their corresponding default risks in a relatively mechanical fashion.[28]

What is less clear or nuanced is the interaction between these two policies. One of the key qualitative results (which shows up quantitatively in the calibrated model) is that (1) capital requirements improve bank liquidity while (2) liquidity requirements lead to a deterioration of bank equity. Stated differently, capital requirements effectively lead to a reduction in both insolvency and liquidity default risk, while liquidity requirements actually lead to an increase in bank insolvency risk.

In the case of capital requirements, more stringent regulation reduces bank profitability and leads to a reduction in balance sheet size. With a reduction in balance sheet size, significant substitution out of wholesale funding and into deposits occurs on the liability side (due to the aforementioned debt funding preference for deposits). This occurs while the balances of liquid assets remain relatively constant on the asset side. The net effect is an improvement in bank liquidity ratios and a reduction in liquidity default risk. In the case of liquidity requirements, again, more stringent regulation leads to a reduction in balance sheet size. Significant substitution into loans occurs on the asset side because the bank operates a DRS loan technology, and the drop in balance sheet size creates a higher marginal benefit for loan origination. At the same time, the level of equity remains relatively constant on the liability side. The net effect is a drop in risk-weighted equity ratios, higher asset risk and higher insolvency default risk. Thus, while liquidity requirements do reduce liquidity default risk, it comes at the cost of higher insolvency default. The main implication of this relationship is that capital requirements effectively reduce both types of default risk.

[28] The above example corresponds to a particular point in the bank state space. Given bank heterogeneity, there exists a cross-section of banks and changes in regulatory policy can affect the stationary distribution over net worth.

6 Calibration

Model calibration occurs in two stages: an external calibration, where a subset of parameters are chosen or estimated outside the model, and an internal calibration, where a subset of parameters are chosen to match a set of moments in the data. The majority of bank data comes from the U.S. Reports of Condition and Income (Call Reports) which contain micro-level bank data with granular information on bank balance sheets and income statements.[29] The dataset I use is quarterly in frequency and ranges from 2000 to 2020.

External Calibration. The bank intermediation technology, which consists of loan origination and the deposit borrowing constraint, is estimated externally using Call Report data. I chose $J = 3$ bank types which correspond to size thresholds in the data (measured by total assets). In particular, I choose $j = \{1, 2, 3\}$ to correspond to banks with total assets in the range of $\{1-10, 10-50, > 50\}$ billion USD which have corresponding probability masses $\{p_1, p_2, p_j\} = \{0.85, 0.1, 0.05\}$.[30] For the loan origination technology, banks have a convex cost $\theta_j \frac{\ell^2}{2}$ in issuing loans. For each bank group j, I create a subset panel consisting of only banks of that size type. I then construct a data analogue to the model origination cost, filter the data, estimate an empirical cost function and lastly infer an estimated $\hat{\theta}_j$ through equating both model and empirical marginal cost functions. To begin, I define *net non-interest expenditures* as the data analogue to a bank's loan origination cost.[31] In the process of filtering, I drop all observations which have negative observations for total lending, labor expense, fixed input expense and borrowings. For each bank group j, I estimate

$$Cost_{it}^j = \beta_0^j + \alpha_t^j + \beta_1^j \ell_{it}^q + \beta_2^j {\ell_{it}^j}^2 + \underbrace{\sum_k \beta_k^j \ell_{it}^j x_{k,(i,t)}^j}_{\text{interactions}} + \sum_j \beta_j^j x_{j,(i,t)}^j \tag{14}$$

which accounts for time fixed effects, total lending and a set of control covariates $\{x_k\}_k$ to capture the relationship with other inputs and outputs of the bank.[32] In the model, a bank of type θ_j has

[29] In particular, I mostly rely upon FFIEC forms 041 and 051.

[30] These size thresholds are relevant from a regulatory standpoint but also in terms of balance sheet composition, when looking at the cross-section of banks.

[31] Net non-interest expense is defined as Total Non-Interest Expense (RIAD 4093) less Net Servicing Fees (RIAD B492) less Net Gains on Other Assets (RIAD B496) less Net Gains from Real Estate (RIAD 5415) less Net Gains from Loans and Leases (RIAD 5416).

[32] Specifically, total loans are RCON 2122 and the set of control covariates are Salaries and Benefits (RIAD 4135) as a labor input, Fixed Asset Expenses (RIAD 4217) as a land/capital input, Total Interest Expense (RIAD 4073) as a borrowing/debt input, and Held-to-Maturity and Available-for-Sale Securities (RCON 1754 + RCON 1773).

a marginal cost of lending $\theta_j \ell$. The empirical analogue of this marginal cost is

$$MC^j\big(\ell, \mathbf{x}\big) = \hat{\beta}_1^j + \big[2\hat{\beta}_2^j + \sum_k \hat{\beta}_k x_k\big]\ell \tag{15}$$

which is a function of bank lending, as well as other input/output control variables.[33] For the latter group of control variables, I use group averages $\bar{\mathbf{x}}^{\mathbf{j}}$ to infer the bank productivity parameters as

$$\hat{\theta}_j = 2\hat{\beta}_2{}^j + \sum_k \hat{\beta}_k{}^j \bar{x}_k^j \quad \forall j = 1, 2, 3 \tag{16}$$

Table 1 presents the estimates for bank θ's. As can be seen, banks in the largest size group (Group 3) have a lower estimated marginal cost parameter which gives them the ability to operate a larger loan portfolio, at lower cost.

TABLE 1
LOAN COST FUNCTION ESTIMATES

Bank Group	**1**	**2**	**3**
Probability Mass	0.85	0.1	0.05
$\boldsymbol{\hat{\theta}_j}$	0.033	0.024	0.021

The other component of the bank intermediation technology is the deposit borrowing constraint process $\bar{d}_j$. In particular, I specify this as an AR(1) process with fixed intercept $\bar{\mu}_{d,j}$; that is,

$$\bar{d}_j' = \bar{\mu}_{d,j} + \rho_j \bar{d}_j + \epsilon_j'$$

where ϵ_j is a mean-zero, normally distributed random variable with variance $\sigma^2_{\epsilon,j}$. Thus, for each bank type j, its deposit constraint technology is defined by the parameters $\{\bar{\mu}_{d,j}, \rho_j, \sigma^2_{\epsilon,j}\}$ such that it has both a fixed component as well as a stochastic component. I internally calibrate the fixed component $\bar{\mu}_{d,j}$ of the process but estimate the persistence and volatility parameters using Call Report data on bank deposits. For the AR(1) estimation, for each bank group j, I first deflate the time series, then for each bank in the panel I (i) normalize deposits with the time series average and (ii) de-trend with an HP-filter before estimating the AR(1) process, at the bank-level. At the

[33] I can generalize the model cost function to include a linear component in lending, but find no quantitative difference in model outcomes under the current estimation.

bank group j-level, I compute averages for both the persistence parameter $\hat{\rho}_j$ and the volatility parameter $\sigma^2_{\epsilon,j}$. Table 2 provides estimates

TABLE 2
DEPOSIT CONSTRAINT PROCESS ESTIMATES

Bank Group	$\boldsymbol{\hat{\rho}_j}$	$\boldsymbol{\hat{\sigma}_{\epsilon,j}}$	$\boldsymbol{\hat{\sigma}_{d,j}}$
1	0.62	0.18	0.23
2	0.67	0.15	0.21
3	0.60	0.09	0.11

where the unconditional volatility of deposit constraints is expressed as $\hat{\sigma}_{d,j} = \frac{\hat{\sigma}_{\epsilon,j}}{(1-\hat{\rho}_j^2)^{\frac{1}{2}}}$. These estimated are then discretized using the Tauchen method. As can be seen in Table 2, estimated deposit funding volatility is lower for larger banks (i.e. banks in group $j = 3$) suggesting some advantage in maintaining more stable funding and gives them incentive to run lower equity ratios.

