Essays on Bank Prudential Regulations

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Abstract

This paper theoretically and empirically analyzes the relationship between deposit competition, model-based capital requirements (Basel Accords) and bank risk-taking. I first build a model where banks are subject to capital requirements in which there are arbitrage opportunities in an internal rating based (IRB) approach introduced in Basel II/III, depositors have preference on banks due to transaction cost, and the regulator conducts supervisory check on bank capital adequacy. The model shows two sets of results: first, given a certain level of deposit competition and as the capital requirements are evolved, the effectiveness of the requirements on reducing bank risk-taking improves when supervisory power is high enough to restrict bank arbitrage in IRB approach; second, the non-risk based leverage ratio in Basel III, when binding, can simultaneously reduce bank risk-taking and lower required supervisory power that restricts bank arbitrage. However, the binding ratio can potentially distort some banks' incentives to invest prudently. I then externally validate some testable implications drawn from the theory with System GMM and Difference-in-Difference using a large panel dataset for U.S. commercial banks. I find that the introduction of IRB approach reduces bank ex ante credit risk, suggesting the potential regulatory capital arbitrage. I also find that lower deposit competition and stricter capital requirements reduce bank credit risk. All empirical findings are consistent with the theory.

Keywords: Capital Requirements, Internal-Rating Based Approach, Leverage Ratio, Competition, Supervision.

JEL classification: G21, G28.

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1 Introduction

1.1 Bank Capital

There are two ways that a bank finances its assets, which consist of a combination of cash, securities, loans and other instruments. The bank can either raise money from borrowed funds by taking in deposits and other debt liabilities, or it can use its own funds by issuing equity to its equity holders. This means that, a bank uses debt and capital to purchase assets. Therefore, capital can be defined as the difference between the value of assets and the value of liabilities. Capital also means that, after liquidating all of the bank's assets, what is owned to its equity holders. The role of bank capital is that it serves as a buffer to against insolvency: if the loans do not pay off, bank capital should absorb the same amount of loss in loan value. As long as the capital account is sufficiently positive, it protects banks from insolvency due to unforeseen losses in asset value.

The role of capital can also be shown for banks that are too big to fail (TBTF). The failure of large banks causes systematic failure in the banking and financial system. To avoid systemic risk, governments bailout large banks using taxpayers' money. TBTF banks, anticipating bailout by the government, have an incentive to take more risks, which could exacerbate moral hazard problem and spill over to the financial system. Therefore, it is important for TBTF banks to operate with sufficient amount of capital, which accurately reflect their asset risk. Moreover, the shortage of capital in the banking system can affect the real economy. Banks that fail to keep sufficient capital (undercapitalized banks) are asked by the banking regulators to restrict their asset growth and supplement enough capital, which reduce their credit supply to healthy borrowers. Meanwhile, the banking system with insufficient capital is more vulnerable to any widespread shocks, reflecting that some banks are lemons and the public losses confidence on banks.

1.2 Bank Capital Requirements

Basel capital requirements, also known as Basel Accords, are designed to ensure the safety and soundness of financial institutions, such as banks, by limiting their risk with capital charges. Ex ante, capital prevents bank shareholders from investing in risky assets. Ex post, it allows banks to internalize their losses from write-downs of their assets without defaulting on their depositors and creditors. In order to reduce the risk, banks are required to hold a minimum amount of capital proportional to risk-weighted assets (RWAs), the total assets weighted according to asset risk. Basel III rules, built on the previous Basel I and II, link banks risk with minimum capital charges that could be estimated by their own internal risk models (the Internal

Rating Based Approach (IRB)).

The IRB approach in Basel II/III allows banks, particularly large banks, to internally calculate their portfolio risk parameters that will be used to calculate RWAs and minimum capital charges. On one side, it aims to improve the sensitivity and soundness of minimum capital charges. On the other side, there are arbitrage opportunities that lie within the approach, which come in the form of banks strategically underreporting their true credit risk exposure for lower minimum capital charges (regulatory capital arbitrage), considering that capital is costly to raise. Besides IRB approach, Basel III also introduces a non-risk based leverage ratio (measured as capital over total assets), which complements the risk-based capital adequacy rules.

1.3 Deposit Competition

Linking capital charges with bank risk may also take into account banks other source of liabilities. Deposits, which are the main source of bank funding, are well suited to invest in risky loans due to their stability. Increasing competition for deposits among banks shrink their interest rate margins, and may trigger banks to invest in more risky assets to offset the impact from competition.

1.4 The Problem

What is behavior of banks under Basel capital requirements? Is the evolution of Basel Accords helpful for preventing banks from taking excessive risk? The basic question of the existence of capital requirements matters because the requirements can help the whole banking system operate with sufficient capital, which prevents the failure of both financial system and real economy. This question had been widely studied in the literature. The whole purpose of revising Basel Accords over time is to force banks to keep accurate amount of capital that matches bank different risks, such as credit risk, liquidity risk, market risk and operational risk. The question of the benefit of the evolution of capital requirements had also been studied in the literature.

This dissertation is concerned, however, with bank behavior and the effectiveness of capital requirements in different and richer aspects, including regulatory capital arbitrage (RCA) by the IRB banks, and the role of leverage ratio in Basel III. The introduction of IRB approach increases bank risk management costs, which consist of costs of forming a risk management team and establishing complex business models to calculate RWAs. Therefore, IRB banks might conduct RCA by holding less sufficient capital without lowering asset risk. The introduction of non-risk based leverage ratio in Basel III results from a more and more popular perspective, which calls for the simplicity of capital requirements to further prevent RCA.

Thus, this dissertation examines bank behavior under capital requirements in which IRB bank conducts RCA, and how supervisory power helps prevent RCA. This dissertation aims to focus on the regulatory capital arbitrage problem in the capital requirements, and the role of the non-risk based leverage ratio in the context of RCA. The results contribute to the understanding of the loopholes that might exist in the current Basel Accords, and of the best direction of how the Accords should be further revised and evolved.

1.5 Objectives and Hypotheses

This dissertation has both theoretical and empirical objectives. The theoretical objective is to identify the efficacy of capital requirements in which there are arbitrage opportunities for banks to exploit. The empirical objective is to better understand the impact of the IRB approach on bank ex ante asset risk. The specific objectives are the following:

- To study bank risk-taking behavior under each capital requirement with and without RCA.
- To explain whether the evolution of capital requirements is helpful in preventing bank from taking excessive risk with and without RCA.

- To identify the supervisory power imposed on banks under each capital requirement in order to prevent RCA.
- To distinguish the role of non-risk based leverage ratio in the context of supervisory oversight and RCA.
- To empirically test the impact of IRB approach on bank ex ante credit risk, using data for U.S. commercial banks collected from Call Reports, Summary of Deposits, and each IRB bank's Pillar 3 report.

The main hypotheses of this dissertation are:

First, the evolution of capital requirements is helpful for preventing bank taking excessive risk only if banking regulator's supervisory power is high enough to prevent regulatory capital arbitrage. Second, the non-risked based leverage ratio in Basel III, which implements risk-based capital rules, is a meaningful backstop to reduce RCA only if the leverage ratio is binding. Meanwhile, the leverage ratio can maintain the effectiveness of capital requirements with lower supervisory power. In other words, the leverage ratio can control bank excessive risk-taking under weak supervisory environment in the context of RCA.

1.6 Contributions

While the impact of capital requirements or deposit competition on bank risk-taking has been widely discussed, little is known about how bank behavior is affected when they are subject to capital requirements in which there are arbitrage opportunities. Therefore, I fill the gap by examining how IRB approach, leverage ratio and risk-based capital rules mutually affect bank behavior when they face deposit competition, and how the leverage ratio and regulatory supervision play a role in reducing banks' incentives to arbitrage. In this dissertation, I theoretically and empirically explore the institutional setup around the introduction of model-based capital regulations combined with deposit competition to identify their impact on bank risk.

1.7 Organization

The rest of the dissertation proceeds as follows: Chapter 2 provides background and evolution of international Basel Capital Accords proposed by the Basel Committee on Banking Supervision, and Basel Accords implemented by the United States. Chapter 3 reviews the literature on bank behavior, deposit competition, and capital requirements, especially IRB approach. Chapter 4 develops a theoretical framework that incorporates banks, depositors, and the regulator. It also presents the model analysis, in which it derives the threshold competition and threshold supervisory power for risky asset under different capital requirements. Chapter 5 provides empirical support for the key assumptions made in the theoretical model using studies that are done by other researchers. Chapter 6 describes the three hypotheses derived from the theory, data sources, discusses identification strategies, and displays results. Chapter 7 concludes and discusses policy implications.

2 The Evolution of Basel Capital Accords

Capital requirements are one of the important tools used by the banking regulators to promote a smooth-functioning banking system. The requirements force banks to operate with sufficient amount of equity capital that match their asset risk, presuming that keeping sufficient capital would reduce banks' incentives to take excessive risk. Ex ante, capital prevents bank shareholders from investing in risky assets. Ex post, it allows banks to internalize their losses from write-downs of their assets without defaulting on their depositors and creditors. These requirements have been evolving over time.

2.1 International Basel Accords

Before Basel Accords were proposed, there was no multilateral agreements on measuring bank risk among countries. For example, the U.S. regulator in the early 1980s adopted a regulation, which uses minimum leverage ratio, the ratio of minimum capital over on-balance sheet assets, to calculate minimum capital charges and measure risk. However, banks could meet the requirement and increase their asset risk by replacing their holdings of low−risk assets with high−risk assets, and the requirement placed US banks in a less competitive position compared to, for example, Japanese banks due to the stricter capital requirement in US.

To promote the financial stability and raise capital requirements in a mutilateral way, the Basel Committee on Banking Supervision (BCBS) introduced Basel Accords, a set of international capital adequacy regulations. The first Basel Accord, which was finalized in July 1988 and implemented over the period of 1988 to 1992, called for a measure of bank risk with risk-based capital ratio. Basel I called for a minimum capital ratio, which was based upon risk-weighted assets (RWAs). In order to reduce the risk, each bank was required to hold a minimum amount of capital proportional to risk-weighted assets (RWAs), the total assets weighted according to asset risk. Basel I contained two tiers of capital: Tier 1 and Tier 2, both of which combined form total capital. There were two minimum capital requirements in Basel I. One was for Tier 1 capital and another one was for the total capital. The minimum Tier 1 capital was set at 4% of RWAs, and the minimum total capital was initially set at 7.25%, and then increased to 8% of RWAs by the end of 1992. In January 1996, in addition to credit risk, Basel I also incorporated market risk of capital requirements, which take into account of the risk of losses in both on- and off- balance sheets that is associated with changes in market prices.

However, there were many critiques regarding the effectiveness of Basel I capital requirements and whether banks operate with sufficient amount of capital that match their asset risk. One reason was regulatory capital arbitrage. Some bank reduced its capital requirement without lowering its asset risk. For example, due to securitization process, the bank could reduce its minimum capital by selling a proportion of its risky loans and buying back only the risky part of the resulting security. Another reason was the risk categories used to calculate RWAs. The number of risk categories was somewhat fix and arbitrary. Assets that fall into the same risk category have different risk characteristics, and should be assigned different risk weights in order to accurately capture banks asset risk.

Thus, the second Basel Accord, Basel II, was proposed in 2004 and built upon Basel I with the aim of fixing above problems. Basel II consists of three pillars: Pillar 1, which refers to expanding the minimum capital requirements; Pillar 2, which refers to imposing effective supervisory oversight on bank capital adequacy and its internal assessment process; Pillar 3, which refers to strengthening market discipline by calling for more public disclosure of banks' financial condition and performance.

Basel II introduced a new credit risk weighting system which allows banks opt for either standardized approach (SA) with fixed risk weights prescribed by the regulator or for the Internal-Rating Based approach (IRB) with risk weights calculated by a bank's own internal business model, when deciding the minimum capital charges. The Basel II also called for supervisory review of a bank's capital adequacy and internal assessment process, and more effective use of disclosure to enhance market discipline.

The standardized approach (SA), similar to the method to calculate RWAs in Basel I, is to group assets into different risk supervisory categories with different risk weights, which Basel II recommends to use external rating to determine. While IRB approach allows banks to internally assess their exposures, report self-calculated risk parameters to the regulator to arrive at the RWAs, of which the minimum capital charges is 8%. The IRB approach can be further categorized into Foundation IRB (F−IRB), which allows bank to calculate probability of default (PD) only, and Advanced IRB (A−IRB) which allows bank to calculate probability of default (PD), loss given default (LGD), exposure at default (EAD), and maturity (M).

After the recent Great Recession, BCBS introduced Basel III with revised version released in 2011. The rule keeps risk-based capital ratios, SA and IRB approach when calculating the minimum capital charges, while adding several additional layers of requirements to enhance banks' solvency. One of the additional regulations is that each bank should subject to a non-risk based leverage ratio, the ratio of Tier1 capital over total assets, based on the on balance-sheet assets and off-balance sheet exposures regardless of risk weighting. The leverage ratio, if used in isolation, might provide banks incentive to hold high risk assets, as mentioned at the very beginning. However, leverage ratio is used to together with risk-based capital ratio and IRB approach to induce bank prudent behavior. This paper investigates how the risk-based capital ratio, IRB approach and leverage ratio mutually reinforce each other. For example, how does the introduction of IRB approach into risk based capital ratio affect bank risk-taking, and how does the leverage ratio affect the above mechanism.

2.2 U.S. Basel Accords

Before Basel Accords, the United States implemented the simple leverage ratio in the early 1980s. The first Basel Accord, which was finalized in July 1988, called for a minimum ratio of capital to risk-weighted assets (RWA) of 8% to be implemented over the period 1988 to 1992 in the US. It became fully effective at the end of 1992 for all US banks. The capital contained both Tier 1 and Tier 2 capital,and the risk-weighted assets were calculated using the fixed regulatory risk weights for different categories of assets. The concerns of risk-based capital ratio in Basel I mentioned in Section 2.1 leads to the 2004 international adoption of Basel II accords. However, the quantitative research expressed the concern that the adoption of the Basel II accords would significantly reduce US banks' capital requirements. Thus, the U.S. commercial bank regulators did not completely adopt Basel II.

In response to the recent Great Recession, the Federal Reserve System (the Fed) and the Office of the Comptroller of the Currency (OCC) issued final Basel III rules to be implemented in July 2013 which were finalized in April 2014. First, the new Basel III rule implemented in the U.S. retained a simple and transparent measure of capital adequacy, the non-risk based leverage ratio, to ensure that banks hold enough capital to absorb losses. Second, Basel III rule also modified the way of how banks calculated RWAs. There are both advanced approach, also known as IRB approach, and standardized approach.

In the United States, IRB approach only applies to very large, internationally active "core" banks: large bank holding companies and their main national depository institutions. The IRB approach became effective for IRB banks on January 2014, and all core banks enter the "parallel run" period during which they must show to their supervisor that they can comply with the rules specified in the IRB approach, which is not yet used to calculate minimum capital charges until they are approved to exit parallel run. Moreover, based on the "Collins Floor", which is a part of the 2010 Dodd-Frank Wall Street Reform and Consumer Protection Act, IRB banks should calculate RWAs using both advanced approach and standardized approach, and establish the minimum capital ratios as the lower of the ratios calculated with two approaches. For non-advanced-approach banks, they are required to use standardized approach that became effective on January 2015.

3 Evolution on Economic Thought on Bank Behavior

3.1 Models of Deposit Competition

I start with the literature on bank risk-taking caused by competition. In the theoretical literature, there are two main contradictory results: (1) increased competition leads to more risk-taking, due to different frictions, such as asymmetric information about borrowers' information (Chan et al., 1986; Marquez, 2002), low franchise values (Furlong and Keely, 1989; Keely, 1990), and product differentiation (Matutes and Vives, 1996,2000). (2) increased competition reduces banks risk-taking behavior. For example, following Stiglitz and Weiss (1981),Boyd and Nicolo (2005) show that as banks' market power in the deposit and loan market become more concentrated, moral hazard is exacerbated because banks charge higher interest rates, which results in attracting risker borrowers.

Since the existing theoretical literature is mixed, I also show how competition affect bank risk. Built on Hotelling (1929) and Salop (1979), the competition in my model is measured as spatial deposit competition among banks with different sizes. In contrast to above papers, the frictions in my model arises from both moral hazard and adverse selection. Moral hazard arises when banks are in favor for risky asset that generates higher returns than safe assets. Adverse selection lies between the regulator and banks, in which banks strategic misreport their asset choice with a probability that they escape regulatory scrutiny and sanctions. Empirically, I measure deposit competition using HHI index (Jimenez et al., 2013; Berger and Bouwman, 2013; Drechsler et al., 2017). Different than their measures, the HHI is bank-specific and time-varying. I find that banks switch from investing in safe assets to risky assets as deposit competition becomes more intense, which is consistent with both my theoretical and empirical findings.

3.2 Models of Capital Requirements

This paper also contributes to the literature on the impact of regulatory policies, such as deposit rate ceiling and capital requirements, on banks' risk behavior and performance. (Allen and Gale, 2000; Francis and Osborne, 2012; Berger and Bouwman, 2013; Aiyar et al., 2014; Allen et al., 2015; Gropp et al., 2018). In my paper, I specifically examine bank capital requirements. My model is built upon Hellman, Murdock and Stiglitz (2000), Repullo (2004), and Hakenes and Schnabel (2011). In the paper written by Hellman, Murdock and Stiglitz, 2000, it aims to prevent moral hazard in the banking sector by studying the interaction between financial liberalization and prudential regulations, namely, capital requirements and deposit-rate controls. The results show that capital requirements alone is not powerful, and freely determined deposit rates reduces the franchise value of banks. Instead, combining binding or nonbinding deposit rate ceilings with capital requirements can create a regulatory regime, which adds policy flexibility and reduces the costs imposed by capital requirements.

Their paper models capital requirements without further discussing the requirements in different aspects. However, this dissertation analyzes the effect of capital requirements on bank behavior through additional and richer aspects, namely model-based IRB approach in Basel II/III and the add-on leverage ratio in Basel III.

The dissertation contributes to a rapidly growing literature on bank behavior due to the introduction of IRB approach (Jacobson et al., 2006; Blum, 2008; Wu and Zhao, 2016; Plosser and Santos, 2017; Ferri and Pesic, 2017; Montes et al., 2018). A recent series of empirical paper show that there is inconsistency between banks actual risk and self-reported asset risk measures by strategically misreporting their risk in the bank trading book (Begley et al., 2017), manipulating risk parameters in weak supervisory scrutiny (Mariathasan and Merrouche, 2014), and building up capital buffers through underreporting their portfolio risk (Vallascas and Hagendorff, 2014). However, other empirical papers show the bright side of IRB approach that it is more risk sensitive (Barakova and Palvia, 2014) and curbs credit risk driven by economic downturn (Cucinelli et al., 2018).

In the paper written by Hakenes and Schnabel, 2011, the authors study the relationship between bank size and risk-taking behavior under Basel II Accords, particularly under IRB approach. They use a model with moral hazard and imperfect competition in the deposit market, and show that if banks have the right to choose between the standardized approach and IRB approach, larger banks have competitive advantage compared to small banks, forcing small banks to take excessive risk and leading to higher aggregate risk-taking. Their paper considers IRB approach, and specifically focuses on bank risk-taking behavior that results from bank size and their right to choose which approach to adopt.

Following both Hellman, Murdock and Stiglitz's model and Hakenes and Schnabel's model, this dissertation constructs a model to study the effect of IRB approach on bank asset choice when they face deposit competition. However, this dissertation focuses on IRB approach in which there are profitable incentives for banks to exploit (regulatory capital arbitrage, RCA). My theory shows that banks have incentive to invest in more risky assets in the means of regulatory capital arbitrage in the context of deposit competition and weak regulatory scrutiny. In addition, this paper exploits a quasi-natural experiment approach (Difference-in-Difference) to evaluate the effect of the introduction of IRB, which is methodologically similar to

Behn et al., 2016, who studied impact of IRB on bank lending with German data.

Of particular relevance to this dissertation is the work by Blum, 2008. His paper examines the role of leverage ratio in the context of dishonest banks understating their asset risk under IRB approach. Different than his paper, bank excessive risk-taking not only results from the increased cost imposed by the IRB approach, but also from bank facing competition in the deposit market. Therefore, to compare the impact of different capital requirements on bank risk-taking, I derive critical competition and critical supervisory power for each capital requirements, and compare the critical values across various requirements.

The results in this dissertation suggest that the capital requirements reduce bank risk-taking from the regulator's perspective, the evolution of capital requirements is helpful only if banking regulators impose enough supersiory power to prevent RCA. Moreover, the leverage ratio in Basel III, the ratio of total capital over total assets, allows to maintain the effectiveness of capital requirements under weak supervisory environment.

4 A Model for the Analysis of Capital Requirements, Deposit Competition, and Supervisory Power

I start with the basic model framework. Consider an economy with three risk-neutral agents: banks, depositors and the regulator.

4.1 Model Setup

Banks

There are in total $n + 1$ banks: one large bank and n small banks. Each bank is indexed by i regarding its size, where $i \in \{L, S\}$, L represents the large bank and S represents small banks. Each bank is run by its managers whose interests are aligned with shareholders, so the inside equity holders and outside equity holders share the same interests[1].

Assume that banks do not have their own funds. Each bank raises its funds from depositors and equity holders. In the deposit market, the interest rate offered by a bank i is denoted as r_i. The large bank offers an interest rate on deposits of r_L in competition with all other small banks which offer depositors interest rates r_S. Assume that small banks only compete with the large bank but not among with

[1]By assuming that managers and shareholders are incentive compatible, this paper ignores the principal-agent problem that lies within them.

each other. The total volume of deposits raised by each bank i is $D_i(r_i, r_{-i})$, where the amount of deposits of a bank increases in its own deposit rate and decreases in its competitors' rates, so $D_1 > 0$ and $D_2 < 0$. For simplicity, I assume that the deposits are insured but not fully insured, and therefore the deposits raised by banks only depend on deposit rates.

Each bank i can also raise money by investing its capital K_i, which is expressed as a percentage k_i of its deposits $D_i(r_i, r_{-i})$ so the total liability for each bank i is $(1 + k_i)D_i(r_i, r_{-i})$. Assume that cost of capital is exogenous, and the participation cost is so high that it prevents depositors from entering in the market (e.g. Allen, Carletti and Marquez (2015); Vanquez and Federico (2015)), and therefore bank capital is more costly than deposits, where the cost of per unit of capital is $\rho > 0$.[2]. I also assume that banks have limited liability.

After funds are raised, banks choose to invest. They can invest in either safe or risky asset. The safe asset generates a certain per unit of return R, while the risky

[2]One explanation that capital is more costlier than deposits is that the opportunity cost of equity providers is the least benefit that they could get by investing in outside investment opportunities. The assumption can also be stated as the supply of equity is perfectly elastic at an exogenously given expected return of per unit of capital, see Hellmann, Murdock and Stiglitz (2000)

asset generates a stochastic per unit of return $\tilde{R}$, that has the following distribution:

$$\tilde{R} = \begin{cases} R^H, & \text{with prob=}p \\ 0, & \text{with prob=}1-p \end{cases} \tag{1}$$

yielding high return R_H with probability of success p, and zero return with probability $1-p$. I assume the following two assumptions:

Assumption 1. $R^H > R > pR^H$

The first inequality states that the return on the risky asset, if it is successful, is higher than the return on the safe asset, which leaves scope for banks' risk-shifting incentives. The second inequality assumes that it is socially efficient to invest in the safe asset.

Assumption 2. $\rho > R$

Following Hellmann, Murdock and Stiglitz (2000), the cost of capital is larger than the return on safe asset. If capital is costless, i.e. $\rho = R$, then banks will comply to hold required amount of capital and moral hazard problem will not even be a serious issue.

Depositors

Following Hotelling(1929) and Salop(1979), n small banks are symmetrically distributed around a circle with radius being one, whereas the large bank is located in the center of the circle. See Figure 2. In the deposit market, competition exists between one large bank and n small banks. There are λ depositors that are uniformly distributed on each radius that connects the large bank and a small bank. Each depositor is endowed with one unit of deposit. Depositors choose which type of bank they deposit, which in turn depends on the benefit from deposit rates offered by banks. Suppose a depositor is located at a distance of x and y respectively from the large bank and the small bank, and transports to deposits his money at a cost c per unit of distance. There are many cases that affect depositors' preferences on one type of bank over another but in this case no depositors have preference except on the ground of deposit rates and travel cost. Whether a bank can attract more deposits depends on the net surplus of depositors. The point of division at which a depositor is at no difference depositing his money to the large bank or the small bank is determined by the following two equations:

$$\begin{cases} r_L - cx = r_S - cy \\ x + y = 1 \end{cases} \tag{2}$$

Solving above equations finds $x = \frac{r_L - r_S}{2c} + \frac{1}{2}$ and $y = \frac{r_S - r_L}{2c} + \frac{1}{2}$,therefore the volume of deposits raised by each small bank and the large bank is:

$$D_S(r_S, r_L) \quad = \lambda \frac{r_S - r_L}{2c} + \frac{1}{2}\lambda \quad = \frac{1}{2}\lambda + \sigma(r_s - r_l) \tag{3}$$

$$D_L(r_L, r_S) \quad = n\lambda \frac{r_L - r_S}{2c} + \frac{1}{2}\lambda \quad = \frac{1}{2}n\lambda + n\sigma(r_L - r_S) \tag{4}$$

where competition is defined as $\sigma \equiv \frac{\lambda}{2c}$. The competition for deposits σ among two types of banks becomes more intense as the number of depositors λ increases and as transportation cost c decreases ($\frac{\partial \sigma}{\partial \lambda} > 0, \frac{\partial \sigma}{\partial c} < 0$). The above two equations can be expressed as

$$D_i(r_i, r_{-i}) = [1 + I_{(i=L)}(n-1)][\frac{1}{2}\lambda + \sigma(r_i - r_{-i})] \tag{5}$$

where $i \in \{L, S\}$ and $I_{(i=L)}$ is an indicator function of being the large bank. The volume of deposits is positively related to its own interest rates offered to depositors and number of depositors'($\frac{\partial D_i(r_i, r_{-i})}{\partial r_i} > 0, \frac{\partial D_i(r_i, r_{-i})}{\partial \lambda} > 0$), and it is negatively related to its competitors' deposit rates and the cost incurred to deposit money in the bank ($\frac{\partial D_i(r_i, r_{-i})}{\partial r_{-i}} < 0, \frac{\partial D_i(r_i, r_{-i})}{\partial c} < 0$).

Regulator

The Role of the Capital Regulations and Supervisory Scrutiny The regulator's goal is to maintain and improve the stability of the banking system by setting regulatory capital requirements and conducting supervisory check on banks. Several features in the banking system that justify the capital requirements and supervisory scrutiny: First, banks are highly leveraged institutions, which they prefer debt financing (e.g. deposits) than equity financing (e.g. capital) due to the fact that the servicing costs that debt imposed on banks are tax-deductible and thus lower banks' funding costs. However, high leverage also means instability for banks due to the structure of the whole banking system. In terms of stress time, banks may not be able to pay their debt due to the fluctuations of cash flows from bank assets, and thus are more vulnerable to insolvency. Second, banks' risk profiles are highly nontransparent. Depositors do not know how risky the asset banks choose. Even for the well-informed regulator, it is difficult to assess the banks precisely due to heterogeneity of banks. Third, the Internal Ratings Based approach under Basel II/III requires banks to evaluate the risk of their own credit portfolios and report it to the regulator, after which the regulator set the corresponding capital requirements based on the report. However, an adverse selection problem lies within the approach, which is the bank with risky asset might report that it invests in the safe asset in order to obtain lower minimum capital charges. Large banks, especially, are more likely to take advantage the IRB framework and misreport their risk profile because they do not internalize the bailout cost if they fail. Fourth, banks exert less monitoring effort on their asset portfolios and therefore exposing depositors' money at risk.

Capital Requirements Thus, I analyze a model of deposits and capital structure under three different capital requirements: simple leverage ratio requirement only, risk-based capital requirement with IRB framework, and risk-based capital requirement with IRB framework and an add-on leverage ratio.

Simple Leverage Ratio The simple leverage ratio was the requirement enforced since the early 1980s before Basel Accords.[3] It is expressed as the ratio of the total bank capital to total assets, therefore the capital that bank i is required to hold regardless of its assets' risk profile is:

$$K_i \geq \beta[K_i + D_i(r_i, r_{-i})] \tag{6}$$

[3] In the United States, the simple leverage ratio requirement was introduced in 1981 aiming to ensure safety of the banking system due to failure of a number of banks. In Canada, it was introduced in 1982 after the increasing leverage by its banks and tightened in 1991.

Risk-Based Capital Ratio with IRB Approach The Basel II of risk-based capital framework requires that the amount of capital that a bank holds should be in accordance with the risk that it is imposed to. The higher the risk imposed by a bank, the higher the amount of required regulatory capital to safeguard its solvency and stability of the banking system. Under Basel II, the Internal-Rating Based Approach assumes that banks fully control their information about the riskiness of assets, and the minimum capital charges depends on banks' reported asset risk profiles. However, the adoption of IRB approach provides profit opportunities for banks to avoid the intention of the regulation while complying with its form. For example, the model-based IRB approach create incentives for bank to conduct regulatory capital arbitrage by strategically misreporting the risk parameters for a lower minimum capital charges. Thus, the regulator should conduct supervisory review on bank capital adequacy and internal assessment. Hence, the process is modeled below:

– Each bank reports its asset type (safe or risky) to the regulator after the state of the world is realized.[4]

– The regulator sets capital requirement based on the reports. If the bank in-

[4]Under Basel II's IRB approach, banks are given freedom to use their own empirical model to evaluate probability of default (PD), loss given default (LGD) and exposure at default (EAD). Here, for simplicity, I assume that the asset type indicates above measurements.

vests in safe asset, then the capital requirement is:

$$K_i \geq \beta_1[K_i + D_i(r_i, r_{-i})] \tag{7}$$

if the bank invests in risky asset, then the requirement becomes:

$$K_i \geq \beta_2[K_i + D_i(r_i, r_{-i})] \tag{8}$$

– After the returns are realized and if the bank is solvent, the regulator conducts supervisory check: with probability η, the regulator detects that the bank misstated its asset type, requires bank to raise capital and imposes a sanction. The cost of raising capital and paying sanction is S, which is defined as proportion of bank's deposits, $C = \delta D_i(r_i, r_{-i})$; with probability $1 - \eta$, the regulator cannot detect bank's misbehavior.

Risk-Based Capital Ratio with IRB Approach and An Add-on Leverage Ratio Introducing leverage ratio [5] to the risk-based capital requirement in Basel III aims to counterbalance the systemic risk that banks build up in boom

[5] Although the leverage ratio introduced in Basel I and III aims to maintain the stability of the banking system, Basel III leverage ratio targets not only depository institutions but also investment banks that imposed large systemic risk on the recent financial crisis. However, theoretically, the leverage ratios under both Basel requirements are represented by the same mathematical equation.

when higher risks are exposed due to expansion of banks' balance sheets. The ratio, which complements the risk-based capital ratio, also serves as a constraint on bank behavior. It requires banks to hold minimum amount of Tier1 capital relative to their combined on-balance and off-balance sheets assets regardless of the their self-reported risk parameters. If a bank holds safe asset, or holds risky asset but claims it to be safe, it is subject to equations (6) and (7); otherwise it is subject to equations (6) and (8). I assume that $\beta_2 > \beta > \beta_1$.[6] The assumption illustrates that a bank takes higher risk should hold higher capital to compensate, and the leverage ratio sets a meaningful binding constraint if the bank claims the risky asset to be safe. In other words, whether the leverage ratio is binding or not depends on the type of their assets and the truthfulness of their reports.

4.2 Competitive Equilibria of Gambling without Capital Requirements

I now investigate the necessity of capital requirements, ex post choice of capital and deposit rate, critical competition and critical deposit rate in the deposit market that induce banks to conduct risk-taking.

In order to justify the necessity of capital requirements, it is important to discuss

[6] This assumption is seen in the literature (see, e.g. Blum (2008); Hakenes and Schnabel (2011)).

bank' risk-taking behavior without any requirements. Therefore, the purpose of this section is to derive the conditions under which banks choose to risk-taking in equilibrium when the deposit market is sufficiently competitive. Each bank chooses to invest either safe or risky asset, and it maximizes its expected returns by choosing the best allocations of capital and deposit rates. The expected return from investing in safe asset for bank i, defined as π_i^P, is $[R(1+k_i)-\rho k_i - r_i]D_i(r_i, r_{-i})$ The expected return from risky asset, defined as π_i^G, is $\{p[R_H(1+k_i)-r_i]-\rho k_i\}D_i(r_i, r_{-i})$. The first term in both equations is the returns that bank i earns from safe or risky asset, and the last two terms represent cost of capital and deposits. All terms are expressed in terms of deposits $D_i(r_i, r_{-i})$, which are defined in equation (5). Banks, regardless of their size, choose safe asset if:

$$\pi_i^P \geq \pi_i^G \tag{9}$$

Solving the above equation finds the critical value of deposit rates above which banks take higher risk:

$$r_i > \frac{R - pR^H}{1-p} \frac{K_i + D_i(r_i, r_{-i})}{D_i(r_i, r_{-i})} = \frac{R - pR^H}{1-p}(1+k_i) \equiv r_i^c \tag{10}$$

The constraint is intuitive: if deposit rates are higher than the critical level, banks are more willing to take more risk due to the high cost of bank deposit funding.

The critical deposit rate is also sensible: it decreases as the probability of success for risky asset increases, and as capital per unit of deposits k_i decreases, which means that it is more likely that banks prefer to invest in risky asset due to higher probability of of success in risky asset and high leverage. Hence, if a bank intends to hold safe asset, its problem is

$$\begin{aligned} \underset{k_i,r_i}{\text{Max}} \quad & \pi_i^P = [R(1+k_i) - \rho k_i - r_i]D_i(r_i, r_{-i}),\ i \in \{L, S\} \\ \text{subject to} \quad & r_i \leqslant r_i^c \\ & D_i(r_i, r_{-i}) = [1 + I_{(i=L)}(n-1)][\frac{1}{2}\lambda + \sigma(r_i - r_{-i})] \end{aligned} \tag{11}$$

$\partial\pi_i^P/\partial k_i < 0$ tells that holding capital reduces the bank's expected return, so the bank will hold no capital. Solving $\partial\pi_i^P/\partial r_i = 0$ combined with $k_i = 0$ yields the optimal allocations (k_i, r_i) for $i \in \{L, S\}$ are $\{k_i = 0, r_i = \frac{1}{2}r_{-i} - \frac{\lambda}{4\sigma} + \frac{1}{2}[R(1 + k_i) - \rho k_i]\}$. Considering symmetric equilibrium $(r_l = r_s)$ and as the deposit market becomes sufficiently competitive $(\sigma \to \infty)$, the allocations become $(k_i = 0, r_i = R)$ and the critical deposit rate under no capital requirements becomes $r_i^c = (R - pR^H)/(1-p)$. Since the bank chooses safe asset if its deposit rate is smaller than the critical level, the results indicate that there is no prudent equilibrium where both types of banks invest in safe asset.