Bank loan returns are assumed iid and normally distributed random variables with mean μ and volatility σ. I externally set μ using average loan returns of 4% (annualized) while loan return volatility σ is determined within the internal calibration. The last exogenous process in the model is the wholesale funding shock process $\{\delta'\}$. For this, I utilize inflow/outflow data from the Call Reports, given my data definition for wholesale funding.[34] Specifically, I assume that δ' follows a finite discrete process with values and probabilities $\left\{ \left(\delta_1, \delta_2, ..., \delta_N\right), \left(p^\delta_1, p^\delta_2, ..., p^\delta_N\right) \right\}$. Given the data analogue for wholesale funding $a_{i,t}$, I compute wholesale funding runoff rates $r_{it} = \frac{a_{i,t-1} - a_{i,t}}{a_{i,t-1}}$ for each bank and time period. For each time period, I generate the cross-section distribution of run-off rates and choose $N - 1$ percentiles $\{\bar{p}_1, \bar{p}_2, ..., \bar{p}_{N-1}\}$ which map to run-off rate values $\{\bar{r}_1, \bar{r}_2, ..., \bar{r}_{N-1}\}$. Then for $i = 1, ..., N$, I compute probabilities and funding shocks as

- if $i = 1$, then $\begin{cases} \delta_1 = \frac{\bar{r}_{min} + \bar{r}_1}{2} \\ p^\delta_1 = \bar{p}_1 \end{cases}$

- if $i = 2, ..., N-1$, then $\begin{cases} \delta_i = \frac{\bar{r}_{i-1} + \bar{r}_i}{2} \\ p^\delta_i = \bar{p}_i - \bar{p}_{i-1} \end{cases}$

[34] Wholesale funding includes repurchase agreements, federal funds, large time deposits with less than 1 year maturity, trading liabilities, and other borrowed money with less than 1 year maturity.

- if $i = N$, then $$\begin{cases} \delta_N = \frac{\bar{r}_N + \bar{r}_{max}}{2} \\ p_N^\delta = 1 - \bar{p}_N \end{cases}$$

Table 3 provides estimates.[35] As can be seen, 90% of quarterly wholesale funding run-off occurs for funding withdrawals of less than 10%. In this sense, large withdrawals of wholesale present a small tail risk to banks, when looking in the cross-section.

TABLE 3
FUNDING SHOCK PROCESS ESTIMATES

$\boldsymbol{p_i^\delta}$	0.5	0.4	0.06	0.02	0.01	0.004	0.002	0.0035	0.0005
$\boldsymbol{\delta_i}$	0	0.1	0.25	0.37	0.51	0.635	0.765	0.92	1

The remaining key external parameters of the model are presented in Table 4. I set the household discount factor $\beta = 0.99$ to target the average interest expense of insured deposits. The cost of default ξ is set using data estimates from the FDIC related to the liquidation expense and cost of maintaining the deposit insurance fund. Using BEA estimates for Personal Income, I set the household endowment to target the share of income which is not related to return on assets and equity such that the endowment properly accounts for other income sources, such as labor compensation.[36] The three key regulatory requirements $\{\phi^{lev}, \phi^{cr}, \phi^{lr}\}$ are set to their pre Dodd-Frank levels. In particular, as the introduction of liquidity requirements was new, the liquidity requirement fraction ϕ^{lr} is set to 0. I set a corporate income tax rate of $\tau = 0.32$ using tax and earnings data from Call Reports. In the model, wholesale funding is collateralized debt whereas my data definition includes other types of unsecured borrowing (such as federal funds and commercial paper). To properly reflect the level of collateral held against wholesale funding and the composition of wholesale funding, I set a collateral haircut of $h = -0.7$ such that for each unit of borrowing, a bank must post collateral at 30% of its value.[37] In a similar fashion, for computing the liquidity ratio, certain assets (known as Level 2) receive a penalty haircut of 15% to reflect lower liquidity. To reflect the actual composition of securities used as liquid assets in the data,

[35] While banks experience negative run-off (i.e. increases in wholesale funding) I abstract from this to avoid model complication. Therefore, I truncate run-off values below 0.

[36] Specifically, in 2010, 13.2% of pre-tax disposable income could be attributed to interest and dividend income.

[37] I treat repurchase agreements as the only source of collateralized borrowing with a haircut of 5% and the remainder as unsecured, requiring no collateral. Given that repurchase agreements make up 29% of the composition of wholesale funding pre -odd-Frank, I determine the haircut to be (1+h)= 1.05*0.29=0.3.

I use estimates from Ihrig et al. [2017] which provides quarterly estimates of high quality liquid assets (HQLA) for banks. I set the regulatory haircut $h^s = 0.083$ to reflect the composition of assets.[38]

TABLE 4
External Calibration

Parameter	Label	Value	Source/Target
β	HH Discount Factor	0.99	$R^d = 1.01$
ξ	Default Recovery	0.65	FDIC
ϕ^{lev}	Leverage Requirement	0.04	Pre-DFA
ϕ^{cr}	Capital Requirement	0.04	Pre-DFA
ϕ^{lr}	Liquidity Requirement	0	Pre-DFA
μ	Mean Loan Return	1.04	Call Reports
τ	Corporate Tax Rate	0.32	Call Reports
h	Collateral Haircut	-0.79	Call Reports
h^s	Liquidity Haircut	0.083	Ihrig et al. [2017]

In addition, I make a normalizing assumption for the outside securities investors endowment ω^s, such that the equilibrium price of liquidated securities p^* is equal to 1, in the event of no liquidations.

Internal Calibration. This leaves a remaining set of internally calibrated parameters $\{\sigma, i_s, \alpha, \gamma, \bar{\mu}_{d,1}, \bar{\mu}_{d,2}, \bar{\mu}_{d,3}\}$ for loan return volatility, risk-free securities rate, firesale liquidation parameter, bank discount factor and the fixed components of each type-j bank's deposit borrowing constraint process, respectively. The parameter estimates and corresponding moments are listed in Table 5. A key parameter in the bank problem is γ such that the bank discounts the future at the rate $\gamma\beta$. As the bank becomes more impatient, it values short run payoffs which places greater emphasize on dividend distributions and a high return on equity. Both liquidity buffers and equity buffers reduce the return on bank equity, such that lower patience translates to banks selecting lower equity ratios and liquidity ratios which increases the bank's risk of default. Thus, I target

[38] Level 1 Assets (such as US Treasuries) do not require a haircut whereas Level 2 Assets (such as GSE MBS) do require the 15% haircut. Focusing on *Standard Bank* (i.e. banks with assets in excess of $250 billion) I find that in 2010, banks held 12% HQLA as a percentage of total assets. Of that stock, GSE MBS was 5%, Treasuries 3%, Reserves 3% and GNMA 1%. Thus the fraction of Level 2 securities was $\frac{5}{9}$.

the banking sector default rate in selecting γ. Given $\gamma = 0.961$, the effective bank discount factor is $\gamma\beta = 0.951$. Further, I target risk-weighted equity ratios using the volatility of loan returns which is the only source of risk in the bank's asset portfolio. Thus, bank loan returns have an annualized average return of 4% with corresponding volatility of 4%, as well.

TABLE 5
INTERNAL CALIBRATION

Parameter	Value	Label	Target	Model (%)	Data (%)
γ	0.961	Bank Discount	Default Rate	0.79	1.04
$i_s - r^d$	0.56	Risk-free Spread	Loan-Security ratio	3.7	3.4
$\tilde{\alpha}$	-0.02	Firesale Elasticity	Deposit-Wholesale Ratio	3.4	3.2
σ	0.04	Volatility Loan Return	Risk-weighted Eq Ratio	5.2	9.6
$\bar{\mu}_{d,1}$	0.012	Capacity Constraint	Deposit Share	71.7	73.3
$\bar{\mu}_{d,2}$	0.034	Capacity Constraint	Deposit Share	84.3	58.2
$\bar{\mu}_{d,3}$	0.011	Capacity Constraint	Deposit Share	44.8	45.3

I use the risk-free interest rate i_s and deposit constraint fixed components $\{\bar{\mu}_{d,j}\}_j$ to help target portfolio shares in the bank problem. Thus, the annualized risk-free spread for bank is 0.56% and the deposit shares reasonably target their corresponding data moments. Lastly, I target the deposit-to-wholesale ratio with the outside security investors firesale parameter α from the demand equation (10). This determines the elasticity of demand for liquidated securities and the equilibrium price p^* such that security investors become more elastic as α tends towards zero . In the table I report the value $\tilde{\alpha}$ which is the price elasticity of liquidated securities in equilibrium, as this is a more meaningful statistic for interpretation. Thus, a value of -0.02 implies a 2% price elasticity.

In addition, Tables 6 and 7 plot other, non-targeted model moments as well as a correlation matrix for observations in the stationary cross-section of banks. As can be seen in Table 6, the model does quite well in matching key features with respect to bank size correlations. In particular, it capture the negative correlation between bank size and risk-weighted equity/capital ratios, as well as the positive relationship between size and liquidity.[39] The pre Dodd-Frank liquidity ratio

[39] Because there were not explicit liquidity measures pre-Dodd-Frank, I used the empirical methodology from Hong et al. [2014] to develop a proxy liquidity ratio measure.

value of 53.1 was taken from Hong et al. [2014]. Given a liquidity ratio of 73.3% banks are still exposed to liquidity default in the event of wholesale funding shocks δ' in excess of 0.733, which do occur under the current calibration.