Similarly, considering a bank investing in risky asset, the problem is set up as below:

$$\begin{aligned} \underset{k_i,r_i}{\text{Max}} \quad & \pi_i^G = \{p[R_H(1+k_i) - r_i] - \rho k_i\}D_i(r_i, r_{-i}),\ i \in \{L, S\} \\ \text{subject to} \quad & r_i > r_i^c \\ & D_i(r_i, r_{-i}) = [1 + I_{(i=L)}(n-1)][\frac{1}{2}\lambda + \sigma(r_i - r_{-i})] \end{aligned} \tag{12}$$

The optimal solution under symmetric equilibrium and sufficiently competition is $(k_i = 0, r_i = R^H)$. Since $R^H > r_i^c$, all banks enjoy to invest in risky asset.

Proposition 1. *Under sufficiently competition in the deposit market ($\sigma \to \infty$), the outcome without capital requirement is as follows: (i) No banks hold capital. (ii) a competitive gambling (risky investment) equilibrium exists.*

4.3 Simple Leverage Ratio Requirement

Since both types of banks engage in risk-taking without capital requirements, some forms of capital requirements are necessary. I now consider banks' problems under which the capital that each bank i is required to hold is β proportion of its total assets. I start with the case that banks only invest in safe asset. Then I analyze the case where banks only invest in risky asset. At last, I analyze the more general case where banks can choose between safe or risky asset.

The Model with Safe Asset I start with analysis for the large bank. The large bank L's optimal allocations $\{k_L, r_L\}$ of safe asset must satisfy three properties: First, it must satisfy deposits constraint . Otherwise the large bank cannot invest with deposits more than D_L. Second, the deposit rate offered should be less than the critical deposit rate so that the large bank is willing to invest in safe asset. Third, the large bank must subject to the simple leverage ratio requirement. Hence the problem is the same with equation (11) with an additional capital constraint, which is equation (6).

Since the assumption 2 assumes that the cost of capital per unit of deposit is greater than the return from safe asset, the large bank's expected returns increase as capital k_L decreases. Therefore, the leverage ratio constraint is binding, where $k_L = \beta/(1-\beta)$. Solving deposit rates give $r_L = \frac{r_S}{2} + \frac{R-\rho\beta}{2(1-\beta)} - \frac{\lambda}{4\sigma}$, where $r_S \leqslant 2r_L^c + \frac{\lambda}{2\sigma} - \frac{R-\beta\rho}{1-\beta}$ and $r_L^c = \frac{R-pR^H}{(1-p)(1-\beta)}$. The results show that the large bank is more likely to increase its interest rate to attract more deposits when the deposit competition becomes more intense or when small banks offer higher deposit rate. The critical deposit rate increases under stricter capital requirements $(\beta \uparrow)$. It means that the large bank takes less risk when the leverage ratio is more stringent. The expected payoff is $\pi_L^P = [\frac{n\lambda}{2} + n\sigma(r_L - r_S)][r_L - r_S + \frac{\lambda}{2\sigma}]$. When r_L increases to r_L^c, the large bank's strategy is still choosing safe asset with payoff being $[\frac{n\lambda}{2} + n\sigma(r_L^c -$

$r_S)][\frac{R-\rho\beta}{1-\beta} - r_L^c]$.

The Model with Risky Asset If the large bank chooses risky asset, the problem setup is similar to equation (12) with an additional capital constraint equation (6). The private optimal solutions are $k_L = \beta/(1-\beta), r_L = \frac{r_S}{2} + \frac{pR^H - \rho\beta}{2p(1-\beta)} - \frac{\lambda}{4\sigma}$, where $r_S > 2r_L^c + \frac{\lambda}{2\sigma} - \frac{pR^H-\rho\beta}{p(1-\beta)}$ and $r_L^c = \frac{R-pR^H}{(1-p)(1-\beta)}$. Therefore, the expected return from risky is $n\sigma p[\frac{pR^H-\rho\beta}{2p(1-\beta)} - \frac{r_S}{2} + \frac{\lambda}{4\sigma}]^2$. The problem for small banks S follows similar analysis with the large bank's problem.

Proposition 2. *For each bank i, where $i \in \{L, S\}$ its private optimal solutions under simple leverage ratio requirement are as follows:*

$$k_i = \frac{\beta}{1-\beta}, \tag{13}$$

$$r_i = \begin{cases} \frac{r_{-i}}{2} + \frac{R-\rho\beta}{2(1-\beta)} - \frac{\lambda}{4\sigma}, & \text{if } r_{-i} \leqslant 2r_i^c - \frac{R-\rho\beta}{1-\beta} + \frac{\lambda}{2\sigma} \\ r_i^c \\ \frac{r_{-i}}{2} + \frac{pR^H-\rho\beta}{2p(1-\beta)} - \frac{\lambda}{4\sigma}, & \text{if } r_{-i} \geqslant 2r_i^c - \frac{pR^H-\rho\beta}{p(1-\beta)} + \frac{\lambda}{2\sigma} \end{cases} \tag{14}$$

The optimal solution for k_i shows that the capital requirement constraint is binding for each bank i. The result shows that, theoretically, bank i chooses to hold the minimum amount of capital due to the assumption 2 that the cost of capital is larger than the return from safe asset, and that the leverage ratio requirement can reduce bank's moral hazard incentive of conducting more risk. However, in reality, the actual capital banks hold is higher than the minimum capital required by the capital regulations, and banks hold capital buffer due to precautionary motives. My model pays more attention on the impact of capital requirement on bank risk-taking, and simplifies the reality by not differentiating regulatory capital and actual capital. Therefore, actual capital in my model always equals to the minimum required by regulation.

The optimal solutions for interest rates show that the interest rates offered by bank i depend upon its competitors' interest rates, capital requirement, amount of deposits in the deposit market, the cost incurred on depositors for depositing their money, the return on assets and cost of capital. Bank i invests in safe asset when cost of raising deposits is small, shown as low interest rates. As its competitors raise deposit rates to attract more deposits, bank i responds by raising its deposit rate. When r_i is above r^c, the cost of raising deposits is so high that bank i chooses risky asset with higher return to offset the cost from raising deposits. Therefore, the economy ends up with two possible equilibria: prudent and gambling equilibrium. Considering the symmetric equilibrium, the above proposition can be can be rewritten as below:

$$
\begin{aligned}
k_i &= \frac{\beta}{1-\beta}, \qquad (15)\\
r_i &= \begin{cases} \dfrac{R-\rho\beta}{(1-\beta)} - \dfrac{\lambda}{2\sigma}, & \text{if both types of banks choose safe asset} \\ r^c = \dfrac{R-pR^H}{(1-p)(1-\beta)}, & \text{if both types of banks choose safe asset} \\ \dfrac{pR^H-\rho\beta}{p(1-\beta)} - \dfrac{\lambda}{2\sigma}, & \text{if both types of banks choose risky asset} \end{cases} \qquad (16)
\end{aligned}
$$

and expected returns associated with three different levels of deposit rates are:

$$
\begin{aligned}
\pi_S &= \frac{1}{n}\pi_L \qquad (17)\\
\pi_L &= \begin{cases} \dfrac{n\lambda^2}{4\sigma}, & \text{if } r_L = \dfrac{R-\rho\beta}{(1-\beta)} - \dfrac{\lambda}{2\sigma} \\ \dfrac{n\lambda(pR^H+\beta\rho p-Rp-\beta\rho)}{2(1-p)(1-\beta)}, & \text{if } r_L^c = \dfrac{R-pR^H}{(1-p)(1-\beta)} \\ \dfrac{n\lambda^2 p}{4\sigma}, & \text{if } r_L = \dfrac{pR^H-\rho\beta}{p(1-\beta)} - \dfrac{\lambda}{2\sigma} \end{cases} \qquad (18)
\end{aligned}
$$

The General Model In the general model, banks with different sizes can invest in either safe or risky asset. Banks keep capital k_i at $\beta/(1-\beta)$ regardless of their size and asset choice. Therefore, when analyzing the general model, I put emphasis on the situation that given capital level k_i, banks jump from the prudent equilibrium to gambling equilibrium. Suppose that in order to attract more deposits, both types of banks have already increases their deposit rates at r^c, the large bank j diverts from the prudent equilibrium and invests in risky asset, then the critical competition above which the large bank prefers safe to risky asset satisfies the following equation:

$$\underset{r_j}{\text{Max}}\{p[R^H(1+\frac{\beta}{1-\beta})-r_j]-\rho\frac{\beta}{1-\beta}\}D_j(r_j,r^c)\leq\frac{n\lambda(pR^H+\beta\rho p-Rp-\beta\rho)}{2(1-p)(1-\beta)} \quad (19)$$

where

$$D_j(r_j,r^c)=\frac{1}{2}n\lambda+n\sigma(r_j-r^c) \quad (20)$$

The left hand side of equation (19) represents the payoff for the large bank j if it chooses risky given all other banks choose safe asset at the critical deposit rate. The right hand side represents the payoff for safe asset at the critical deposit rate. The same analysis applies to small banks if they divert from the prudent equilibrium. Solving the above equation yields the following outcomes:

Proposition 3. *Under simple leverage ratio requirement, the outcomes are as follows: (i) The critical competition level above which both types of banks choose risky asset is:*

$$\sigma_l^c=\frac{\lambda p(1-p)(1-\beta)}{2[p(R^H-R)-\rho\beta(1-p)]} \quad (21)$$

(ii) The comparative study shows that: - if $\rho < \dfrac{p(R^H - R)}{1-p}$, $\dfrac{\partial \sigma_l^c}{\partial \beta} < 0$ *- if* $\rho > \dfrac{p(R^H - R)}{1-p}$, $\dfrac{\partial \sigma_l^c}{\partial \beta} > 0$

Proposition 3 shows that there exists a critical competition level above which banks choose risky asset. Moreover, if the leverage ratio forces banks to hold more capital, they are more inclined to invest more aggressively when the cost of capital is low. This is because banks, regardless of their asset choice, are required to keep higher amount of capital, they have incentives to invest in risky asset in order to gain the higher return R^H when cost of capital is cheap. If the cost of capital is too high, banks are more conservative when considering risky asset because the failure of risky asset results in insolvency.

4.4 Risk-Based Capital Requirement with IRB Approach

As mentioned before, the capital that each bank holds must match the risk profile of its assets. I start with the informal description of the model and the asymmetric information problem that lies within. Each bank's decision problem maximizes the expected cash flow from its investment by choosing optimal capital and deposit rates subject to the capital requirement where the required capital level matches the risk that it exposes. Specifically, if the bank finances risky asset, it is subject to more stringent capital requirement. The introduction of IRB approach allows banks to conduct internal calculations on the risk parameters of their asset and report them to the regulator. The approach is based on the assumption that banks truthfully report their risk profile of assets. However, banks may not have incentive to report truthfully and might invest aggressively to gain higher return that comes with higher risk imposed to the banking system. Therefore, the uncertainty imposed on the banking system comes from the incentives that banks strategically misreport their risk parameters for a lower minimum capital charges. I model the misstated risk parameters as wrong asset type. I first assume that all banks follow IRB approach, and analyze banks' behavior under three cases: (1) all banks invest in safe asset; (2) all banks invest in risky asset with no incentive to misreport; (3) all banks invest in risky asset with tendency to misreport.

The Model with Safe Asset Consider first that all banks choose safe asset. Its problem follows the similar setup as before. Hence the problem becomes:

$$\begin{aligned} \underset{k_i, r_i}{\text{Max}} \quad & \pi_i^P = [R(1+k_i) - \rho k_i - r_i] D_i(r_i, r_{-i}), \\ \text{subject to} \quad & r_i \leqslant r^c_{RB,IRB} \\ & D_i(r_i, r_{-i}) = [1 + I_{(i=L)}(n-1)][\frac{1}{2}\lambda + \sigma(r_i - r_{-i})] \\ & K_i \geq \beta_1 [K_i + D_i(r_i, r_{-i})] \end{aligned} \tag{22}$$

where $r^c_{RB,IRB}$ represents the critical deposit rate below which banks choose safe asset in risk-based capital ratio (RB) and IRB approach. The third constraint specifies the capital constraint for safe asset under risk-based capital requirement. Solving the model yields that it is binding. The first constraint indicates the incentive compatibility for which each bank, regardless of its size, prefers to invest in safe than risky asset. The optimal solutions for the above problem is

$$k_i = \frac{\beta_1}{1-\beta_1}, \quad (23)$$

$$r_i = \frac{r_L}{2} + \frac{R-\rho\beta_1}{2(1-\beta_1)} - \frac{\lambda}{4\sigma} \quad (24)$$

where $r_i \leq r^c_{RB,IRB}$[7].

The Model with Risky Asset, No Misreport Now consider the case where all banks choose to invest in risky asset and report truthfully about their asset choices. The capital constraint that banks are subject to is $K_i \geq \beta_2[K_i + D_i(r_i, r_{-i})]$. Banks prefer risky asset when $r_i > r^c_{RB,IRB}$. The optimal solution for capital is a binding solution which is $\beta_2/(1-\beta_2)$.

For each bank i, regardless of its size, the incentive compatibility constraint for

[7] $r^c_{RB,IRB}$ is calculated in the following subsection, see equation (24)

choosing risky asset other than safe asset, given binding capital constraints, is:

$$\{R(1+\frac{\beta_1}{1-\beta_1})-\rho\frac{\beta_1}{1-\beta_1}-r_i\}D_i(r_i,r_{-i}) < \{p[R^H(1+\frac{\beta_2}{1-\beta_2})-r_i]-\rho\frac{\beta_2}{1-\beta_2}\}D_i(r_i,r_{-i}), \tag{25}$$

Solving the above inequality gives

$$r_i > \frac{R-pR^H}{(1-p)(1-\beta_2)} + \frac{(\rho-R)(\beta_2-\beta_1)}{(1-p)(1-\beta_1)(1-\beta_2)} \equiv r^c_{RB,IRB} \tag{26}$$

Proposition 4. *Under risk-based capital requirement, the outcomes are as follows:*

(i) The critical deposit rate above which banks choose risky asset is:

$$r^c_{RB,IRB} \equiv \frac{R-pR^H}{(1-p)(1-\beta_2)} + \frac{(\rho-R)(\beta_2-\beta_1)}{(1-p)(1-\beta_1)(1-\beta_2)} \tag{27}$$

(ii) The critical competition level above which banks prefer risky asset is:

$$\begin{aligned} \sigma^c_{RB,IRB} &= \frac{\lambda p}{2A} \\ where A &= \frac{pR^H(1-\beta_1)-pR(1-\beta_2)}{(1-p)(1-\beta_1)(1-\beta_2)} + \frac{\rho[\beta_1 p(1-\beta_2)]-\beta_2(1-\beta_1)}{(1-p)(1-\beta_1)(1-\beta_2)} \end{aligned} \tag{28}$$

Assume that banks do not misstate their risk parameters of their asset portfolio risk under IRB framework, and that the self-measured credit risk matches the risk assigned by the regulator. In Proposition 4, both the critical deposit rate and the critical competition show that they are positively related to β_2, and negatively related to β_1. The intuition is straightforward: if the regulator imposes stricter capital requirement on safe asset (higher β_1), then both critical values decreases. This shows that banks are more opt to risky asset because of higher minimum capital charges if they invest in safe asset. Similarly, increasing capital requirement for the risky asset, β_2, raises both critical deposit rate and competition level, which makes safe asset more attractive for banks.

The Model with Risky Asset, Misreport There is no incentives for banks to invest in safe asset and misstate the asset type. I have shown the case where banks choose to invest in risky asset without strategically misreporting their asset type. However, the model-based IRB approach provides incentives for banks to conduct regulatory capital arbitrage. The regulator, therefore, conducts supervisory check on the remaining solvent banks after the returns are realized.The regulator detects misbehaved banks with probability η. Once a misbehaved bank is detected, the bank needs to replenish capital and pays a sanction. The total cost incurred on banks to raise capital and pay sanction is defined as proportion of bank's deposits $C = \delta D_i(r_i, r_{-i})$; with probability $1 - \eta$, the regulator cannot detect banks' misreport. Hence, the expected return of bank i from risky asset and misreporting is

$$\begin{aligned}\pi_i^G &= (1-\eta)\pi_i^{G,nd} + \eta\pi_i^{G,d},\\ &= (1-\eta)\{p[R^H(1+k_i^G) - r_i] - \rho k_i\}D_i + \eta\{p[R^H(1+k_i^G) - r_i - \delta] - \rho k_i\}D_i,\\ &= \{p[R^H(1+k_i) - r_i] - \rho k_i - p\eta\delta\}D_i,\end{aligned} \tag{29}$$

The first component,denoted as $\pi_i^{G,nd}$ represents the expected return from risky asset and not being detected by the regulator, the second component $\pi_i^{G,d}$ represents the expected return from risky asset, and being detected by the regulator.

Proposition 5. *Under the risk-based capital requirements with IRB approach, if banks misreport, the outcomes are as follows:*

(i) the critical deposit rate above which banks choose to invest in risky asset and misreport is defined as

$$r^c_{RB,IRB+RCA} = \frac{R - pR^H}{(1-p)(1-\beta_1)} + \eta\delta\frac{p}{1-p}. \tag{30}$$

(ii) The critical competition level above which banks choose to invest in risky asset and misreport is

$$\sigma^c_{RB,IRB+RCA} = \frac{\lambda p}{2H} \quad \text{where } H = \frac{p(R^H - R) - \beta_1\rho(1-p)}{(1-p)(1-\beta_1)} - \eta\delta\frac{p}{1-p}, \tag{31}$$

(iii) Banks do not have incentives to strategic misreport if

$$\eta\delta > \frac{(\beta_2 - \beta_1)(\rho - pR^H)}{p(1-\beta_1)(1-\beta_2)} \equiv \eta\delta^c_{RB,IRB+RCA} \tag{32}$$

where RB represents risk-based capital ratio and $IRB + RCA$ represents the Internal-rating Based approach (IRB) with regulatory capital arbitrage (RCA).