TABLE 6
Other Model and Data Moments

Label	**Model (%)**	**Data (%)**
Corr(Size,RWE)	-0.29	-0.22
Corr(Size,Liq)	0.21	0.21
Liquidity Ratio	73.3	53.1
Return on Equity	7.2	11.0
Leverage Ratio	5.2	7.3

As for the cross-section correlation matrix, the relationship between bank profitability and insolvency default risk is well-illustrated. In particular, there is a negative correlation between bank return on equity and insolvency default. As banks increase their debt funding, they simultaneously increase the likelihood of insolvency default (due to smaller equity buffers) while increasing the return on equity in non-default states (due to the impact of leverage on asset returns). The key benefit to banks for increasing their debt funding is that limited liability default creates an asymmetric payoff to banks. A couple other key features in the correlation matrix also warrant further empirical investigation. In particular, there exists a -0.26 correlation between bank size and insolvency default risk and a 0.27 correlation between bank size and liquidity default risk, suggesting that large banks are more prone to liquidity default while small banks are more prone to insolvency default.

TABLE 7
Bank Cross-Section Correlation matrix

	Size	RWE	Lev	Liq	Ins Def	Liq Def	ROE
Size	1	–	–	–	–	–	–
RWE	**-0.29**	1	–	–	–	–	–
Lev	0.21	-0.09	1	–	–	–	–
Liq	**0.21**	-0.05	-0.05	1	–	–	–
Ins Def	**-0.26**	-0.08	-0.15	-0.08	1	–	–
Liq Def	**0.27**	-0.07	0.01	-0.06	**-0.12**	1	–
ROE	-0.01	**-0.57**	-0.19	-0.03	**0.69**	**-0.21**	1

7 Quantitative Analysis

In this section, I apply the calibrated model to evaluate the impact of the Dodd-Frank Act regulations and the policy interaction between both capital and liquidity requirement. I further solve for the jointly optimal policy and also consider the impact of unanticipated aggregate shocks.

Evaluating Dodd-Frank. The Dodd-Frank Act implemented an increase in pre-existing capital requirements from 4% to 6% and established a new liquidity ratio measure, which must exceed 100%. Table 8 provides model output comparing pre-DFA outcomes (i.e. the baseline calibrated model) to outcomes under the Dodd-Frank Act, as well as two hybrid experiments which vary only one policy, holding the other constant, to gain insight for the marginal contribution of capital and liquidity requirements.

Beginning with the Dodd-Frank Act (DFA), it is clear that default rates were significantly reduced. Specifically, pre-DFA insolvency and liquidity default were 0.79% and 0.14% in annualized terms, respectively, making for a total default rate of 0.93%. The Dodd-Frank Act led to a threefold reduction in total default rates to 0.23% and virtually eliminated the risk of liquidity default. The reduction in insolvency risk corresponded with large increases in both the leverage and risk-weighted equity ratios of the banking sector: relative increases in equity create a buffer against default for the bank. The more stringent DFA regulation was also reduced profitability, as proxied by return on equity: the average return on equity dropped from 7.2% to 5.8%, annualized.

TABLE 8
OUTCOMES UNDER DODD-FRANK (LEVELS)

Label	**Pre-DFA**	**DFA**	**Partial DFA I** (6% CR,0% LR)	**Partial DFA II** (4% CR,100% LR)
RW Equity Ratio	5.2	6.4	6.3	5.2
Leverage Ratio	4.1	6.0	6.0	4.0
Liquidity Ratio	73.3	100.1	72.4	102.7
Insolvency Default	0.79	0.23	0.22	0.96
Liquidity Default	0.14	0	0.09	0
Total Default	0.93	0.23	0.31	0.96
Debt Premium ($r^a - r^d$)	0.41	0.07	0.33	0.35
Risk Premium ($E[r^\ell] - i_s$)	2.3	2.3	2.3	2.3
Return on Equity	7.2	5.8	5.8	7.5

The first DFA experiment (Partial DFA I) considers just the capital requirement component of the reform. This partial reform exhibits a large drop in insolvency default, from 0.79% to 0.22%, and in liquidity default, from 0.14% to 0.09%, respectively. This highlights the complementary effect that capital regulation has on bank liquidity: the increased capital requirement leads to a balance sheet reduction of -19% (as illustrated in Table 9) accompanied by a large substitution out of wholesale funding and into deposits, on the liability side. This drop in wholesale funding is large relative to the stock of liquid bank assets, leading to an improvement in bank liquidity and a reduction in liquidity default.[40]

The second DFA experiment (Partial DFA II) considers just the liquidity requirement component of the reform. While this reform is effective in reducing liquidity default, from 0.14% to virtually 0%, the insolvency default rate rises from 0.79% to 0.96%. This highlights the adverse effect that liquidity regulation has on bank equity: the increased liquidity requirement leads to a balance sheet reduction of -10% (as illustrated in Table 9) with a large substitution into loans, due to the increased marginal benefit of lending. The increase in lending is large relative to the stock of bank equity, leading to a drop in risk-weighted bank equity and an increase in insolvency default.[41] Notice that the net effect on the total default rate is actually an increase, from 0.93% to 0.96%.

In this paper, the mechanism by which capital and liquidity requirements affect outcomes involves banks reducing their balance sheet in response to more stringent regulation. Further, on the liability side, the reduction in the size of the balance sheet is accompanied by a reduction in wholesale funding usage. Figure 8 graphs the model impact of the Dodd-Frank Act on bank aggregates, relative to the drop observed in the data (as detailed in the Background section of the paper). As can be seen, total balance sheet size, lending and wholesale funding debt declined by similar levels when comparing data and model moments. Clearly, there are factors, outside the scope of this model, which affected the observed drop in data aggregates but this is taken as some validation for the quantitative model, as well as for the model mechanism by which capital and liquidity requirements affect bank decisions.

[40]The improvement in bank liquidity does not show up in the aggregate liquidity ratio measure, as the impact mostly affects the tail behavior of the cross-section.

[41]Again, the impact on equity ratios does not show up in the aggregate statistic but instead shows up in the tail behavior of the cross-section.

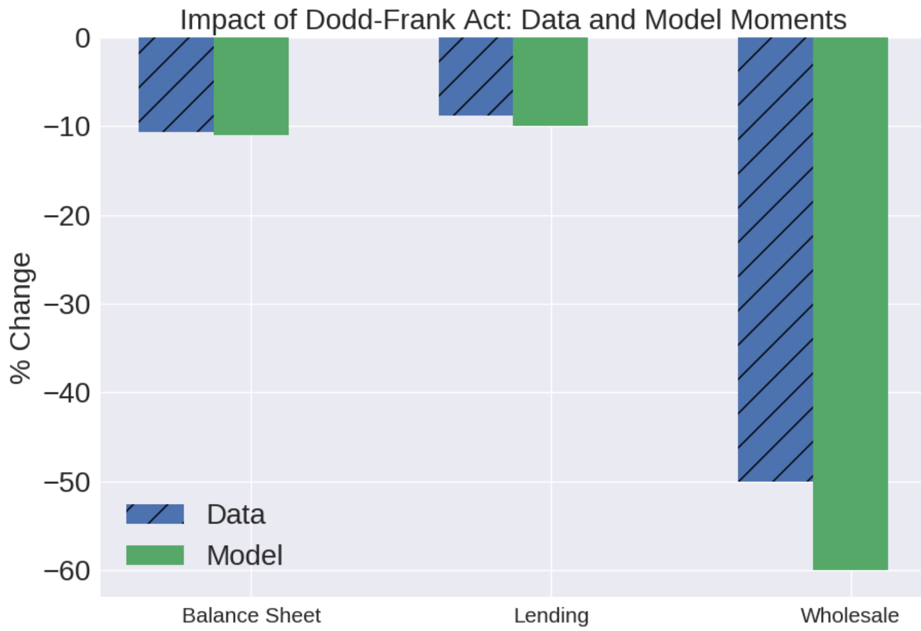

Figure 8: Model Validation Exercise

In addition, Table 9 lists % differences in aggregate outcomes under each policy experiment. In particular, the reduction in both wholesale lending and total balance sheet show up as key effects of setting more stringent capital and liquidity regulation.

TABLE 9
Aggregate Outcomes Under Dodd-Frank (% Differences)

Label	**Pre-DFA**	**DFA**	**Partial DFA I** (6% CR,0% LR)	**Partial DFA II** (4% CR,100% LR)
Aggregate Lending	–	-2.0	-1.8	-10.0
Aggregate Balance Sheet	–	-15.7	-18.9	-9.2
Aggregate Wholesale Funding	–	-86.0	-88.6	-32.7
Household Consumption	–	0.74	0.70	-1.97

Lastly, I use household consumption as my main welfare criterion. Housing consumption is affected by bank activities through five channels: the net return on deposit savings $r^d d_h$, banking equity income via dividends Div_b, taxes related to the cost of deposit insurance DI, as well as taxes related to debt servicing and the corporate income tax. From Table 9, household welfare increases under both the DFA as well as Partial DFA I. Specifically, 95% of the DFA welfare gains can be achieved solely through the implementation of the capital requirement component of the reform. Under this reform, while household consumption is negatively affected by lost bank profitability and equity income, this is offset by a large reduction in the cost of deposit insurance. Deposit insurance expenditures drop because of the threefold reduction in default rates, largely due to the positive interaction from capital regulation.

Optimal Policy. I next solve for the joint optimal policy for capital and liquidity requirements using the same welfare criterion.[42] I find the jointly optimal capital and liquidity requirement to be 6.75% and 95%, respectively, such that the capital requirement increases by 12.5% relative to the Dodd-Frank Act and the liquidity requirement reduces by 5%. Under the optimal policy, there is only a slight reduction in the level of liquidity regulation, relative to the DFA. This result seems counter-intuitive given the negative effect liquidity regulation has on bank equity and insolvency default. The policy interaction, again, plays an important role in determining the optimal policy: while DFA liquidity requirements are harmful when capital requirements are at pre-DFA levels (as in Partial DFA II), they become relatively innocuous at higher levels of the capital requirement. The primary reason for this is the effect that capital regulation has on wholesale funding usage. More stringent capital regulation leads to a reduction in wholesale funding usage (as evidenced by Partial DFA I in Table 9); thus, the relative stock of runnable debt declines. In that environment, it becomes easier for banks to hold sufficient liquid assets to reduce the probability of liquidity default. Thus, conditioned upon an optimal policy with capital requirements set at 6.75%, the planner can set a higher level of liquidity requirements without the adverse effects seen in Partial DFA I, for example.

Aggregate Shocks and Transitional Dynamics. In this section, I consider the impact of unanticipated aggregate shocks to loan returns and wholesale funding, and the transition back to the original steady state. The key interest of the analysis is to understand the sensitivity of default rates and lending to common shocks which hit the banking sector. I first examine the impact of a negative 1% shock to net loan returns and then a negative 10% shock to wholesale funding in the Settlement Stage of the bank problem. Both scenarios occur for the baseline calibration of the model.

Figure 9 plots the path of default rates and total bank lending, given a negative 1% shock to net loan returns. Periods of time represent quarters and the shock occurs at time period 1. As can

[42] At this point, I set $\phi^{lev} = \phi^{cr}$ but plan to vary each of these policy parameters, as well, in future research.

be seen in the far left graph, total lending decreases by approximately 8%, relative to the steady state, before a slow recovery over the following periods. In the middle panel, the rates of insolvency default nearly triple in the first quarter. A negative loan return shock reduces the period-to-period net worth that banks operate with. This leads to a reduction in lending (as documented in the left panel) and in the use of wholesale funding debt. The net effect is an improvement in bank liquidity ratios and a drop in liquidity default rates. This point is illustrated in the right panel, where liquidity defaults drop, relative to the steady state, due to the larger reliance of banks on deposit funding in the wake of the loan shock.

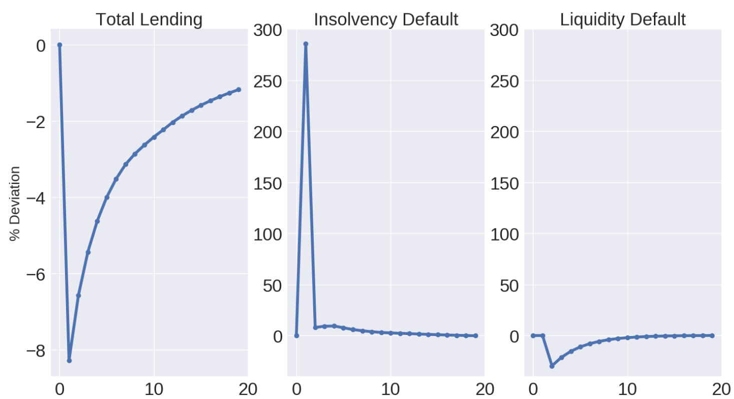

Figure 9: Unanticipated, Aggregate Shock to Loan Returns

Figure 10 plots the path of default rates and total bank lending, given a negative 10% shock to wholesale funding (i.e. 10% of banking sector wholesale debt is withdrawn during the Settlement Stage). In the far left graph, total lending decreases by approximately 0.4%, relative to the steady state. In the middle panel, the rates of insolvency default are virtually unaffected whereas liquidity default rates (right panel) spike to nearly 30% above their steady state levels.

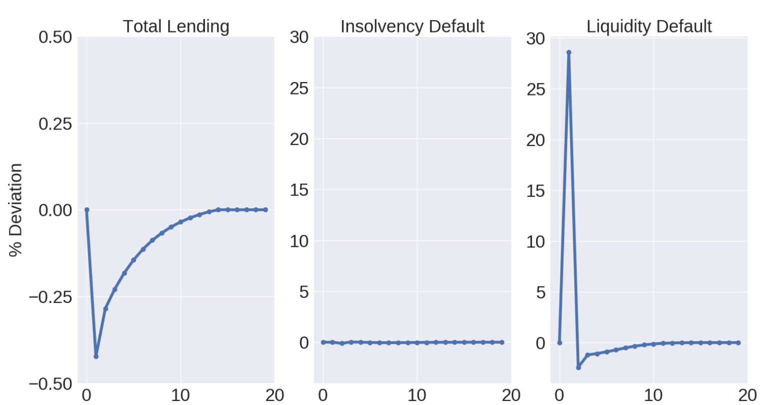

Figure 10: Unanticipated, Aggregate Wholesale Funding Shock

8 Conclusion

Basel III and the Dodd-Frank Act introduced liquidity requirements in conjunction with an increase in pre-existing capital requirements with the purpose of reducing both liquidity and insolvency default risk. Given the novelty of liquidity regulation, the reform has prompted a new set of academic and policy-relevant questions as to the joint role of both capital and liquidity requirements in attaining certain policy objectives. In building upon the literature, I develop a general equilibrium framework with a heterogeneous banking sector where banks are exposed to both endogenous insolvency and liquidity default risk. Banks hold a portfolio of assets (consisting of loans, securities and cash) as well as liabilities (consisting of deposits, wholesale funds and equity) which are attached to corresponding markets. Capital and liquidity requirements affect bank portfolio choices over equity and liquidity buffers, respectively, which further impact bank default rates.

Using U.S. Call Report bank data, I calibrate the model to the pre-Dodd-Frank era. In implementing the Dodd-Frank Act, I find that the joint use of capital and liquidity regulation led to a threefold reduction in banking sector default risk, from 0.93% to 0.23%, and improved household welfare. When I solely implement the reform to capital requirements, I find it accounts for large reductions in both insolvency and liquidity default, and the reform accounts for 95% of the welfare gains of the Dodd-Frank Act. Conversely, when I solely implement the reform to liquidity requirements, I find it accounts for an increase in total banking sector default risk and leads to welfare losses for households. The reason for these outcomes stem from significant interactions which occur between the two policies. In particular, capital requirements have a complementary effect on bank liquidity while liquidity requirements have an adverse effect on bank equity. In both cases, increasing bank requirements reduces bank profitability, leading to a reduction in bank balance sheet size and adjustments to bank portfolio shares on both the asset and liability side. When I solve for the jointly optimal policy, I find that capital requirements should be increased by 12.5% relative to their Dodd-Frank level and liquidity requirements reduced by 5% relative to their Dodd-Frank level, but argue that these levels are economically close to those imposed by Dodd-Frank.