Considering the case that banks misreport, the critical deposit rate and critical competition above which banks prefer risky asset and misreport to safe asset are $r^c_{RB,IRB+RCA}$ and $\sigma^c_{RB,IRB+RCA}$. The comparative statics show that $\partial r^c_{RB,IRB+RCA}/\partial\beta_1 > 0$, $\partial\sigma^c_{RB,IRB+RCA}/\partial\beta_1 > 0$ and $\partial\sigma^c_{RB,IRB+RCA}/\partial\rho > 0$. Higher β_1 requires banks to hold more capital when investing in risky asset and misreport, which indirectly reduces the benefit of misreport. The regulator's supervisory power (δ and η) matters to banks' behavior. As supervisory scrutiny increases, both critical values increase, which means that banks prefer to invest safe assets under tighter supervisory environment.

The importance of supervisory scrutiny is also shown in (iii) of proposition 5. Banks prefer to invest in risky asset and misstated their asset risk if the payoff from risky asset and misreport is higher than the one from truthfully report. Comparing the two payoffs arrives at inequality (30). It illustrates that, given banks prefer risky asset, if the amount of sanction, represented as proportion of deposits, or the probability that the regulator is able to detect banks' misbehavior or both are higher than a certain level, then banks report truthfully. In other words, banks are willing to truthfully report their asset type if the ex post sanction is larger than the ex ante benefit of not telling the truth.[8] The supervisory power depends upon the differentiation of capital requirements for risky and safe asset ($\beta_2 - \beta_1$). Higher supervisory power and increasing supervisory scrutiny are needed to guarantee bank prudent behavior as the differentiation increases because it provides banks more incentives to misreport with low minimum capital charges.

4.5 Risk-Based Capital Requirement with IRB Approach and an Add-on Leverage Ratio

This section extends the model to study Basel III, which introduces a leverage ratio to risk-based capital requirement and IRB approach. Banks, regardless their sizes and portfolio choices, are subject to a non-risk based leverage ratio, which requires all banks to hold minimum Tier1 capital relative to both on-balance- and off-balance- sheet assets. As mentioned in previous sections, the leverage ratio in

[8] I assume that bank are indifferent between reporting the correct asset type and misreport when $\eta\delta = \dfrac{(\beta_2 - \beta_1)(\rho - pR^H)}{p(1-\beta_1)(1-\beta_2)}$.

Basel III is different than the leverage ratio in Basel I in terms of the component of capital and total assets. However, my model, for simplicity, does not differentiate between regulatory capital and actual capital, also it does not categorize capital into Tier1 and Tier2 capital. Thus, the leverage ratio is Basel III has the same form with the leverage ratio in Basel I, expressed as $K_i \geqslant \beta(K_i + D_i)$.

Therefore, each bank is subject to two capital regulations: risk-based capital ratio and the leverage ratio. I assume that $\beta_2 > \beta > \beta_1$. The relationship between βs sets a lower bound on the required capital for the case that banks invest in risky asset and misreport. The risky banks hold β capital instead of β_1, reducing their incentive to misreport. The purpose of this section is to investigate the impact of an additional leverage ratio on banks' incentives under IRB framework and their prudent behavior, and how leverage ratio affects supervisory scrutiny. To determine the critical competition levels, banks compare the expected returns between choosing safe asset and risky asset, with the possibility that banks misreport.

Proposition 6. *Under the risk-based capital requirements with leverage ratio, the outcomes are as follows: (i) The critical deposit rate and competition above which banks invest in risky asset and truthfully report are*

$$r^c_{RB+Lev,IRB} = \frac{R(1-\beta_2) + \rho(\beta_2 - \beta) - pR^H(1-\beta)}{(1-\beta)(1-\beta_2)(1-p)} \tag{33}$$

$$\sigma^c_{RB+Lev,IRB} = \frac{\lambda p}{2A'} \quad \text{where } A' = \frac{(pR^H - \beta_2\rho)(1-\beta) - p(1-\beta_2)(R-\beta\rho)}{(1-p)(1-\beta)(1-\beta_2)}, \tag{34}$$

(ii) The critical deposit rate and competition level above which banks invest in risky asset and misreport are:

$$r^c_{RV+Lev,IRB+RCA} = \frac{R - pR^H}{(1-\beta)(1-p)} + \frac{p\eta\delta}{1-p} \tag{35}$$

$$\sigma^c_{RB+Lev,IRB+RCA} = \frac{\lambda p}{2H'} \quad \text{where } H' = \frac{p(R^H - R) - \beta\rho(1-p)}{(1-p)(1-\beta)} - \frac{p}{1-p}\eta\delta, \tag{36}$$

(iii) Banks do not have incentive to strategic misreport if:

$$\eta\delta > \frac{(\beta_2 - \beta)(\rho - pR^H)}{p(1-\beta)(1-\beta_2)} \equiv \eta\delta^c_{RB+Lev,IRB+RCA} \tag{37}$$

Proposition 6, similar to Proposition 4 and 5, shows that, without regulatory capital arbitrage, the critical deposit rate and competition level in (i) are positively related to β_2, and negatively related to β. It shows that higher capital charges on risky asset reduces banks' incentives to conduct risk-taking. However, the leverage ratio constraint forces banks with safe asset to hold higher minimum capital charges β other than β_1. The reason lies in two aspects: first, the leverage ratio in Basel III is a non-risk based capital ratio, so banks with higher proportion of safe assets are required to hold as much as minimum capital as banks with higher proportion of risky assets. Second, my model assumes that $\beta_2 > \beta > \beta_1$. It guarantees the leverage ratio serves as a binding constraint for risky banks. However, banks with safe asset are required to hold higher minimum capital given the assumption.

With the possible regulatory capital arbitrage introduced by IRB approach, higher leverage ratio and higher supervisory scrutiny increase the critical deposit rate and competition level, and thus, reduce bank risk-taking. The critical supervisory power (right hand side of equation (35)), above which banks do not misreport, depends upon the risk-based capital ratio on risky asset and the leverage ratio. The regulator needs to impose higher supervisory power to prevent banks from regulatory capital arbitrage as the minimum capital charges on risky asset increase or as leverage ratio decreases.

Proposition 7. *The comparative studies show that:*

(i) Under risk-based capital ratio with IRB approach,

$$\textit{if } \eta\delta > \frac{(\beta_2 - \beta_1)(\rho - pR^H)}{p(1-\beta_1)(1-\beta_2)} \quad \textit{, then } \sigma^c_{RB,IRB+RCA} > \sigma^c_{RB,IRB}\textit{; vice versa.} \tag{38}$$

(ii) Under risk-based capital ratio with IRB approach and leverage ratio,

$$\textit{if } \eta\delta > \frac{(\beta_2 - \beta)(\rho - pR^H)}{p(1-\beta)(1-\beta_2)} \quad , \textit{ then } \sigma^c_{RB+Lev,IRB+RCA} > \sigma^c_{RB+Lev,IRB} > \sigma^c_l; \textit{ vice versa.} \tag{39}$$

(iii) Without regulatory capital arbitrage (RCA),

$$\sigma^c_{RB+Lev,IRB} > \sigma^c_{RB,IRB} > \sigma^c_l; \tag{40}$$

With regulatory capital arbitrage,

$$\sigma^c_{RB+Lev,IRB+RCA} > \sigma^c_{RB,IRB+RCA} \quad \textit{with } \eta\delta^c_{RB+Lev,IRB+RCA} < \eta\delta^c_{RB,IRB+RCA} \tag{41}$$

The (i) and (ii) of Proposition 7 show that as long as supervisory power is high, the thresholds of critical competition levels for risky asset increase even when banks arbitrage. This indicates that when supervisory power is high enough, banks with incentive to arbitrage are less likely to conduct risk-taking behavior given a certain level of deposit competition. The inequality (38) in Proposition 7 (iii) shows that the effectiveness of capital requirements on reducing bank credit risk improves as capital requirements being evolved, if banks do not arbitrage. The (39) shows that if banks arbitrage, the non-risk based leverage ratio can simultaneously improve the effectiveness of capital requirements and lower supervisory power that restricts bank arbitrage. Figure 1 displays the thresholds of competition levels and supervisory powers under capital requirements with and without regulatory capital arbitrage.

5 Empirical Support for Key Assumptions

The discussion in this part provides descriptive empirical support for the key assumptions mentioned in the model such as the adverse selection and moral hazard in banking, costly external finance, banks competition for deposits and market power.

5.1 Moral Hazard and Adverse Selection Problem

The model relies on the assumption that given inside equity holders (managers) and outside equity holders share the same interests, the asymmetric information problems come from: (1) the moral hazard in which depositors whose money are insured do not have information about banks portfolio choice and (2) the adverse selection in which the regulator cannot directly verify banks' reports before setting capital requirements. Both assumptions find numerous support.

Jensen and Meckling (1976) state that shareholders (banks), after raising deposits and other forms of debt, have stronger incentives to invest aggressively with an expectation that those investments generate higher return even when they have low probability of success. Duran and Lozano-Vivas (2014) study whether risk-shifting exists in the US banking system with data from 1998-2011. Their findings show that it does exist in the pre-crisis and crisis subsamples, which exacerbated the severity of the 2008 financial crisis. A finding similar to that of Landier, Sraer and Thesmar (2011) for the subprime mortgage originator who reacts to the increasing interest rate with more riskier loan contracts. For depositors, most of them do not monitor their money carefully given their money is insured. In reality, most depositors are sparsely distributed and do not even have information to monitor banks' portfolio choice. Lyer, Rajkamal and Puri (2012) study the depositors' behavior when facing a run of their bank whose neighboring bank had failed in India using micro-depositor-level data. They find that inside staff and depositors with loan linkages exhibit a tendency to withdraw earlier together with uninsured depositors prior to the release of public information, while depositors with less information start to withdraw after the information is released.

Another asymmetric information comes from the adverse selection aspect of capital requirement.

5.2 Competition for Deposits and Market Power

The model of deposit market aims at capturing spatial competition and market power issues. In my model, market power arises from customer deposits. In this section, I report some evidence of this.

Market power and competition of banks with different size in the deposit market can arise from four features: (1) the federal reserve is raising interest rates and reversing quantitative easing; (2) there are comments and uniform agreements from bankers that deposits are becoming more competitive; (3) the Basel III regulation emphasizes the importance of retail deposits funding for large banks; (4) large banks are more likely to operate widespread branches and ATM networks.

At the end of 2008, in order to stimulate economy, the Fed launched large scale asset purchase (also called quantitative easing, QE) QE1 with a purchase of $600 billions agency mortgage-backed securities (MBS). Continued with QE2 and QE3 of purchasing long-term treasury bonds and MBS, the Fed's balance sheets have been expanded from less than $900 billions in the mid-2008 to nearly $4.5 trillion by July 2015. Late in 2017, the Fed started to unwind the QE purchasing and increased the short-term interest rates, such as federal funds target rate. As of September 2018, the federal funds target rates have increased to 2%-2.25%. The unwinding QE leads bank asset managers to purchase the newly issued MBS with banks' excess reserves. Nonbanks can also pay for the securities by drawing down their nonoperational deposits from banks, which results in a decrease in banks' deposits and a shrink in the Fed's balance sheets. The reversing QE results in lower bank deposits, which in turn increasing the funding costs of banks. Banks, therefore, would increase its deposit rates to attract more deposits given the increasing policy rates environment.

Since this is the first time that the Fed used QE to stimulate economy in 2008, the consequence of reversing QE on banks' deposits is not clear. For example, Tony and Poi (2016) demonstrates with their Moody's macro model that there is no risk of declining deposits in the banking system from reversing QE. The model in this paper does not explicitly consider the effect of reserving QE on banks' deposit and competition, but the assumption of competition in the deposit market can be justified by the current interest rate environment.

Regarding the last three features, a survey of 370 bankers conducted by Promontory Interfinancial Network shows that four-fourth of them are expecting more intense deposit competition in 2018 [9]. The data released from FDIC till June 2018 shows that banks with assets less than $10 billions suffered deposits loss by 3% within a 12-month period and deposits at banks with assets more than $10 billions climbed 6% during the most recent 12-month period [10]. In addition, the new liquidity ratio requirement that came out of Basel III and finalized in 2004 requires large banks with more than $250 billions assets to keep a ratio of 100 percent high qual-

[9] The survey conducted by Promontory Interfinancial Network showed that bankers are unanimous about the increasing competition in the deposit market (see "Bank competition heats up for US customer deposits," Financial Times, April 8, 2018).

[10] The data till June 2018 from FDIC shows that deposits at large banks, e.g. BOA, jumped 2.8% during the recent 12-month period to $1.32 trillion. Even though the model does not specifically model median-size banks, in reality their deposits growth is even robust. For example, deposits MidFirst Bank (with $15.4 billions assets) in Oklahoma City increased 6% to $8.3 bilions from 2017-2018; At FirstBank (with $18.2 billions assets) in Lakewood, Colorado, deposits increased 5.6% to $16.5 billions (see "Small banks' big challenge: Growing deposits," American Banker, September 25, 2018).

ity liquid assets. Banks tend to move to retail deposit market and treasury bonds market for less volatile level of funds. Large banks are also more likely to provide higher fees to retail depositors and to operate widespread branches and ATM networks than small banks (see DeYoung and Hunter 2001). Furthermore, Egan et al. (2017) empirically demonstrate that the banks with larger ATM network provide more services to depositors and the services provided by the U.S. major large banks are valued highest by depositors after controlling for the number of branches.

6 Empirical Analysis

6.1 Testable Implications

Starting from this section, I confront three of the implications derived from the theory with large panel data for U.S. commercial banks. The first, on which the theoretical implications are based, is that deposit competition induces bank to take more risk. The second is that, under the assumption of no capital arbitrage, capital requirements reduce bank risk-taking. The third implication is that the introduction of IRB approach reduces bank credit risk.

The empirical analysis is made possible by the several features of the U.S. banking sector for studying the relationship between capital requirements and bank behavior, taking into account the deposit competition. First, according to the report from the assessment team of the Regulatory Consistency Assessment Programme (RCAP) , US risk based capital requirements are consistent with Basel rules framework. It allows me to examine bank behavior under capital requirements without too much deviations imposed by the country specific factors. In addition to the consistency with Basel framework, the availability of the data allows me to distinguish between each capital requirement regime and examine the effect of capital requirements in each regime on bank behavior.

Second, the US banking regulators choose only core banks to be subject to the advanced IRB approach in Basel III. The core banks account for nearly 75% of US banking assets, which play a significant role in US banking sector. This allows me to investigate the effect of introducing IRB framework on almost the whole US banking sector. The recent advanced IRB framework in Basel III was effective in January 2014. This allows me to use difference-in-difference to study the impact of IRB approach on bank credit risk and to examine post-crisis strengthening of the US capital regime.

6.2 Data Sources

In this section, I construct a panel of U.S. commercial banks from 2001 to 2018. The dataset is drawn from several sources, which described in detail below.

Bank data The primary source of data is a panel of U.S. commercial banks' financial statements known as the Quarterly Reports of Conditions and Income (Call Reports), which is available on Federal Financial Institutions Examination Council (FFIEC). It is a large and detailed dataset, including all banks that are regulated by the Federal Reserve System (FRS), Federal Deposit Insurance Corporation (FDIC) and Office of the Comptroller of the Currency (OCC). Banks are required to report their balance sheet, income statement, regulatory capital and demographics on a quarterly basis. The data is from 2001 Q1 to 2018 Q4.

Branch Office Deposits I supplement the bank data with branch office deposits data collected from Federal Deposit Insurance Corporation (FDIC) Summary of Deposits (SOD). It is a panel of all U.S. bank branches at annual frequency from June 1994 to June 2018. It includes information on branch demographics and deposits quantity in each branch. This data allows me to construct deposit competition measurement, such as Herfindahl-Hirschman Index (HHI), to account for differences in deposit concentration across local markets defined as county. However, there are several limitations for the data, which may affect my calculations competition measurements and empirical analysis. The data does not cover all other branch level information except deposits for which the location is known. Since the data is collected at annual frequency, I do not observe quarterly changes in deposit quantity. Therefore, for each branch, I assign the same deposit quantity for the four quarters within a year. I also limit my analysis to bank level instead of branch level. I construct bank-level HHI using branch office deposits data and merge it to Call Reports data using the unique FDIC bank identifier.

6.3 Measuring Bank Risk, Capital Ratios, and Deposit Competition

The bank credit risk, denoted as RWATA, is measured as a ratio of risk-weighted assets (RWA) to total assets(TA). It is a measure of ex ante bank risk exposure from the regulator's perspective. The advantage of this measure is that, first, it reflects mainly banks credit risk which involves the effect of capital requirements; second, it represents bank credit risk that is assessed by the regulator, which justifies the role of supervisory scrutiny indicated in the theory.

The main regulatory capital ratios are total risk-based capital ratio (RBC), defined as total capital over risk-weighted assets. I further split the RBC to Tier 1 risk-based capital ratio (Tier1 RBC) and Tier 2 risk-based capital ratio (Tier2 RBC) to count for the variation in the quality of capital to absorb losses. Figure 3 displays the relationship between RWATA and RBC over time.