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A Appendix

A.1 Nomenclature and Data Definitions

Bank Problem	
n_b	Net worth
j	Bank technology type
$\bar{d}_j$	Bank-j deposit constraint
ℓ	Loans
s	Securities
c	Cash
a	Wholesale funding debt
d	Deposits
div	Dividends to equity owners
$\tilde{s}$	Security liquidations in Settlement Stage
$\tilde{c}$	Cash settlement in Settlement Stage
θ_j	Bank-j loan cost parameter
h	Collateral haircut
$\gamma\beta$	Bank discount factor
$\lambda^{\mathbf{j}}$	Bank-j marginal distribution over net worth
Prices, Processes	
i_ℓ	Loan net return
i_s	Securities net return
r^a	Wholesale debt net return
r^d	Deposit debt net return
δ'	Wholesale funding shock
μ	Loan return average
σ	Loan return volatility
p^*	Security liquidation price in Settlement Stage
α	Outside investor elasticity parameter
$\bar{\mu}_{d,j}$	Bank-j average deposit borrowing constraint
Regulatory	
ϕ^{lr}	Leverage requirement
ϕ^{cr}	Risk-weighted capital requirement
ϕ^{liq}	Liquidity requirement
h^s	Securities liquidity haircut
Other	
ω^s	Outside investor endowment
τ	Corporate income tax
d_h	Household deposits
c_h	Household consumption
n_h	Household net worth
β	Household discount factor
ξ	Recovery value in default
Div_j	Aggregate dividends from sector $j \in \{b, m\}$

The majority of bank data comes from U.S. Call Reports forms 041 and 051. In the table below, I report the mnemonics used for balance sheet items utilized for empirical analysis in this paper.

Total Assets	RCON2170
Loans	RCON2122
Cash	RCON0071 + RCON0081
Securities	RCON1754 + RCON1773
Total Liabilities	RCON3300
Deposits	RCON2200 - RCONA242
Wholesale (2000-2001)	RCON2800 + RCONA242 + RCON3548 + RCON3571
Wholesale (2002-2010)	RCONB993 + RCONB995 + RCONA242 + RCON3548 + RCON3571
Wholesale (2011-2020)	RCONB993 + RCONB995 + RCONK222 + RCON3548 + RCON3571
Capital	RCON3210
Leverage Ratio (2000-2013)	RCON7204
Leverage Ratio (2014-2020)	RCOA7204
Risk-Weighted Capital Ratio (2000-2013)	RCON7206
Risk-Weighted Capital Ratio (2014-2020)	RCOA7206

A.2 Figures and Tables

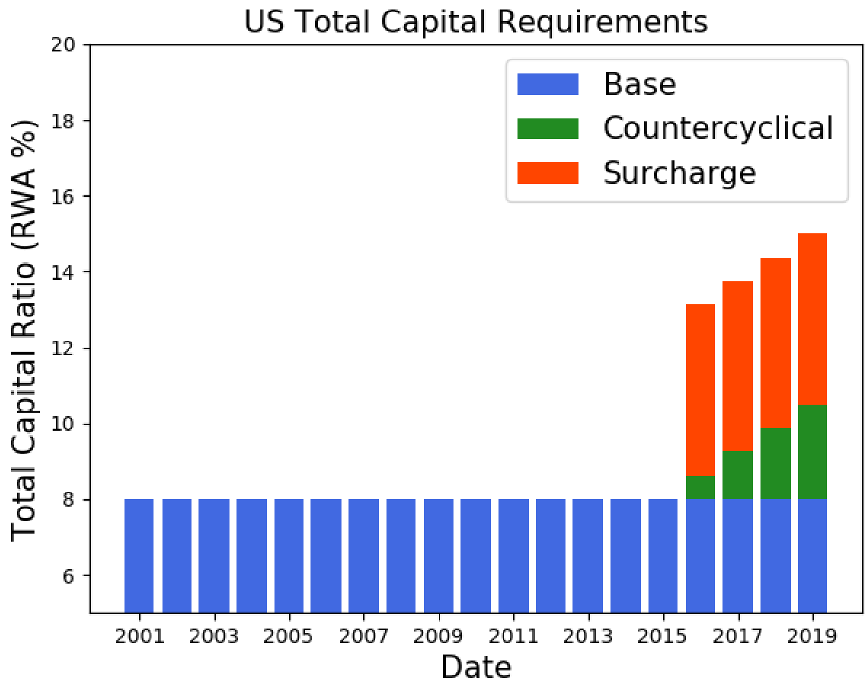

Figure 11: Evolution of Bank Capital Requirements

Notes: This figure represents total capital requirements relative to risk-weighted assets (RWA) for U.S. banks. For color blind, entries in legend are opposite as they appear in figure. Both the countercyclical capital buffer and capital surcharge are discretionary measures. When implemented, the countercylical capital buffer applies uniformly to all banks, whereas the capital surcharge is a function of a bank's G-SIB score.

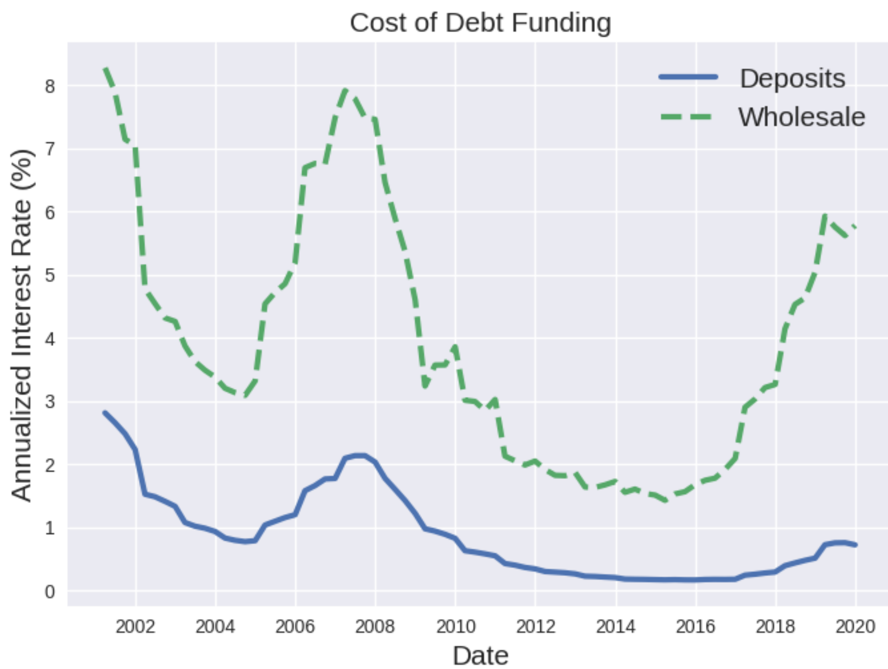

Figure 12: Cost of Debt Funding

Notes: Data comes from FFIEC Forms 041 and 051. The level values for deposits and wholesale funds come from the same line items as cited in Figure 16.

TABLE 10
WHOLESALE FUNDING SHARES REGRESSION

	(Pre-DFA) wholesale share	(Post-DFA) wholesale share	(Full Sample) wholesale share
Intercept	1,670***	675***	1,071***
	(11.4)	(4.37)	(5.07)
Size	**19.1*****	**-0.23**	**3.51*****
	(1.37)	(0.34)	(0.44)
Income Ratio	-26.5***	-1.25***	-2.02***
	(3.29)	(0.30)	(0.43)
Time FE	✓	✓	✓
Time Periods	37	39	76
Entities	842	1061	1407
R^2	0.017	0.001	0.002

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

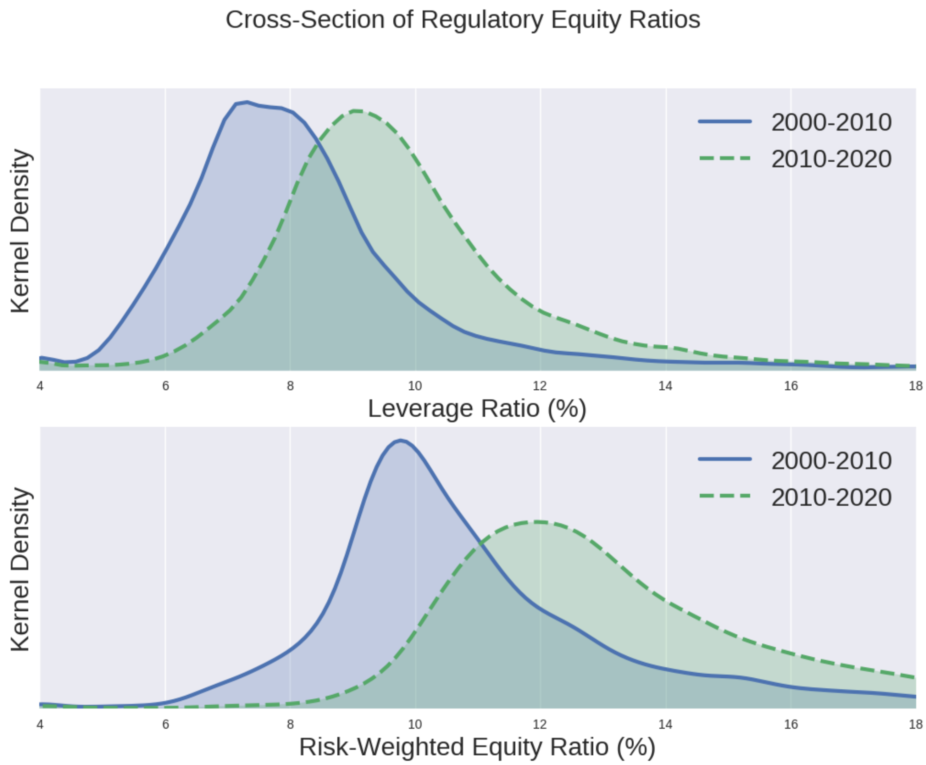

Figure 13: U.S. Equity Ratios, Pre- and Post-DFA

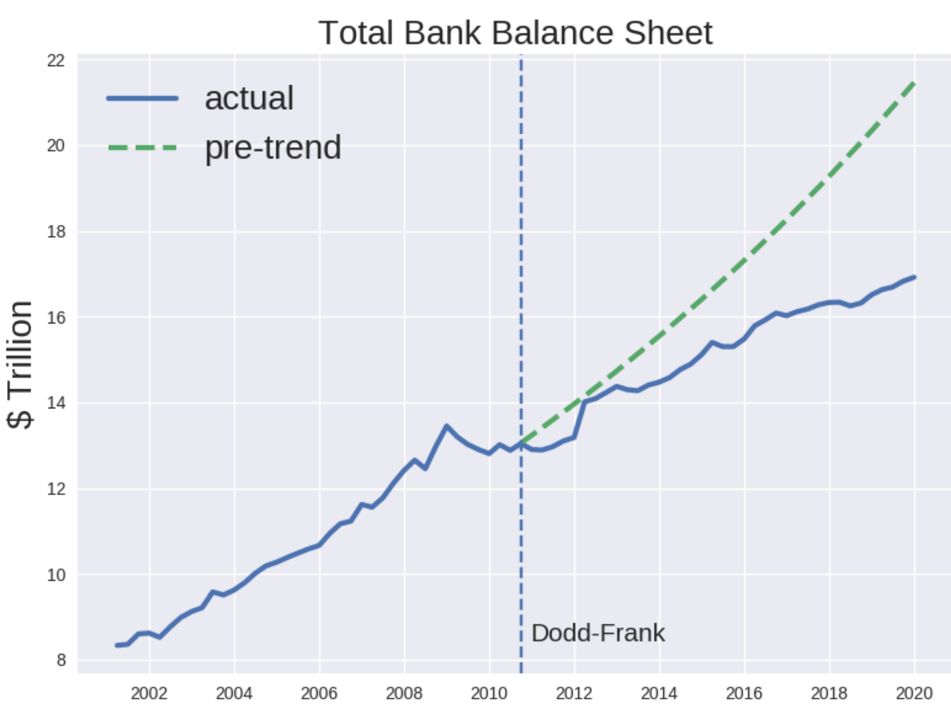

Figure 14: U.S. Banking Aggregates, Pre- and Post-DFA

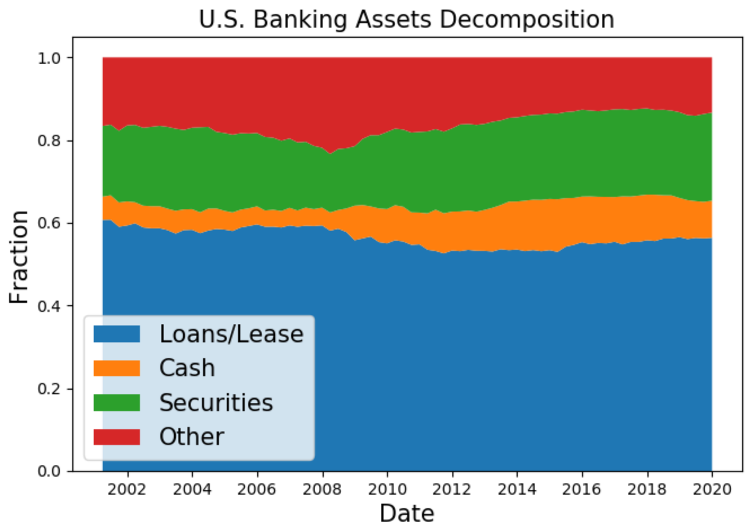

Figure 15: U.S. Bank Asset Decomposition

Notes: Data comes from FFIEC Forms 041 and 051. For color blind, entries in legend are opposite as they appear in figure. Total assets is defined as [RCON2170]. Loans/Lease is defined as [RCON2122]. Cash is defined as Interest-bearing Balances [RCON0071]+ Noninterest-Bearing Balances and Currency/Coin [RCON0081]. Securities is defined as Held-to-Maturity [RCON1754]+ Available-for-Sale [RCON1773].

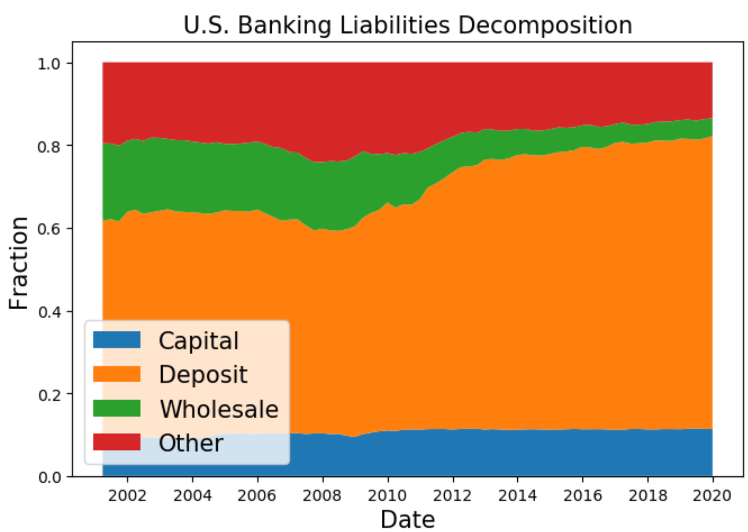

Figure 16: U.S. Bank Liability Decomposition

Notes: Data comes from FFIEC Forms 041 and 051. For color blind, entries in legend are opposite as they appear in figure. Total liabilities including equity is defined as [RCON3300]. Capital is defined as [RCON3210]. Deposits is defined as Domestic [RCON2200]- Large Time Deposits with Maturity $<$ *1yr [RCONA242]. Wholesale funding is defined as Repurchase Agreements & Fed Funds Loans[RCON2800] + Large Time Deposits with Maturity* $<$ *1yr [RCONA242] + Trading Liabilities [RCON3548] + Other Borrowings with Maturity* $<$ *1yr [RCONB571]. For quarters after 2001, substitute [RCONB993]+[RCONB995] for [RCON2800]. For quarters after 2010, substitute [RCONK222] for [RCONA242].*

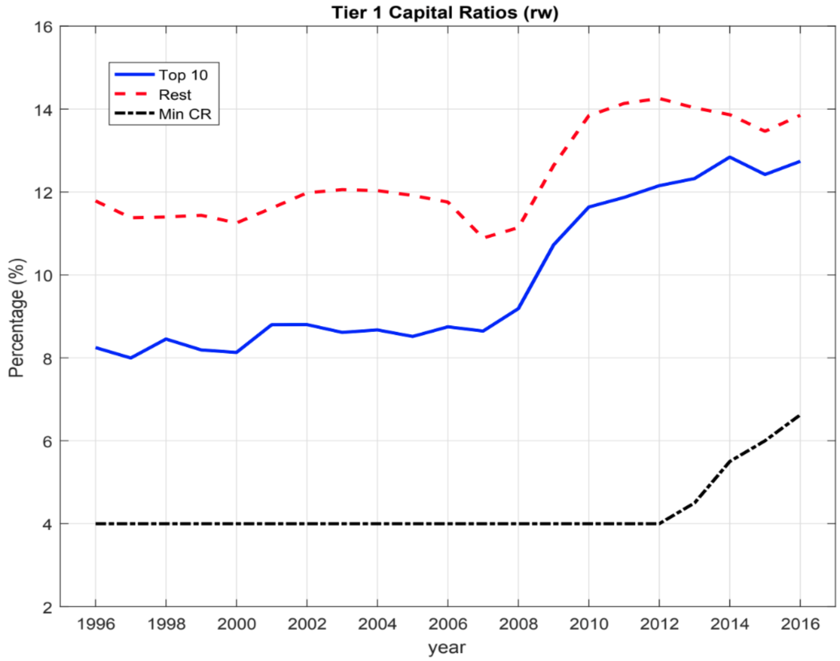

Figure 17: Tier 1 Capital Ratios

Source: Corbae and D'Erasmo [2018]