Deposit competition is measured using Herfindahl-Hershman Index (HHI), which is used by banking regulators to analyze market concentration. I create bank- and time-specific measure of deposit competition, which allows me to exploit the time-varying geographic variation in market power induced by differences in the concentration of local deposit markets. I first create branch-level HHI by summing up the squared deposit shares of all banks that operate branches in a given county in a given year. Therefore, banks that operate branches in the same county and year share the same branch-level HHI, and a bank may have more than one branch-level HHI given the fact that a bank may operate branches at different county. In order to graphically illustrate the variation in deposit concentration across local markets, Figure 4 plots the branch-level HHI for each county. A lower number of HHI indicates a low level of market concentration, which in turn indicates a high level of market competition.

Since the empirical analysis is conducted at bank level, built on branch-level HHI I further create bank-level HHI by summing up the weighted average of branch-level HHI across all of a bank's branches, with weights to be the ratio of the branch deposit to the total deposits of the bank. Figure 5 plots the market concentration based on bank-level HHI over time.

The major advantage of bank-level HHI is that its bank-specific and time-varying features allow me to explore the variations in local deposit market concentration across banks and time. Moreover, it accounts for the market shares of all banks in a market and stresses the importance of larger banks by assigning greater weights.

6.4 Other Control Variables

To avoid a potential omitted variables problem, I also include a broad set of control variables.

My theoretical model shows that an increase in cost of capital reduces bank risk, I include return on equity (ROE), calculated as net income over total equity, to account for the effect of cost of capital on bank risk. I also control for bank size (size) by taking log of aggregate total assets, which is a traditional measure of size that focuses on bank on-balance sheet activities. Besides, I account for the structure of bank funding, denoted as structure, by including a ratio of total deposits to total liability. Deposits are relative cheap and stable source of bank funding, and banks with large deposit base are more likely to engage in risk behavior.

I include a ratio of total loans to total assets since the share of loans is highly correlated with bank portfolio risk. Also, the ratio can be used as a rough proxy for loan market competition due to the fact that banks with higher market power can gain more loan share than banks with less favorable position in the loan market. Therefore, it allows me to study the effect of deposit market competition on bank risk, conditional on loan market competition. I further calculate total loan growth rate to capture bank lending strategy since banks with aggressive lending strategy have higher loan growth rate and therefore higher portfolio risk than banks with moderate and cautious lending behavior. Among various types of loans, heavy concentration in real estate loans and commercial and industry (C&I) loans can substantially increase bank risk. To account for that, I also include two ratios: total real estate loans to total assets and total C&I loans to total assets.

There is empirical literature about how liquidity assets affect bank behavior due to moral hazard incentives. Therefore, I add two control variables: cash ratio, which is defined as total cash and balances due from depository institutions to GTA, and core deposit ratio, which is defined as total domestic deposits minus time deposits of more than $250,000 held in domestic offices and brokered deposits of $250,000 or less held in domestic offices, to GTA. Both cash ratio and core deposit ratio allow me to account for the effect of the most liquid assets on bank behavior since a reduction in liquidity risk can instead increase bank credit risk due to moral hazard.

Banks in my dataset belong to different charter class, and the bank primary regulator varies across charter classes. The primary regulators for nationally charted banks, state chartered membered banks and state chartered nonmembered banks are Office of the Comptroller of the Currency (OCC), Federal Reserve Board (FRB), and Federal Deposit Insurance Corporation (FDIC) respectively. To capture the potential differences in quality and leniency of supervision, I construct three dummies variables indicating each primary regulator. I only include FRB and FDIC in the regression to avoid collinearity. I also include a dummy variable, which takes the value of 1 if a bank belongs to a large bank holding company (BHC) and zero otherwise. The inclusion of BHC indicator allows me to study whether bank risk choice depends upon BHC membership.

6.5 Sample Restrictions, Descriptive Statistics, and Correlation

Before summary statistics, I impose several restrictions on my data. I first restrict my sample to banks that are only located in 50 states of the United States. I drop banks in five permanently-inhabited territories[11], as behavior of those banks are more likely to be affected by political legislation and public policy. I also drop U.S. branches of foreign banks to obtain a more unanimous sample of U.S. banks because the behavior of foreign banks is also affected by foreign policy, foreign political environment and business models etc.

I impose another two restrictions to generate my sample. First, I drop thrifts because thrifts are small and do not have diversified asset portfolio due to the fact that they, by design, must have at least 65% of their lending portfolios tied to U.S. consumers than to business. Second, the theoretical framework is about studying

[11]These five permanently inhabited territories include: Puerto Rico, U.S. Virgin Islands, American Samoa, Guam and Northern Mariana. In total 1070 bank quarter observations are dropped.

the effect of capital and competition on bank behavior, I, therefore, exclude banks with no deposits, domestic deposits, total capital and negative return on equity. Regarding mergers and acquisitions, I treat banks before being merged as one bank and another bank after being merged. After all of the restrictions, the sample is reduced to around 500000 bank quarter observations.

Table 1 contains descriptive statistics on all bank level variables used in regressions. Column 1 of Table 1 reports information on the dependent variable, key controls which consist of regulatory capital ratios and deposit competition, other controls such as return on equity (ROE), size, and bank funding structure (structure). The statistics show that the average total risk-based capital (RBC) ratio and Tier1 risk-based capital ratio is around 21% and 19.9% respectively, which are way above the minimum capital requirement of 8% and 4%. All capital ratios contain large variations both between and within banks, suggesting the differences in capital ratios both reflect variations in capital decision and business models across banks, and changes in a specific bank's circumstances over time.

The average of bank-level HHI is around 0.22, which means that the deposit market is highly concentrated based on the merger guidelines issued by the Department of Justice (DOJ), and thus the maker is less competitive. The variation is largely explained by between variation because the way I construct bank-level HHI demonstrates no variation for a specific bank over time if its branches are all located in only one state and county.

I further partition the whole data based on some key variables. I first split the sample based on total RBC ratio. Consistent with my theoretical results, banks with high RBC ratio (higher than its 75th percentile) are less likely to engage in risky behavior than banks with meadium RBC (between its 25th and 75th percentile) and low RBC (lower than its 25th percentile). I also split the data into IRB banks and non-IRB banks. The statistics show that IRB banks have higher total risk-based capital ratios and higher concentration in deposit market.

I start by presenting the pairwise correlation between the variables, described in Table 2. I find a negative relationship between bank credit risk (RWATA) and all measures of regulatory capital ratios except Tier 2 RBC. Deposit concentration is negatively related to bank credit risk, which means that deposit competition and bank credit risk are positively related. Therefore, the simple correlation analysis supports the hypotheses drawn from the theory.

6.6 Estimating Equations and Identifying Assumptions: Static Model

The main estimating equation is:

$$RWATA_{i,t} = \gamma_0 + \gamma_1 RC_{i,t} + \gamma_2 bankHHI_{i,t} + \gamma_3 X_{i,t} + \alpha_i + \tau_t + \varepsilon_{i,t} \tag{42}$$

where $RWATA_{i,t}$ represents ratio of risk-weighted assets over total assets for bank i at time t. It is a proxy for bank credit risk. $RC_{i,t}$ represents regulatory capital ratios, which can be total risk-based capital ratios, or Tier 1 risk-based capital ratios and Tier 2 capital ratios. The measure of deposit competition is $bankHHI_{i,t}$. $X_{i,t}$ is a vector of other controls for bank charateristics described in section 9.1.3. I control for bank- and time- fixed effects, denoted as α_i and τ_t. The bank fixed effects absorb time invariant differences between banks (e.g the quality of bank management). Time (quarter) fixed effects control for variation of bank risk across time. The key coefficients are γ_1 and γ_2. γ_1 measures the effect of capital on bank risk, conditional on a certain level of deposit competition and other bank characteristics. γ_2 estimates the effect of deposit competition on bank risk, taking account of regulatory capital ratios and other time variant and time invariant differences between banks across time.

6.7 Results for Static Models

The empirical analysis advances in three stages. First, I quantify the effects of regulatory capital ratios and deposit competition on bank portfolio risk with static models. Second, I reexamine the impact on bank credit risk of capital ratios and deposit competition in a dynamic setting. And third, I explore the effect of IRB approach on bank credit risk with a quasi-natural experimental approach.

I first present the quantitative impacts of capital and deposit competition on bank risk-taking with static models. Table 3 presents the estimates from regressing the key control variables, regulatory capital ratio and deposit competition measure, on bank risk measure RWATA. The t-statistics are based on robust standard errors clustered by bank. All specifications include both bank- and time- fixed effects to allow me to control for time-invariant differences in bank-specific characteristics, and for the bank-invariant factors that change over time. The estimates in the first column are the preferred baseline specification from equation (40), which include both key controls and fixed effects, and further controls for other bank characteristics.

The baseline estimate indicates that a one percentage point increase in total RBC leads to 0.08 percentage point decrease in RWATA. This is consistent with my theoretical result that, after controlling for deposit competition, banks demonstrate less ex ante portfolio risk as regulatory capital ratio increases. The negative relationship between these two variables either show the role of capital ratios in restricting bank risky behavior or capture the banks' incentive to circumvent capital regulations via capital arbitrage, for instance, switching assets with high risk weights to low risk weights or reporting lower RWA by IRB banks under Basel II/III. From now, I assume that banks do not engage in capital arbitrage. The economic impact of total RBC is small because of the huge variance of total RBC in my dataset (variance=60104.22). Therefore, I further split my sample into three subsamples based on the size of total RBC.

Column (2)-(4) show the estimates when the RBC is below 25%, between 25% and 75%, and above 75% of the whole dataset. The estimates show that banks with RBC below 25% and between 25% and 75% are -0.804 and -0.960, respectively, suggesting the effect of capital ratios on bank portfolio risk is more economically and statistically significant among low- and medium-capitalized banks than high capitalized banks with RBC estimate to be -0.053. This is consistent with the view that banks with low or medium RBC react to the change of capital ratios by adjusting their risk of asset portfolio more than banks with high capital ratios.

The estimates of deposit competition measure, bank-level HHI (bankHHI), in the first four columns range from -0.738 to -3.117, showing that as deposit competition become more intense (smaller bankHHI), banks are more prone to risky portfolios. This is consistent with the assumption on which my theoretical model is built that competition induces banks switching from investing in safe assets to risky assets because higher returns from risky assets can partially offset the increasing cost of raising deposits due to deposit competition. Figure 6 Panel A displays the estimates of RBC and bankHHI for each specification presented in the first four columns of Table 3.

6.8 Exploiting Differences in Interactive Terms

Even though capital ratio and deposit competition are controlled in the baseline regression, they appear in the regressions separately, which ignores the fact that the effect of capital ratio/competition on bank portfolio risk can also depend upon the level of deposit competition/capital ratio. For instance, low capitalized banks may take more risk in investing than high capitalized banks, especially when deposit competition increases. This is because deposit competition increases cost of raising bank funds and shareholders' funds in low capitalized banks are at lower risk of loss in the event of insolvency. Therefore, I address this concern that bank capital and deposit competition may jointly affect bank risk-taking by adding an interaction term. I run the regressions of the following form:

$$RWATA_{i,t} = \gamma_0 + \gamma_1 RC_{i,t} + \gamma_2 bankHHI_{i,t} + \gamma_3 RC_{i,t} \times bankHHI_{i,t} + \gamma_4 X_{i,t} + \alpha_i + \tau_t + \varepsilon_{i,t} \tag{43}$$

Column (5) in Table 3 presents estimates of capital ratio, deposit competition and their interactive term. The results show that bank risk increases by 1.5% from a unit increase in deposit competition when banks hold no capital, and by 2.433% when capital ratio is at its mean level (21.07%). Moreover, bank portfolio risk increases more from one unit increase in deposit competition as RBC decreases, suggesting that low capitalized banks react more than high capitalized banks from deposit competition. The effect of RBC on bank risk, based on the interactive term, also shows that bank risk decreases as RBC increases when deposit competition is at its mean level 0.22.

6.9 Exploiting Differences in Total RBC: Tier1 & Tier2

I further provide evidence that my results are driven by the differences in quality of the capital by decomposing risk-based capital ratios (RBC) into Tier 1 risk-based capital ratio (Tier1 RBC) and Tier 2 risk-based capital ratio. (Tier2 RBC). Tier1 RBC (Tier 2 RBC) is a ratio of Tier 1 (Tier 2) capital over risk-weighted assets (RWA). Tier

1 capital is the core measure of a bank's capability to absorb losses. Banks with high quality Tier 1 capital are prone to take less risk than banks with same amount of Tier 2 capital. In order to differentiate the difference in the quality of capital to absorb losses, I run the regressions of the following form:

$$RWATA_{i,t} = \gamma_0 + \gamma_1 Tier1RBC_{i,t} + \gamma_2 Tier2RBC_{i,t} + \gamma_3 bankHHI_{i,t} + \gamma_4 X_{i,t} + \alpha_i + \tau_t + \varepsilon_{i,t} \tag{44}$$

The results are reported in Table 4. The estimates in column (1) show that both Tier 1 and Tier 2 RBC reduce bank portfolio risk. Bank risk decreases by 0.084% and 0.047%, respectively, as Tier 1 RBC and Tier 2 RBC increases by one percentage point. This is consistent with my theoretical result that banks is more likely to invest in safe assets than risky assets when banks hold more capital. Meanwhile, Tier 1 RBC has a significant and larger negative effect on bank portfolio risk than Tier 2 RBC. This is exactly consistent with the view that Tier 1 capital, from the regulators' perspective, is the highest quality of regulatory capital to absorb losses.

I further split the sample based on the size of Tier1 RBC (25%,75% and 100%) with estimates presented in Column (2)-(4). All results clearly show that Tier 1 RBC has a significant negative impact on bank asset risk. The impacts of Tier 2 RBC on bank risk vary with the initial level of Tier 1 RBC. For instance, increasing

Tier 2 RBC for highly capitalized banks can have a positive effect on bank asset risk, suggesting that Tier 2 capital increases bank risk when they have already hold large amount of high quality Tier 1 capital. Figure 6 Panel B displays the estimates of Tier1 RBC, Tier2 RBC and bankHHI for each specification presented in the first four columns of Table 4.

6.10 Exploiting Differences in Basel I, Basel II, Basel III

In this section, I explore the differences in capital adequacy rules from Basel I to Basel III. I would expect that banks portfolio risk varies within and across each Basel Accords. First, assuming no capital arbitrage, banks are more prone to take less risk because each set of rules are much stricter and rigorous than its previous ones and also because banks are much closer to regulatory scrutiny. Second, considering capital arbitrage (IRB framework), core banks might take advantage of the framework in Basel II/III and report lower risk parameters for calculating risk-weighted assets. In both cases, I would expect that Basel III exerts a higher negative impact on bank credit risk than Basel II, which in turn exerts a higher negative impact on bank risk than Basel I.

To account for the variation in different capital regimes, I construct three dummies variables Basel I, Basel II and Basel III, and each indicator takes the value 1 if all banks adopt it under each capital regime. Basel I equals 1 from 2001 Q1 to 2008 Q1. Basel II equals 1 from 2008 Q2 to 2013 Q2. Basel III equals 1 from 2013 Q3 to 2018 Q4. Then, I construct interactive terms between regulatory capital ratios, deposit competition and Basel indicators. Table 5 and 6 show estimates for eight specifications. The first two columns in both tables represent estimates using the whole data and the last two columns in both tables represent estimates excluding the period for the recent financial crisis.

The two panels clearly demonstrate that total RBC or Tier1 RBC has a negative impact on bank portfolio risk, and the deposit competition is positive related to bank risk, which are consistent with what I found in previous sections. Within each specification, Basel III decreases bank risk more than Basel II. However, Basel II does not decrease more risk than Basel I. This may be because the recent financial crisis occurred when banks were adopting Basel II rules. Therefore, I exclude the Great Recession period from 2007 Q3 to 2009 Q4 and rerun the models, shown on columns (3) and (4) in both tables. However, the results stay the same.

6.11 Estimating Equation and Identifying Assumption: Dynamic Model

I next turn to estimate the effect of capital requirements and deposit competition in a dynamic setting. I estimate a dynamic specification of the baseline regression:

$$RWATA_{i,t} = \gamma_0 + \gamma_1 RWATA_{i,t-1} + \gamma_2 RC_{i,t} + \gamma_3 bankHHI_{i,t} + \gamma_4 X_{i,t} + \alpha_i + \tau_t + \varepsilon_{i,t} \quad (45)$$

where $RWATA_{i,t-1}$ is the one period lag of $RWATA$, which allows me to control for the partial dynamic adjustment mechanism of bank risk-taking behavior. Even though the bank- and time- fixed effects capture bank specific and time specific shocks, the equation (43) suffers endogeneity issue. First, persistent growth in risk-weighted assets (RWA) may cause banks to keep more regulatory capital. Some researchers even show that RWA and capital are jointly determined. Second, since lag of bank risk appear as an explanatory variable, removal of fixed effects using first difference transformation introduces the correlation between $\Delta RWATA_{i,t-1}$ and $\Delta\varepsilon_{i,t}$, both of which have a term dated $t-1$. It means that changes in bank risk at $t-1$ is related to changes of unobserved determinants of bank risk at t, conditional on the included covariates. In both cases, strict exogeneity of the regressors no longer hold and the estimators suffer dynamic panel bias (Nickell, Econometrica, 1981).

In order to purge fixed effects and eliminate dynamic panel bias, I use system GMM approach, suggested by Blundell and Bond (Journal of Econometrics, 1998). The approach assumes that good instruments exist within the data and uses internal IV estimators, lag of the instrumented variables, based on the identifying assumptions that $E(RWATA_{i,s}\Delta\varepsilon_{i,t}) = 0$ for $s \leq t-2$ and $E(\Delta RWATA_{i,t-1}\varepsilon_{i,t}) = 0$. The primary concern is that there are unobserved changes in bank risk that are correlated with regulatory capital ratios and competition but not captured by the covariates. Therefore, I treat all covariates endogenous and instrument all variables in the level equation with their first lag difference and instrument all variables in the difference equation with the second to third lags.