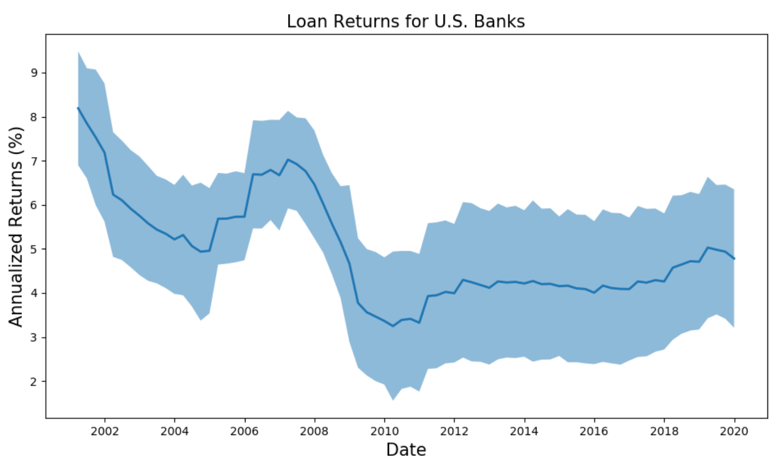

Figure 18: U.S. Bank Loan Returns (2019)

Notes: Data comes from FFIEC Forms 041 and 051. The bands represent 1 standard deviation movements, based upon returns in each quarter's cross-section. The level value for loans is defined as Held for Sale [RCON5369] + Held for Investment including Allowances [RCONB529]. The interest income from loans is defined as Interest and Fee [RIAD4010] + Lease [RIAD4065] + Recoveries [RIAD4605] - Charge-offs [RIAD4635].

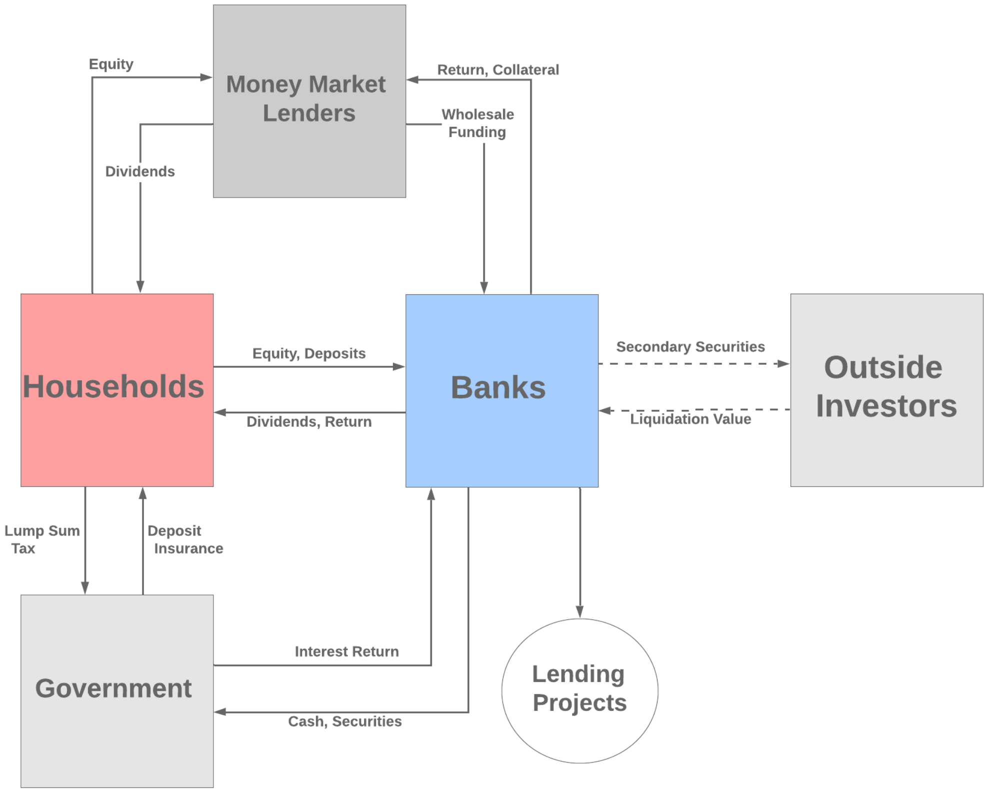

Figure 19: Model Illustration

A.3 Agent Problems, Deposit Insurance and Proofs

Money Market Lenders. Each period, given networth n_m, money market lenders issue dividends div_m and collateralized wholesale loans a_m subject to a haircut h and an exogenous distribution of early withdrawal shocks $\delta' = (\delta'_1, ..., \delta'_{n1})$. Banks lend to a share-weighted mutual fund of banks. As shown in Figure 6, there are four ways in which money market lenders receive cash flows: {early withdrawal liquidity default, early withdrawal repayment, maturity insolvency default, maturity repayment }.

Thus, for each unit of lending, some fraction α^c receives payoffs from collateral seizures, some fraction α^w receives payoffs from early withdrawals and the remainder receives repayment at maturity R^a where $\{\alpha^c, \alpha^w\}$ are equilibrium objects. Money market lenders solve

$$
\begin{aligned}
V^m(n_m) = \max_{a_m, div_m} \quad & div_m + \beta V^m(n'_m) \\
s.t. \quad & div_m + a_m = n_m \\
s.t. \quad & n'_m = a_m\big[\alpha^c(1+h) + \alpha^w + (1-\alpha^c-\alpha^w)R^a\big]
\end{aligned}
$$

As proposition 2 shows, this problem can be reformulated and used to show how the rate R^a is determined in the competitive equilibrium.

Outside Securities Investors Problem. Similar to Lorenzoni [2008] and Stein [1988], the inverse price demand function can be derived from a simple static formulation of an investor problem, where the investor utilizes the liquidated securities in the operation of decreasing returns to scale technology. Specifically, investors purchase security inputs at a price p^* to maximize their period profit:

$$\max_{s_o} \quad (s_o)^\alpha - p^* s_o$$

where $\alpha < 1$.

Deposit Insurance. Each period, some proportion of banks default. In default, a pecking order exists over the remaining liabilities of the bank. Specifically, money market lenders are first to seize remaining collateral owed. At this point, of the remaining bank assets, a fraction ξ is lost such that default imposes a real cost on the economy.[43] The remainder of bank assets is used to repay deposits and the residual debts are funded through deposit insurance. For a bank that defaults

[43]This cost is meant to capture the recovery vale of bank assets in default. Current legal provisions for secured lending (such as repurchase agreements) allow external creditors to seize collateral immediately. For this reason, I model the cost of bankruptcy occurring after the money market lenders collect their collateral.

via liquidity after a withdrawal shock δ', deposit insurance covers

$$R^d d - \xi\big[(1+i'_\ell)\ell + (1+i_s)s + c - (1+h)a\big]$$

where I assume the bank's assets get to appreciate in the following period. For a bank that defaults via insolvency, deposit insurance covers

$$R^d d - \xi\big[(1+i'_\ell)\ell + (1+i_s)(s-\tilde{s}) + (c-\tilde{c}) + \delta' a - (1-\delta')(1+h)a\big]$$