6.12 Results for Dynamic Models

Table 7 and 8 show eight dynamic specifications. Table 7 presents estimates with total RBC as capital ratios, while Table 8 presents estimates with Tier 1 RBC and Tier 2 RBC as capital ratios. The results in both tables show that here is dynamic feature of RWATA, which lower the estimates of total RBC and Tier 1 RBC to -0.027% and -0.026% respectively. The effect of deposit competition on bank credit risk increases after controlling for the partial dynamic adjustment mechanism of bank portfolio risk.

6.13 Difference-in-Difference for IRB Approach

In this section, I examine how the introduction of IRB approach affects bank ex ante credit risk. I run models of the following form:

$$RWATA_{i,t} = \gamma_0 + \gamma_1 Treat_i \times Post_t + \gamma_2 AllControls_{i,t} + \alpha_i + \tau_t + \varepsilon_{i,t} \qquad (46)$$

The coefficients γ_1 describe the effect of the IRB approach by comparing changes in bank ex ante credit risk over time between IRB banks and nonIRB banks. Table 10 represents U.S. commercial banks that are subject to IRB approach and time when they exit parallel run. Since IRB approach became effective on January 2014 for all IRB banks, Figure 7 displays RWATA among IRB banks and nonIRB banks before and after 2014.

The results are shown in Table 9. Column (1) in Table 9 represents estimates from the classical difference-in-difference, assuming that IRB approach became effective from 2014 onwards. Since IRB banks did not exit parallel run before 2018, Column (2) in Table 9 represents estimates considering that banks exit parallel run at different time. The estimates γ_1 in both columns show that the introduction of

IRB approach reduces bank ex ante credit risk by ranging from 3.46% to 3.64%. This indicates that, after controlling for bank regulatory capital ratios and deposit competition, the effect of IRB approach significantly reduces bank ex ante credit risk.

7 Conclusion

7.1 Summary

Capital regulations seek to limit each bank's insolvency risk. Unless there are no regulatory arbitrage opportunities to be exploited in the regulations, banks will always have the incentives to take risk and create profit opportunities by avoiding the intention of the regulation while complying with its form. In the case of the capital regulations in general, this comes in the form of lower funding cost, which allows banks that reduce capital requirements to earn higher expected returns, especially when cost of raising deposits is high due to deposit competition. There are various forms of regulatory capital arbitrage. One way lies in the Internal-rating based approach (IRB) proposed in Basel II/III, which allows banks, particularly large banks, to internally calculate risk parameters that are further used to determine minimum capital charges. Banks arbitrage by strategically reporting lower ex ante credit risk without easily being detected by the regulator due to the complexity of heterogeneous bank business models and opaqueness of their asset portfolio. The concern of this underreported risk forces the regulator to strength supervisory scrutiny.

In this paper, I build a model to examine bank behavior when they face deposit competition and are subject to capital requirements in which there are arbitrage opportunities. The model considers a number of banks that decide on how much capital to raise and how much deposit rate to offer in order to maximize their profits in the presence of deposit competition and capital requirements. Deposit competition is modelled as monopolistic competition, where the product differentiation arises from the cost of depositing money imposed on depositors. I model capital requirements, taking into account of their evolution over time, as three sets of regulations: simple leverage ratio (measured as the ratio of total capital over total assets); risk-based capital ratio (measured as the ratio of total capital over risk-weighted assets) with IRB approach; risk-based capital ratio with IRB approach and a non-risk based leverage ratio (proposed in Basel III). A regulator considers the possibility of regulatory capital arbitrage and imposes supervisory check on banks behavior.

My model is built on Hellman, Murdock and Stiglitz (2000) and Hendrik and Schnabel (2011), and thus assumes costly capital. I examine the role of leverage ratio and supervisory power in restricting capital arbitrage within the IRB approach, which is the key modelling innovation and in a spirit similar to Blum (2008). My model also incorporates asymmetric information in variety forms. In particular, I model moral hazard as banks investing in risky asset when they face intense deposit competition, and I model adverse selection as banks strategically underreport credit risk exposure before they are subject to capital requirements.

The results show that, first, without regulatory capital arbitrage (RCA), capital requirements reduce bank portfolio risk, and the effectiveness of those requirements increases as they are being evolved; second, with RCA, the leverage ratio plays an important role in reducing the banks incentives to conduct RCA. The ratio serves as a binding constraint on bank behavior if the size of it is set between the risk-based capital ratio for risky and safe asset. It, coupled with risk-based capital ratio (RBC), can also achieve the same effectiveness on reducing bank risk with just RBC alone, while reducing the regulator's supervisory assessment effort.

I further empirically test some implications derived from /based upon the theory with large panel data for U.S. commercial banks. Specifically I examine three implications: first, higher deposit competition leads banks take more risk; second, higher capital requirements reduce bank asset risk; third, the introduction of IRB approach reduces bank ex ante credit risk. Empirically identifying these issues faces a number of challenges. First, in most countries, minimum capital requirements vary little over time, and when they change, they change for all banks at one time, leaving little cross-sectional variation to exploit. Second, rates for various deposit products are hard to obtain for all banks. Third, bank risk behavior, capital requirements and deposit competition are likely to be jointly determined, which means that the effect of capital requirement and deposit competition on bank risk might suffer potential endogeneity. Fourth, banks that are subject to IRB approach employ complex and opaque business models, thus it is difficult to determine whether the self-calculated risk parameters truthfully represent their asset risk.

I overcome these challenges by combining several novel identification strategies that exploit the effect of model-based capital requirement and deposit competition with rich U.S. banking data that contains bank demographics, detailed financial statements, and U.S. branch level deposit information. Even though the minimal capital regulations in the U.S are unanimous for all banks and vary little over time, most banks keep a capital buffer, the difference between actual capital ratios and minimum capital ratios, suggesting banks have a precautionary motive. Thus, I use actual capital ratio (with buffers) instead of minimum regulatory capital ratio as a proxy for capital requirements, which allows me to study how banks adjust their regulatory capital and to explore the cross-sectional variation among banks that might result from different business model and risk management. The deposit competition is proxied indirectly by using an bank-specific and time-varying Herfindahl-Hirschman Index (HHI), which allows me to explain the differences in deposit competition among banks and across time. Besides the static fixed effects model that assumes strong exogeneity assumption, I analyze the dynamic feature of my research and address three types of potential endogeneity issues: unobserved heterogeneity, simultaneity and dynamic endogeneity with system generalized method of moments (system GMM) approach. This approach, developed by Blundell and Bond (1998), allows me to reduce the above endogeneity issues in a dynamic setting. Moreover, the U.S. institutional setup of the IRB approach requires large bank holding companies (BHC) and their main national depository subsidiaries to subject to IRB approach starting from 2014 January 1st in Basel III. Thus, I estimate the effect of IRB using a difference-in-difference approach(DID), which is spiritually similar to Begley, Purnanandam and Zheng (2017) and Behn, Haselma and Wachtel (2016).

The data comes from the Quarterly Reports of Conditions and Income (Call Reports). I merge the Call Reports database with bank branch-level deposit information from Summary of Deposits (SOD). The panel data covers the period of evolution of Basel capital requirements. I also hand pick the information about the banks that are subject to IRB approach and when they officially adopt the approach after gaining regulator's approval from each bank's Pillar 3 report. The key controls are capital requirements, defined as risk-based capital ratios, and deposit competition. The main dependent variable is a ratio of risk-weighted assets to total assets, which is an ex ante measure of bank portfolio risk assessed by the regulator.

I start by regressing the measures for capital requirement and deposit competition on bank's ex ante portfolio risk in static fixed effects models. Besides other covariates, I include both bank- and time- fixed effects in all of my specifications to account for the variation among banks and over time. The results show that bank credit risk increases by 2.4 percentage point from one unit increase in deposit competition, and it decreases by 0.08 percentage points from 1 percentage point increase in capital requirements. Moreover, I decompose risk-based capital ratios (RBC) into two parts, Tier 1 RBC and Tier 2 RBC, based on the variation in the quality of capital to absorb losses. I find that Tier 1 capital significantly reduces bank asset risk than Tier 2 capital. All of the results are consistent with what I find in the theory.

The primary threat to the consistency of above estimated parameters is that they might suffer potential endogeneity. I address these issues using System GMM approach with bank and time fixed effects, and rerun the main specifications and the results remain qualitatively the same with what I find in the static models.

The U.S. banking regulations require large bank holding companies and their main national depository institutions to subject to IRB approach starting from January 2014, which allows me to use Difference-in-Difference approach to study the impact of IRB approach on bank portfolio risk. My data contains information for the national depository institutions. Starting from 2014, all IRB banks entered the parallel run and waits for approval from the regulator to offically use IRB approach to calculate minimum capital charges. Therefore, I also hand pick information on when each bank officially exit parallel run from each bank's Pillar 3 report. The results show that the introduction of IRB approach reduces bank ex ante credit risk exposure from the regulator's perspective by ranging from 3.46% to 3.64%. Overall, the results in the empirical analysis support some of my findings from the theory.

7.2 Policy Implications

My findings have immediate policy implications. The current capital requirements are complex. The number of risk weights used to calculate minimum capital charges based on the risk-based capital ratio has increased from 4 to over 200,000. The IRB approach, built upon risk-based ratio, further increases the complexity. The stricter and more sophisticated capital regulations are effective and better at controlling heterogeneous bank risk if banks themselves do not exploit opportunities to reduce measured risk. However, the loopholes in the regulations together with weak supervisory power create profitable incentives for banks to circumvent the rules. The simple non-risk based leverage ratio proposed in Basel III can maintain the effectiveness of the regulations at the same time reduce the required supervisory power to minimize regulatory capital arbitrage. Thus, echoing Kane (1977) and Wall's 2014 talk[12] at the Atlanta Federal Reserve, my findings support a much simpler reform of capital adequacy rules than currently proposed. However, how large the leverage ratio should be in order to prevent bank arbitrage and to reduce the distortion of banks investing in safe asset deserves further study.The results from my empirical analysis raise immediate questions: What are the causes for the lower ex ante credit risk after IRB approach? What is the role of leverage ratio and how does supervisory power affect bank behavior after IRB approach was introduced? All of these questions deserve to be empirically investigated.

[12]Larry D. Wall's talk note is available at
https://www.frbatlanta.org/cenfis/publications/notesfromthevault/1401.aspx/

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A Theoretical Appendix

Proof. Proposition 3

$$\operatorname*{Max}_{r_j}\{p[R^H(1+\frac{\beta}{1-\beta})-r_j]-\rho\frac{\beta}{1-\beta}\}D_j(r_j,r^c) \tag{47}$$

where

$$D_j(r_j,r^c)=\frac{1}{2}n\lambda+n\sigma(r_j-r^c) \tag{48}$$

For the large bank j, solving the equation (45) subject to the deposit constraint (46) yields

$$r_j=\frac{1}{2}r^c-\frac{\lambda}{4\sigma}+\frac{pR^H-\beta\rho}{2p(1-\beta)}=\frac{1}{2}r^c+\frac{1}{2}r^G \tag{49}$$

where r^G is the interest rates if both types of banks choose risky asset (see equation 16). Substituting r_j back to the following equation

$$\{p[R^H(1+\frac{\beta}{1-\beta})-r_j]-\rho\frac{\beta}{1-\beta}\}D_j(r_j,r^c)=\frac{n\lambda(pR^H+\beta\rho p-Rp-\beta\rho)}{2(1-p)(1-\beta)} \tag{50}$$

finds $\sigma_l^c=\frac{\lambda p}{2B}$, where $B=\frac{pR^H-pR+\rho(p-1)\beta}{(1-p)(1-\beta)}$. Taking derivative of B with respect to β gives $\frac{\partial B}{\partial\beta}=\frac{pR^H-pR-\rho+p\rho}{(1-p)(1-\beta)^2}$. If $pR^H-pR>(1-p)\rho$, which is equivalent to $\rho<\frac{p(R^H-R)}{1-p}$, and based on assumption 1 that $R^H>R$, I get

$\frac{\partial \sigma_l^c}{\partial \beta} < 0$, vice versa. $\square$

Proof. Proposition 4 Considering the symmetric equilibrium where $r_S = r_L$. Both types of banks choose to invest safe asset if expected returns for safe and risky assets are the same. Solving the following equation:

$$[R(1+\frac{\beta_1}{1-\beta_1})-\rho\frac{\beta_1}{1-\beta_1}-r_i]D_i(r_i, r_{-i}) = \{p[R^H(1+\frac{\beta_2}{1-\beta_2})-r_i]-\rho\frac{\beta_2}{1-\beta_2}\}D_i(r_i, r_{-i}) \tag{51}$$

gives $r_i = \frac{R - pR^H}{(1-p)(1-\beta_2)} + \frac{(\rho - R)(\beta_2 - \beta_1)}{(1-p)(1-\beta_1)(1-\beta_2)} \equiv r^c_{RB,IRB}$. The large bank's expected return of safe asset when $r = r^c_{RB,IRB}$ is $\frac{1}{2}n\lambda(\frac{R-\beta_1\rho}{1-\beta_1} - r^c_{RB,IRB})$. Then the critical competition level above which the large bank j jumps from choosing safe asset to risky asset is calculated from the following equation:

$$\underset{r_j}{\text{Max}}\{p[R^H(1+\frac{\beta_2}{1-\beta_2}) - r_j] - \rho\frac{\beta_2}{1-\beta_2}\}D_j(r_j, r^c_{RB,IRB}) \tag{52}$$

where

$$D_j(r_j, r^c) = \frac{1}{2}n\lambda + n\sigma(r_j - r^c_{RB,IRB}) \tag{53}$$

Solving equation (50) gives the interest rate for the large bank j: $r_j = \frac{1}{2}r^c_{RB,IRB} + \frac{1}{2} + r^G$, where $r^G = \frac{pR^H - \beta_2\rho}{p(1-\beta_2)} - \frac{\lambda}{2\sigma}$ is the symmetric interest rates that both types of banks choose risky asset under risk-based capital requirement. Substituting r_j to the following equation

$$\{p[R^H(1+\frac{\beta_2}{1-\beta_2})-r_j]-\rho\frac{\beta_2}{1-\beta_2}\}D_j(r_j,r^c_{RB,IRB})=\frac{1}{2}n\lambda(\frac{R-\beta_1\rho}{1-\beta_1}-r^c_{RB,IRB}) \quad (54)$$

finds $\sigma^c_{RB,IRB}$ shown in equation (26). □

Proof. Proposition 5 Similar analysis applied for Proposition 5. If banks strategic underreport their asset type, they keep β_1 proportion of the total asset as required capital. Solving the following equation

$$\begin{aligned}[R(1+\frac{\beta_1}{1-\beta_1})-\rho\frac{\beta_1}{1-\beta_1}-r_i]D_i(r_i,r_{-i})=\\ \{p[R^H(1+\frac{\beta_1}{1-\beta_1})-r_i]-\rho\frac{\beta_1}{1-\beta_1}-p\eta\delta\}D_i(r_i,r_{-i})\end{aligned} \quad (55)$$

gives $r=\frac{R-pR^H}{(1-p)(1-\beta_1)}+\eta\delta\frac{p}{1-p}\equiv r^c_{RB,IRB+RCA}$. Solving the following equations:

$$\underset{r_j}{\text{Max}}\{p[R^H(1+\frac{\beta_1}{1-\beta_1})-r_j]-\rho\frac{\beta_1}{1-\beta_1}-p\eta\delta\}D_j(r_j,r^c_{RB,IRB+RCA}) \quad (56)$$

where

$$D_j(r_j,r^c)=\frac{1}{2}n\lambda+n\sigma(r_j-r^c_{RB,IRB+RCA}) \quad (57)$$

give $r_j=\frac{r^c_{RB,IRB+RCA}+r^G}{2}$, where $r^G=\frac{1}{p}(\frac{pR^H-\rho\beta_1}{1-\beta_1}-p\eta\delta)-\frac{\lambda}{2\sigma}$. Substituting r_j

to the following equation:

$$\begin{aligned}\{p[R^H(1+\frac{\beta_1}{1-\beta_1})-r_j]-\rho\frac{\beta_1}{1-\beta_1}-p\eta\delta\}D_j(r_j,r^c_{RB,IRB+RCA})=\\ \frac{1}{2}n\lambda(\frac{R-\beta_1\rho}{1-\beta_1}-r^c_{RB,IRB+RCA})\end{aligned} \tag{58}$$

gives $\sigma^c_{RB,IRB+RCA}$ shown in equation (29). For Proposition 5 (iii), solving the following inequality

$$\begin{aligned}\{p[R^H(1+\frac{\beta_1}{1-\beta_1})-r_i]-\rho\frac{\beta_1}{1-\beta_1}-p\eta\delta\}D_i(r_i,r_{-i})\leq\\ \{p[R^H(1+\frac{\beta_2}{1-\beta_2})-r_i]-\rho\frac{\beta_2}{1-\beta_2}\}D_i(r_i,r_{-i})\end{aligned} \tag{59}$$

gives the inequality (30).

□

Proof. Proposition 6 Similar analysis applies for Proposition 6. □

Proof. Proposition 7 Comparing equations (26) and (29) gives equation (36). Comparing equations (32) and (34) gives equation (37). Comparing equations (21), (26), and (32) gives inequality (38). Comparing (29) and (34), and comparing critical supervisory powers in (30) and (35) give inequalities (39). All of the results are based upon the assumption that $\beta_2 > \beta > \beta_1$.

□

B Tables and Figures

Table 1: Descriptive Statistics

	All	Low RBC	Medium RBC	High RBC	IRB Banks	nonIRB Banks
Dependent Variable						
RWATA	67.65	78.24	68.89	54.58	72.82	67.75
	(14.34)	(9.73)	(10.88)	(14.33)	(30.46)	(14.41)
Key Controls						
RBC	21.07	11.38	15.52	41.87	27.63	21.52
	(256.45)	(0.91)	(1.90)	(512.32)	(51.20)	(245.56)
Tier1 RBC	19.93	10.24	14.37	40.75	25.49	20.38
	(256.46)	(0.99)	(1.94)	(512.33)	(51.69)	(245.57)
Tier2 RBC	1.14	1.14	1.15	1.12	2.13	1.14
	(0.71)	(0.42)	(0.39)	(1.23)	(1.84)	(0.85)
bankHHI	0.22	0.20	0.22	0.24	0.25	0.22
	(0.13)	(0.10)	(0.13)	(0.14)	(0.17)	(0.13)
Other Controls						
ROE	10.78	13.15	10.72	8.56	14.79	6.80
	(36.86)	(72.59)	(6.62)	(8.10)	(13.68)	(552.30)
Size	12.01	12.46	12.07	11.45	17.81	11.95
	(1.37)	(1.42)	(1.33)	(1.19)	(2.39)	(1.33)
Structure	93.07	91.01	93.40	94.49	65.69	93.21
	(9.34)	(8.53)	(8.02)	(11.88)	(29.86)	(9.10)
Observations	458559	114639	229281	114639	1536	504859

Note: The first entry in each row is the mean, and the standard deviation is in parentheses. The Low RBC, Medium RBC and High RBC represent samples with RBC lower than its 25th percentile, between its 25th and 75th percentile, and higher than its 75th percentile. The last two columns represent samples with IRB banks and nonIRB banks.

Table 2: Pairwise Correlation: Important Variables

	(1)							
	RWATA	RBC	Tier1 RBC	Tier2 RBC	bankHHI	ROE	Size	Structure
RWATA	1							
RBC	-0.0768***	1						
Tier1 RBC	-0.0769***	1.000***	1					
Tier2 RBC	0.0652***	-0.00909***	-0.0118***	1				
bankHHI	-0.104***	0.00157	0.00157	0.00203	1			
ROE	0.0288***	-0.00144	-0.00144	0.00121	0.00875***	1		
Size	0.234***	-0.0216***	-0.0219***	0.122***	-0.128***	0.0151***	1	
Structure	-0.0975***	-0.0536***	-0.0534***	-0.0881***	0.0539***	-0.0265***	-0.308***	1

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

Note: This table shows the pairwise correlations among key variables. The first column represents the correlations between the dependent variable and some key controls. The dependent variable is a ratio of risk-weighted assets over total assets. The key controls include risk-based capital ratios (RBC), Tier 1 risk-based capital ratios (Tier1 RBC), Tier 2 risk-based capital ratios (Tier2 RBC), bank competition (bkHHI), return on equity (ROE), size (Size) and proportion of liabilities invested in deposits (structure).

Table 3: Impact of Capital Ratios and Deposit Competition on Bank Credit Risk: Main Specification

	Baseline	Low RBC	Medium RBC	High RBC	With interactions
	(1)	(2)	(3)	(4)	(5)
RBC	-0.0835***	-0.8035***	-0.9599***	-0.0525***	-0.0743*
	(0.0016)	(0.0000)	(0.0000)	(0.0009)	(0.0653)
bankHHI	-2.3988*	-3.1166**	-1.7472	-0.7379	-1.5001
	(0.0599)	(0.0377)	(0.1624)	(0.7225)	(0.5672)
RBC * bankHHI					-0.0443
					(0.7223)
ROE	0.0019***	-0.0001	-0.0615***	0.0119	0.0019***
	(0.0000)	(0.9170)	(0.0000)	(0.5263)	(0.0000)
Size	-0.4821	-0.2395	-2.4225***	-2.6950***	-0.4881
	(0.1198)	(0.2874)	(0.0000)	(0.0002)	(0.1138)
Structure	0.0467***	0.0883***	0.1207***	0.0050	0.0464***
	(0.0039)	(0.0000)	(0.0000)	(0.8693)	(0.0041)
R-sqrd within	0.553	0.541	0.585	0.536	0.553
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes
Clustered S.Es	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes

Note: This table represents estimates from equations (40) and (41). Specifications vary by each column. The Low RBC, Medium RBC and High RBC represent samples with RBC lower than its 25th percentile, between its 25th and 75th percentile, and higher than its 75th percentile. All regressions control for both bank- and time- fixed effects. P values are in parentheses. Levels of significance: *** p<0.01; ** p<0.05; * p<0.1.

Table 4: Impact of Capital Ratios and Deposit Competition on Bank Credit Risk: Tier 1 & Tier 2

	(1) Splited RBC	(2) Low Tier1 RBC	(3) Medium Tier1 RBC	(4) High Tier1 RBC	(5) With Interactions	(6) With Interactions
Tier1 RBC	-0.0843***	-0.8362***	-0.9755***	-0.0605***	-0.0771**	
	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0187)	
Tier2 RBC	-0.0469	-0.4781**	-1.7533***	0.2544	0.4689	
	(0.9190)	(0.0140)	(0.0000)	(0.3979)	(0.4408)	
bankHHI	-2.4009*	-2.6502*	-1.4324	-0.7376	1.7250	5.4674**
	(0.0596)	(0.0991)	(0.2217)	(0.7276)	(0.5764)	(0.0492)
Tier1 RBC * bankHHI					-0.0386	-0.2871***
					(0.7448)	(0.0007)
Tier2 * bankHHI					-2.7993	-1.9806
					(0.1750)	(0.2407)
ROE	0.0019***	0.0008*	-0.0671***	0.0121	0.0019***	0.0019***
	(0.0000)	(0.0712)	(0.0000)	(0.5206)	(0.0000)	(0.0000)
Size	-0.4852	-0.2250	-2.5389***	-2.7528***	-0.4936	-0.4251
	(0.1047)	(0.3756)	(0.0000)	(0.0001)	(0.1023)	(0.1607)
Structure	0.0469***	0.0798***	0.1284***	0.0042	0.0463***	0.0414**
	(0.0032)	(0.0000)	(0.0000)	(0.8838)	(0.0035)	(0.0132)
R-sqrd within	0.553	0.535	0.577	0.541	0.553	0.551
Bank fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Clustered S.Es	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table represents estimates from equations (42). Specifications vary by each column. The Low Tier1 RBC, Medium Tier1 RBC and High Tier1 RBC represent samples with Tier1 RBC lower than its 25th percentile, between its 25th and 75th percentile, and higher than its 75th percentile. All regressions control for both bank- and time- fixed effects. P values are in parentheses. Significance level: *** p<0.01; ** p<0.05; * p<0.1

Table 5: Impacts by Basel I, II, III

	(1) With Crisis	(2) With Crisis	(3) Exclude Crisis	(4) Exclude Crisis
RBC * Basel I	-0.1213***	-0.1218***	-0.1381***	-0.1387***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RBC * Basel II	-0.0625***	-0.0625***	-0.0551**	-0.0552**
	(0.0082)	(0.0082)	(0.0113)	(0.0113)
RBC * Basel III	-0.0999***	-0.0997***	-0.1044***	-0.1040***
	(0.0011)	(0.0011)	(0.0016)	(0.0016)
bankHHI	-2.4898**		-2.5881*	
	(0.0497)		(0.0520)	
ROE	0.0018***	0.0018***	0.0016***	0.0016***
	(0.0000)	(0.0000)	(0.0032)	(0.0033)
Size	-0.5099	-0.5160*	-0.5343	-0.5430*
	(0.1000)	(0.0968)	(0.1000)	(0.0951)
Structure	0.0514***	0.0512***	0.0594***	0.0591***
	(0.0010)	(0.0011)	(0.0010)	(0.0010)
bankHHI * Basel I		-2.1164		-2.2019
		(0.1008)		(0.1043)
bankHHI * Basel II		-2.7487**		-2.5689*
		(0.0460)		(0.0884)
bankHHI * Basel III		-3.1880**		-3.5613**
		(0.0293)		(0.0203)
R-sqrd within	0.555	0.555	0.550	0.550
Bank fixed effects	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Clustered S.Es	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes

Note: This table represents estimates by Basel I, II, and III. Specifications vary by each column. The first two columns represents estimates from the whole sample, and the last two columns represent estimates from the sample excluding the Great Recession. All regressions control for both bank- and time- fixed effects. P values are in parentheses. Levels of significance: *** $p<0.01$; ** $p<0.05$; * $p<0.1$

Table 6: Impacts by Basel I, II, III: Tier 1 & Tier 2

	(1) With Crisis	(2) With Crisis	(3) Exclude Crisis	(4) Exclude Crisis
Tier1 RBC * Basel I	-0.1212***	-0.1216***	-0.1382***	-0.1388***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Tier1 RBC * Basel II	-0.0646***	-0.0645***	-0.0591***	-0.0592***
	(0.0005)	(0.0005)	(0.0014)	(0.0014)
Tier1 RBC * Basel III	-0.1020***	-0.1017***	-0.1069***	-0.1065***
	(0.0013)	(0.0013)	(0.0022)	(0.0022)
Tier2 RBC * Basel I	-0.3048	-0.3073	-0.3338	-0.3361
	(0.1325)	(0.1297)	(0.1159)	(0.1136)
Tier2 RBC * Basel II	0.0313	0.0306	0.0884	0.0909
	(0.9518)	(0.9530)	(0.8527)	(0.8486)
Tier2 RBC * Basel III	-1.3134***	-1.3184***	-1.2468***	-1.2533***
	(0.0015)	(0.0015)	(0.0017)	(0.0016)
bankHHI	-2.4367*		-2.5360*	
	(0.0544)		(0.0566)	
ROE	0.0018***	0.0018***	0.0016***	0.0016***
	(0.0000)	(0.0000)	(0.0024)	(0.0025)
Size	-0.5416*	-0.5483*	-0.5668*	-0.5764*
	(0.0750)	(0.0721)	(0.0779)	(0.0733)
Structure	0.0509***	0.0507***	0.0587***	0.0585***
	(0.0010)	(0.0011)	(0.0010)	(0.0010)
bankHHI * Basel I		-2.0503		-2.1394
		(0.1113)		(0.1140)
bankHHI * Basel II		-2.6709*		-2.4745
		(0.0526)		(0.1022)
bankHHI * Basel III		-3.1890**		-3.5629**
		(0.0288)		(0.0199)
R-sqrd within	0.556	0.556	0.551	0.551
Bank fixed effects	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Clustered S.Es	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes

Note: This table represents estimates by Basel I, II, and III. Specifications vary by each column. The first two columns represents estimates from the whole sample, and the last two columns represent estimates from the sample excluding the Great Recession. All regressions control for both bank- and time- fixed effects. P values are in parentheses. Levels of significance: *** p<0.01; ** p<0.05; * p<0.1

Table 7: Impact of Capital Ratios and Deposit Competition on Bank Credit Risk: Main Specification: System GMM

	(1) Baseline	(2) Low RBC	(3) Medium RBC	(4) High RBC
L.RWATA	0.6924***	0.7214***	0.6568***	0.7792***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RBC	-0.0267*	-0.4041***	-0.2952***	-0.0222**
	(0.0591)	(0.0000)	(0.0000)	(0.0236)
bankHHI	-5.1240*	-7.9368*	-2.6618	12.3349*
	(0.0614)	(0.0582)	(0.2843)	(0.0810)
ROE	-0.0035	0.0017	0.0192*	-0.0836***
	(0.4087)	(0.3639)	(0.0582)	(0.0009)
Size	2.0505***	1.1769***	0.8524***	6.1690***
	(0.0000)	(0.0000)	(0.0014)	(0.0000)
Structure	-0.0302*	-0.0633**	-0.0871***	-0.1029**
	(0.0646)	(0.0241)	(0.0085)	(0.0292)
Bank fixed effects	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Clustered S.Es	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes

Note: This table represents estimates from equations (43). Specifications vary by each column. The Low RBC, Medium RBC and High RBC represent samples with RBC lower than its 25th percentile, between its 25th and 75th percentile, and higher than its 75th percentile. All regressions control for both bank- and time- fixed effects. P values are in parentheses. Levels of significance: *** p<0.01; ** p<0.05; * p<0.1

Table 8: Impact of Capital Ratios and Deposit Competition on Bank Credit Risk: Tier1 & Tier2: System GMM

	(1) Baseline	(2) Low Tier1 RBC	(3) Medium Tier1 RBC	(4) High Tier1 RBC
L.RWATA	0.6898***	0.7273***	0.6262***	0.7758***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Tier1 RBC	-0.0258***	-0.3131***	-0.1891***	-0.0163
	(0.0002)	(0.0038)	(0.0017)	(0.1630)
Tier2 RBC	0.2419	0.1406	0.8847	-0.5197
	(0.6660)	(0.6450)	(0.1124)	(0.3550)
bankHHI	-4.9561**	-8.0750*	-4.2217*	9.2629
	(0.0190)	(0.0575)	(0.0502)	(0.1445)
ROE	-0.0035	0.0004	0.0110	-0.0784***
	(0.4069)	(0.4668)	(0.5524)	(0.0035)
Size	2.0529***	1.2178***	0.7944***	5.8824***
	(0.0000)	(0.0000)	(0.0063)	(0.0000)
Structure	-0.0276*	-0.0553**	-0.1289***	-0.0938*
	(0.0891)	(0.0433)	(0.0002)	(0.0872)
Bank fixed effects	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Clustered S.Es	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes

Note: This table represents estimates with Tier1 RBC and Tier2 RBC. Specifications vary by each column. The Low Tier1 RBC, Medium Tier1 RBC and High Tier1 RBC represent samples with Tier1 RBC lower than its 25th percentile, between its 25th and 75th percentile, and higher than its 75th percentile. All regressions control for both bank- and time- fixed effects. P values are in parentheses. Levels of significance: *** p<0.01; ** p<0.05; * p<0.1

Table 9: The Effect of IRB Approach on Bank Credit Risk

	(1)	(2)
Treat × Post	-3.4645	-3.6365
	(0.4924)	(0.3364)
RBC	-0.0835***	-0.0835***
	(0.0016)	(0.0016)
bankHHI	-2.3757*	-2.3700*
	(0.0631)	(0.0634)
ROE	0.0019***	0.0019***
	(0.0000)	(0.0000)
Size	-0.4721	-0.4648
	(0.1241)	(0.1297)
Structure	0.0485***	0.0492***
	(0.0020)	(0.0018)
R-sqrd within	0.552	0.552
Bank fixed effects	Yes	Yes
Time fixed effect	Yes	Yes
Clustered S.Es	Yes	Yes
Other Controls	Yes	Yes

Note: This table represents estimates from equations (44). Specifications vary by each column. The first column represents estimates based on a classical difference-in-difference approach (all IRB banks follow IRB rules starting from 2014). The second column represents estimates based on a more general difference-in-difference approach (banks exit parallel run at different time). All regressions control for both bank- and time- fixed effects. P values are in parentheses. Levels of significance:*** $p<0.01$; ** $p<0.05$; * $p<0.1$

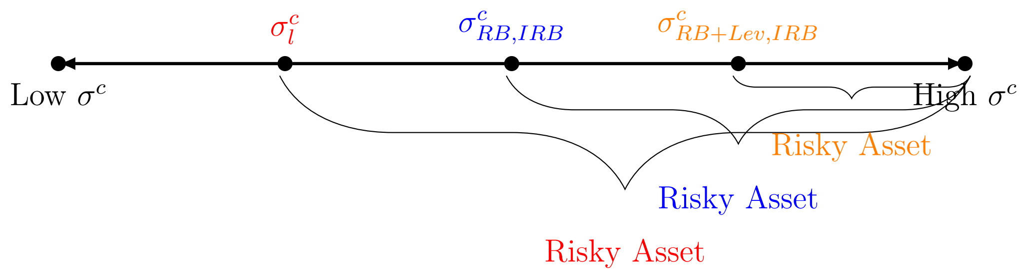
Table 10: IRB Banks

Bank	Date when officially adopt IRB
Bank of America N.A.	2015 Q4
Bank of America California N.A.	2015 Q4
American Express National Bank	Not existing parallel run
Bank of New York Mellon, THE.	2014 Q2
BYN Mellon, N.A.	2014 Q2
Capital One, N.A.	Not existing parallel run
Capital One Bank (USA), N.A.	Not existing parallel run
CitiBank, N.A.	2014 Q2
Goldman Sachs Bank USA	2014 Q2
Chase Bank USA, N.A.	2014 Q2
JPMorgan Chase Bank, N.A.	2014 Q2
Morgan Stanley Bank, N.A.	2014 Q2
Morgan Stanley Private Bank, N.A.	2014 Q2
Northern Trust Company, THE	2014 Q2
PNC Bank, N.A.	Not existing parallel run
State Street Bank and Trust Company	2014 Q2
U.S. Bank, N.A.	2014 Q2
Wells Fargo Bank, LTD	2015 Q2
Wells Fargo Bank, N.A.	2015 Q2
Wells Fargo National Bank West	2015 Q2

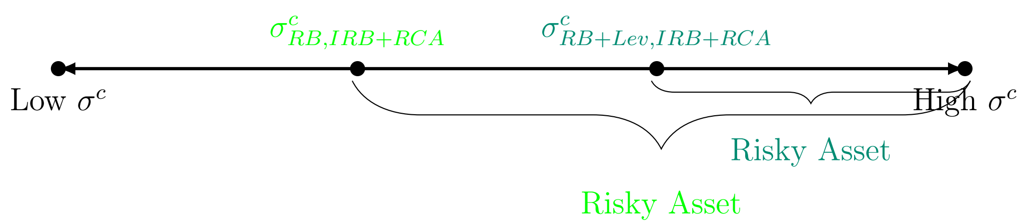
Note: This table represents bank holding companies' main national depository institutions that are subject to IRB approach and the time at which they exit parallel run. All IRB banks in the sample entered parallel run in January 2014 and waited for approval from the regulator to exit parallel run and officially adopt IRB approach.