Proposition 1 Proof. From the money market lenders problem in A.2, next-period networth is determined via the equation

$$n'_m = a_m\big[\alpha^c(1+h) + \alpha^w + (1-\alpha^c-\alpha^w)R^a\big] \tag{1}$$

where (α^c, α^w) are objects determined in the competitive equilibrium. Given market clearing, the RHS of equation (1) must be equal to the aggregation of payoffs constructed from individual bank policy functions. That is, total returns from wholesale lending can be written

$$\begin{aligned}
\int_{N_b}\sum_j\sum_{\bar{d}_j}\sum_{\delta'}\pi_{\delta'}\Bigg[&\underbrace{I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)(1+h)a(n_b,j,\bar{d}_j)}_{\text{early withdrawal, liquidity default}} + \underbrace{\big(1-I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)\big)\delta' a(n_b,j,\bar{d}_j)}_{\text{early withdrawal, repayment}} + \\
&\underbrace{\big(1-I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)\big)\sum_{\bar{d}'_j}\sum_{i'_l}\pi_{\bar{d}'_j,i_l}I^{In}(n'_b,j,\bar{d}'_j)(1+h)(1-\delta')a(n_b,j,\bar{d}_j)}_{\text{maturity, insolvency default}} \\
&\underbrace{\big(1-I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)\big)\sum_{\bar{d}'_j}\sum_{i'_l}\pi_{\bar{d}'_j,i_l}\big(1-I^{In}(n'_b,j,\bar{d}'_j)\big)R^a(1-\delta')a(n_b,j,\bar{d}_j)}_{\text{maturity, repayment}}\Bigg]d\lambda^j(n_b,\bar{d}_j) \\
= \Big[\int_{N_b}\sum_j\sum_{\bar{d}_j}a(n_b,j,\bar{d}_j)d\lambda^j(n_b,\bar{d}_j)\Big]&\int_{N_b}\sum_j\sum_{\bar{d}_j}\frac{a(n_b,j,\bar{d}_j)d\lambda^j(n_b,\bar{d}_j)}{\int_{N_b}\sum_j\sum_{\bar{d}_j}a(n_b,j,\bar{d}_j)d\lambda^j(n_b,\bar{d}_j)}\times \\
&\sum_{\delta'}\pi_{\delta'}\Bigg[I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)(1+h) + \big(1-I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)\big)\delta' + \\
&\big(1-I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)\big)\sum_{\bar{d}'_j}\sum_{i'_l}\pi_{\bar{d}'_j,i_l}I^{In}(n'_b,j,\bar{d}'_j)(1+h)(1-\delta') \\
&\big(1-I^{liq}(\mathbf{y},\delta',j,\bar{d}_j)\big)\sum_{\bar{d}'_j}\sum_{i'_l}\pi_{\bar{d}'_j,i_l}\big(1-I^{In}(n'_b,j,\bar{d}'_j)\big)R^a(1-\delta')\Bigg]
\end{aligned}$$

and through market clearing

$$
\begin{aligned}
=& a_m \int_{N_b} \sum_j \sum_{\bar{d}_j} \omega(n_b, j, \bar{d}_j) \sum_{\delta'} \pi_{\delta'} \Big[I^{liq}(\mathbf{y}, \delta', j, \bar{d}_j)(1+h) + \big(1 - I^{liq}(\mathbf{y}, \delta', j, \bar{d}_j)\big)\delta' + \\
& \big(1 - I^{liq}(\mathbf{y}, \delta', j, \bar{d}_j)\big) \sum_{\bar{d}'_j} \sum_{i'_l} \pi_{\bar{d}'_j, i_l} I^{In}(n'_b, j, \bar{d}'_j)(1+h)(1-\delta') \\
& \big(1 - I^{liq}(\mathbf{y}, \delta', j, \bar{d}_j)\big) \sum_{\bar{d}'_j} \sum_{i'_l} \pi_{\bar{d}'_j, i_l} \big(1 - I^{In}(n'_b, j, \bar{d}'_j)\big) R^a (1-\delta') \Big] \\
=& a_m \big[(1+h) E[\tilde{Def}^{liq}] + E[(1 - \tilde{Def}^{In})\delta'] + (1+h) E[(1 - \tilde{Def}^{liq})(1-\delta')\tilde{Def}^{In}] + \\
& \qquad R^a E[(1 - \tilde{Def}^{liq})(1-\delta')(1 - \tilde{Def}^{In})] \big] \\
=& a_m \tilde{R}^a
\end{aligned}
$$

which equals the RHS of equation (1). By substituting in aggregate lending a_m, weights $\omega(\cdot)$ are derived to represent bank market shares in the wholesale lending market. The object $\tilde{Def}^{liq}$ represents share-weighted liquidity default rates for each bank type in the Settlement Stage, where the type is given by the tuple $(n_b, j, \bar{d}_j, \delta')$. In similar fashion, the object $\tilde{Def}^{In}$ represents share-weighted insolvency default rates for each bank type in the following period, where the type is given by the tuple $(n_b, j, \bar{d}_j, \delta', \bar{d}'_j, i'_l)$. Notice that $\tilde{R}^a$ is a deterministic object but takes expectation over the various idiosyncratic risks that banks face. Taking the money market lender first-order condition with respect to wholesale lending provides

$$
[a_m]: \quad -1 + \beta \tilde{R}^a = 0
$$

which leads to the pricing condiiton

$$
R^a = \frac{\frac{1}{\beta} - (1+h)E[\tilde{Def}^{liq}] - E[(1 - \tilde{Def}^{liq})\delta'] - (1+h)E[(1 - \tilde{Def}^{liq})(1-\delta')\tilde{Def}^{In}]}{E[(1 - \tilde{Def}^{liq})(1-\delta')(1 - \tilde{Def}^{In})]}
$$

Proposition 2 Proof. The liquidation constraint $\delta' a = p^* \tilde{s} + \tilde{c}$ binds for each realization of δ'. Sub this into the next-period law of motion for net worth (abstracting from the one-sided corporate income tax τ):

$$
\begin{aligned}
n_b' =&(1+i_l')l + (1+i_s)[s-\tilde{s}] + [c-\tilde{c}] - R^d d - R^a(1-\delta')a \\
=&(1+i_l')l + (1+i_s)s + c - R^d d - R^a a + \tilde{s}[R^a p^* - (1+i_s)] + \tilde{c}[R^a - 1] \\
=&n_{b,no}' + \tilde{s}[R^a p^* - (1+i_s')] + \tilde{c}[R^a - 1]
\end{aligned}
$$

where $n_{b,no}$ represents next-period net worth in the event of $\delta' = 0$. Observe

$$
\begin{aligned}
\frac{\partial n_b'}{\partial \tilde{s}} =& R^a p^* - (1+i_s) \\
\frac{\partial n_b'}{\partial \tilde{c}} =& R^a - 1
\end{aligned}
$$

and under the conditional statement, $\frac{\partial n_b'}{\partial \tilde{s}} < \frac{\partial n_b'}{\partial \tilde{s}}$ for all values of i_s'. Thus, it strictly dominates for the banks to liquidate all available cash first.

A.4 Dynamic Analysis and Transitions

Define a sequence of aggregate shocks $s_t = \{\bar{\delta}_t, \bar{i}_t\}$ for time periods $t = 1, 2, ..., T$ where $\boldsymbol{s}_1 = \{0, 0\}$.[44] The key equilibrium objects are $\{V_t^b, \boldsymbol{y}_t, \lambda_t\}_{t=1}^T$ which are the bank value functions, bank policy functions and joint distribution for each time period. Assume T is sufficiently high such that the economy is in the stationary equilibrium $\{V^{b*}, y^*, \lambda^*\}$ in periods 1 and T. Guess a path for prices $\{\boldsymbol{p}_t\}_{t=1}^T$.[45] Then for each period $t = T - 1$ to $t = 2$, solve $\{V_t^b, \boldsymbol{y}_t\}$ given $\{\boldsymbol{s}_{t+1}, V_{t+1}, \boldsymbol{p}_t\}$. Given the set of equilibrium objects, Compute the law of motion for the distribution λ_{t+1} as a function of $\{\lambda_t, \boldsymbol{y}_t, \boldsymbol{s}_{t+1}, \boldsymbol{p}_t\}$. For each period compute aggregates[46] and compute the implied prices $\tilde{\boldsymbol{p}}_t$. Given the set of prices guesses $\{\boldsymbol{p}_t\}_{t=1}^T$ and implied prices $\{\tilde{\boldsymbol{p}}_t\}_{t=1}^T$, update the vector of price guesses and repeat until a convergence criterion has been met.

[44] That is, in the first period there are no aggregate shocks and the economy is in the stationary equilibrium.
[45] In this context, the key price objects are secondary market prices p^* and the wholesale funding rate R^a.
[46] Aggregate wholesale funding demand by banks and aggregate security liquidations by banks.