Figure 1: Thresholds for Risky Asset

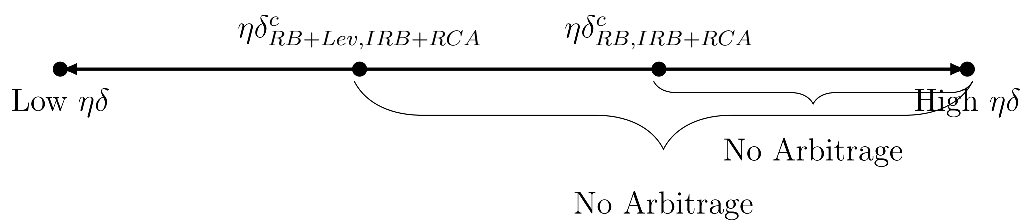
Panel A: Without Regulatory Capital Arbitrage - Critical Competition



Panel B: With Regulatory Capital Arbitrage - Critical Competition

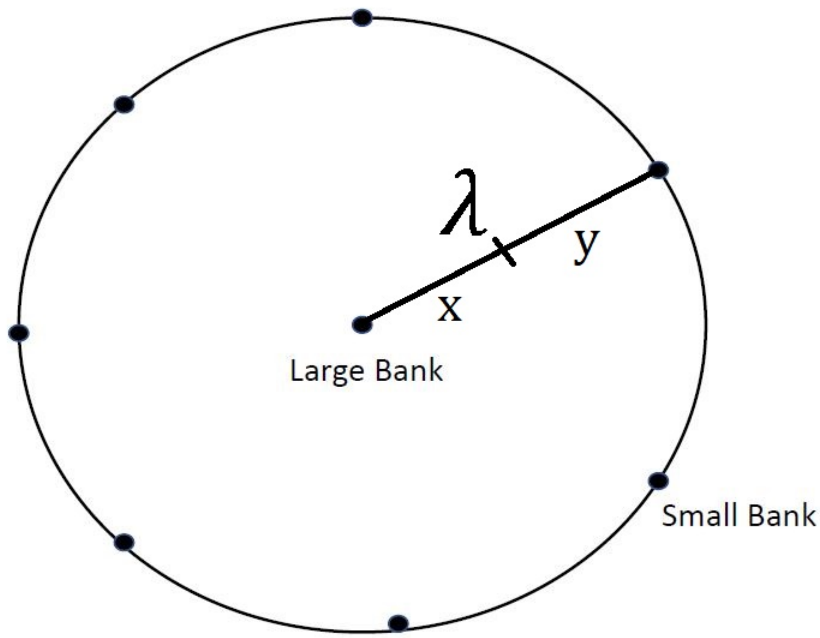


Panel C: With Regulatory Capital Arbitrage - Critical Supervisory Power



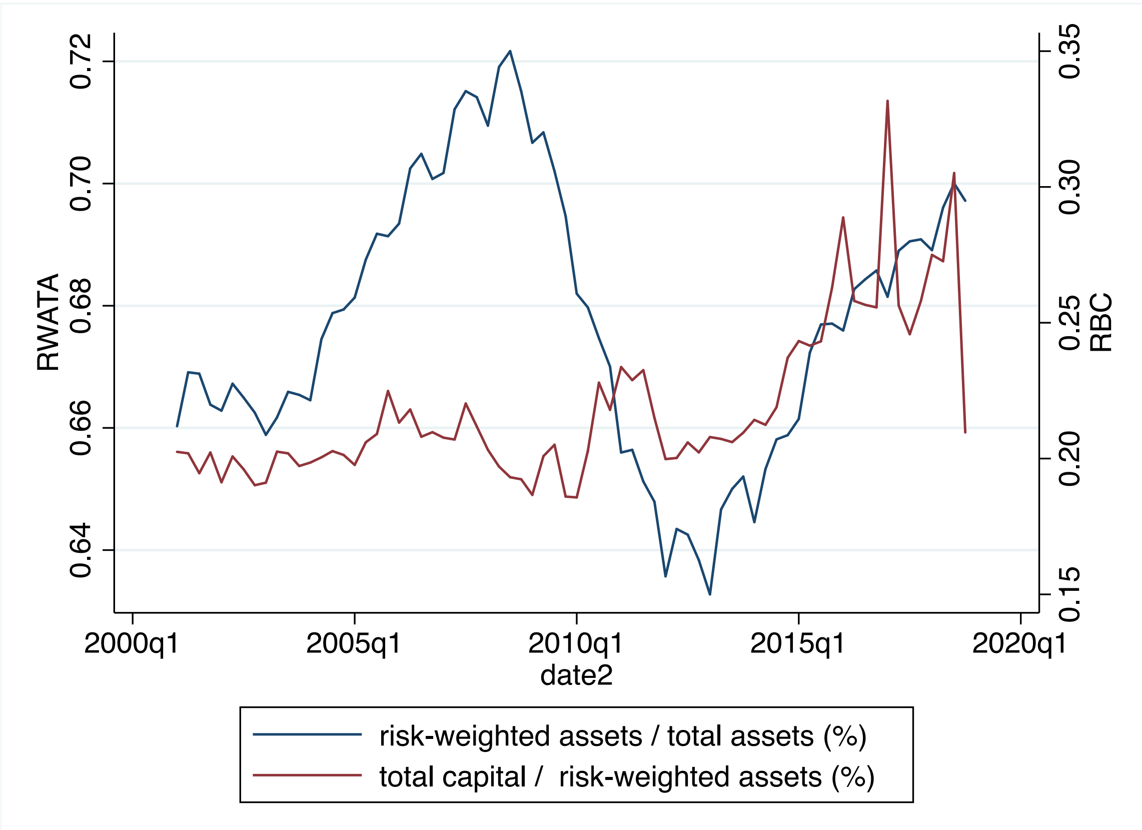
Note: This figure illustrates the main theoretical results in Section 4 Proposition 7 (iii). Panel A and Panel B show comparative study for the thresholds of competition levels for risky asset with and without regulatory capital arbitrage. Panel A shows that, without arbitrage, the threshold for risky asset under risk-based capital ratio and leverage ratio is higher than the threshold for risky asset under risk-based capital ratio alone, which is higher than the threshold for the simple leverage ratio alone. Panel B shows that, with arbitrage, the threshold for risky asset under risk-based capital ratio and leverage ratio is higher than the threshold without leverage ratio, suggesting the role of leverage ratio in reducing bank risk-taking. Panel C shows the threshold for supervisory power that restricts bank arbitrage. With added leverage ratio, the threshold of required supervisory power for no arbitrage decreases.

Figure 2: Deposit Competition among Banks with Different Sizes



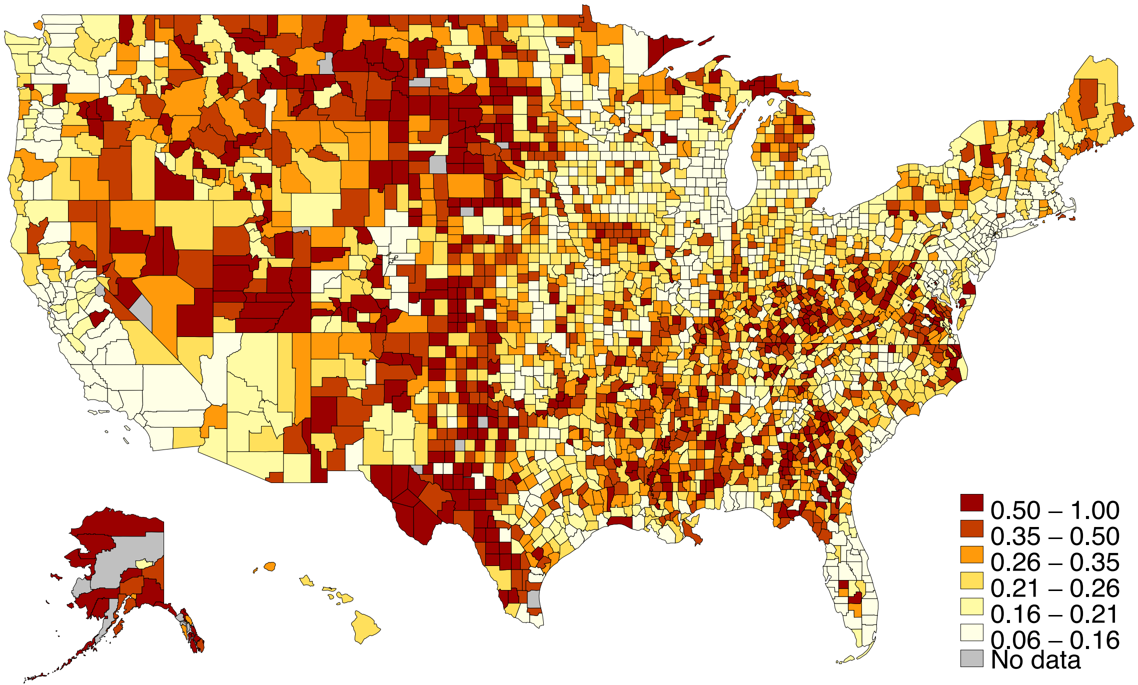
Note: This figure illustrates competition for deposits among banks with different sizes. The large bank is located at the center and n small banks are located systematically around the circle. The large bank and n small banks compete for deposits, and λ depositors are located on a line segment between the large bank and a small bank. The distance for depositors to travel to the large bank is x, and the distance to a small bank is y. The deposit competition is modeled as monopolistic competition, where the product differentiation is due to transaction cost, such as travel cost, imposed on depositors.

Figure 3: Change of RWATA & RBC Over Time



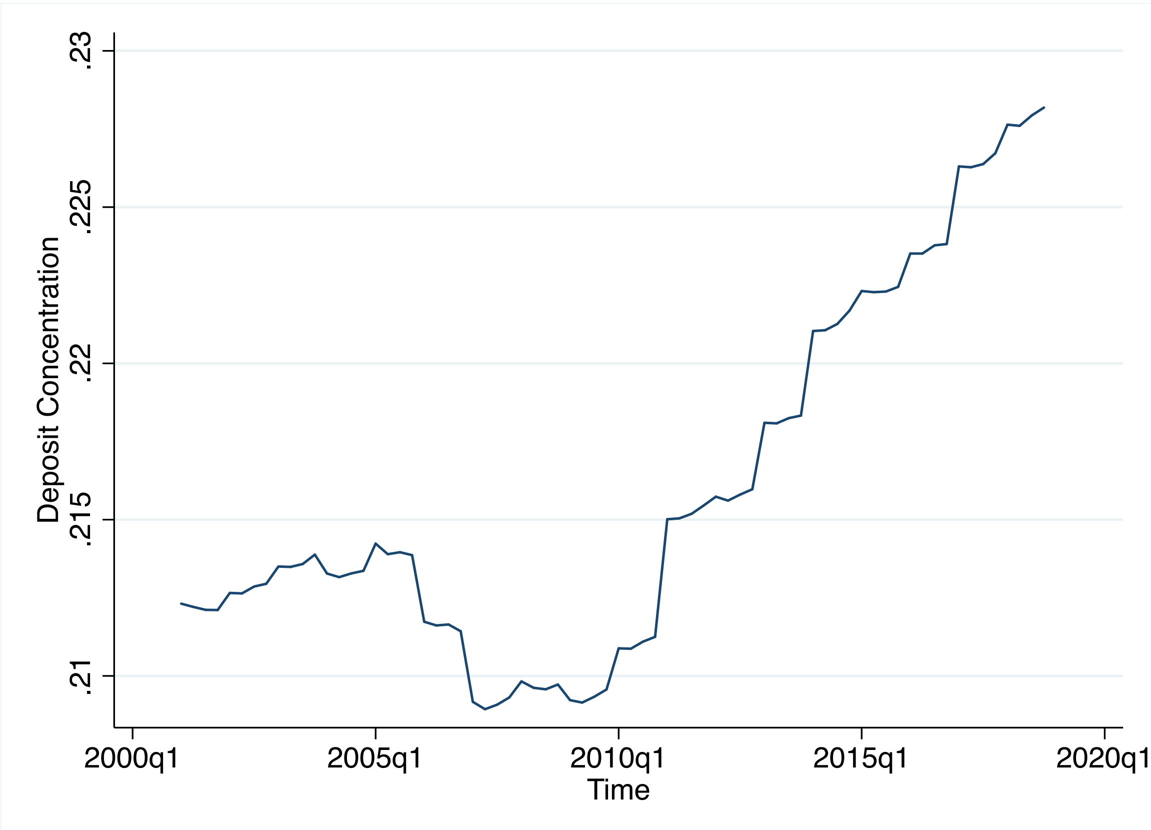
Note: This figure shows how RWATA and RBC change over time. RWATA is a ratio of risk-weighted assets over total assets. RBC is a ratio of total capital over risk-weighted assets. The data is from 2001 Q1 to 2018 Q4.

Figure 4: Branch-HHI: U.S. County



Note: This figure shows Herfidahl Hirschman Index (HHI) for deposits in U.S. counties. I first create branch-level HHI by summing up the squared deposit shares of all banks that operate branches in a given county in a given year. Then I calculate average of branch-level HHI for each county over 2001 Q1 to 2018 Q4. The darker a county, the higher HHI it has, which indicates higher deposit market concentration and thus, lower deposit competition.

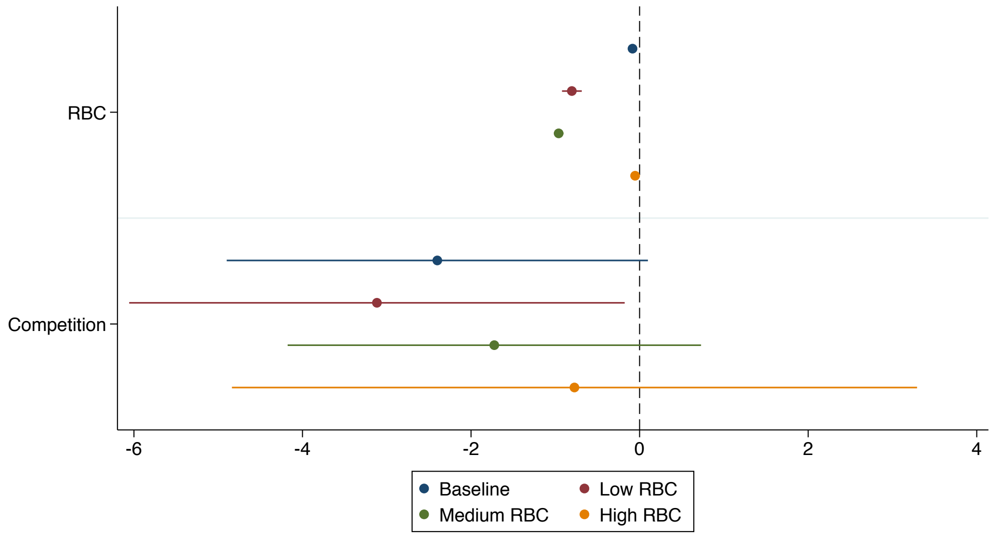
Figure 5: Deposit Market Concentration Over Time



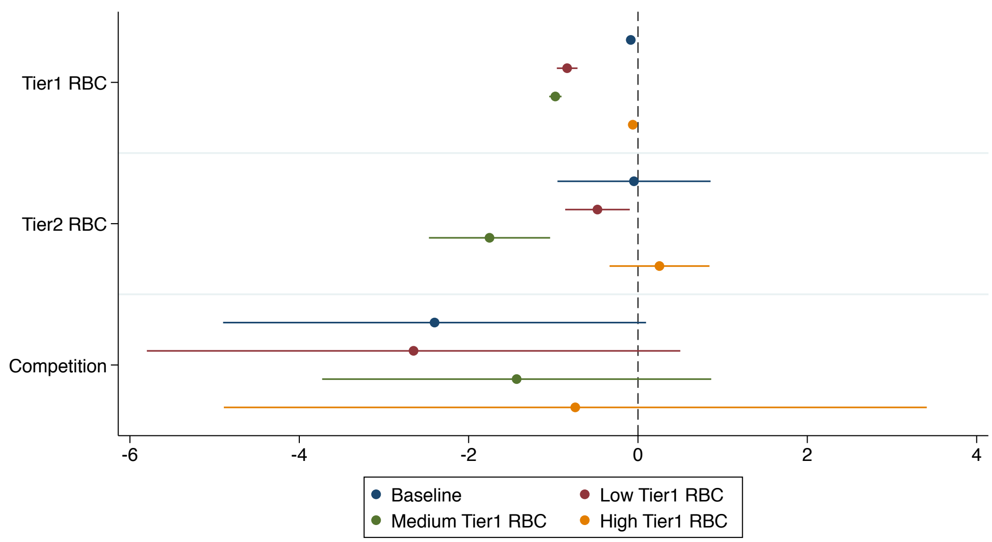
Note: This figure shows how deposit market concentration changes over time. I first create branch-level HHi by summing up the squared deposit shares of all banks that operate branches in a given county in a given year. I then create bank-level HHI by summing up the weighted average of branch-level HHI across all of a bank's branches, with weights to be the ratio of the branch deposit to total deposits of the bank. This figure is plotted based on bank-level HHI.

Figure 6: Reduced Form Results: Static

(a) Panel A: RBC & Competition

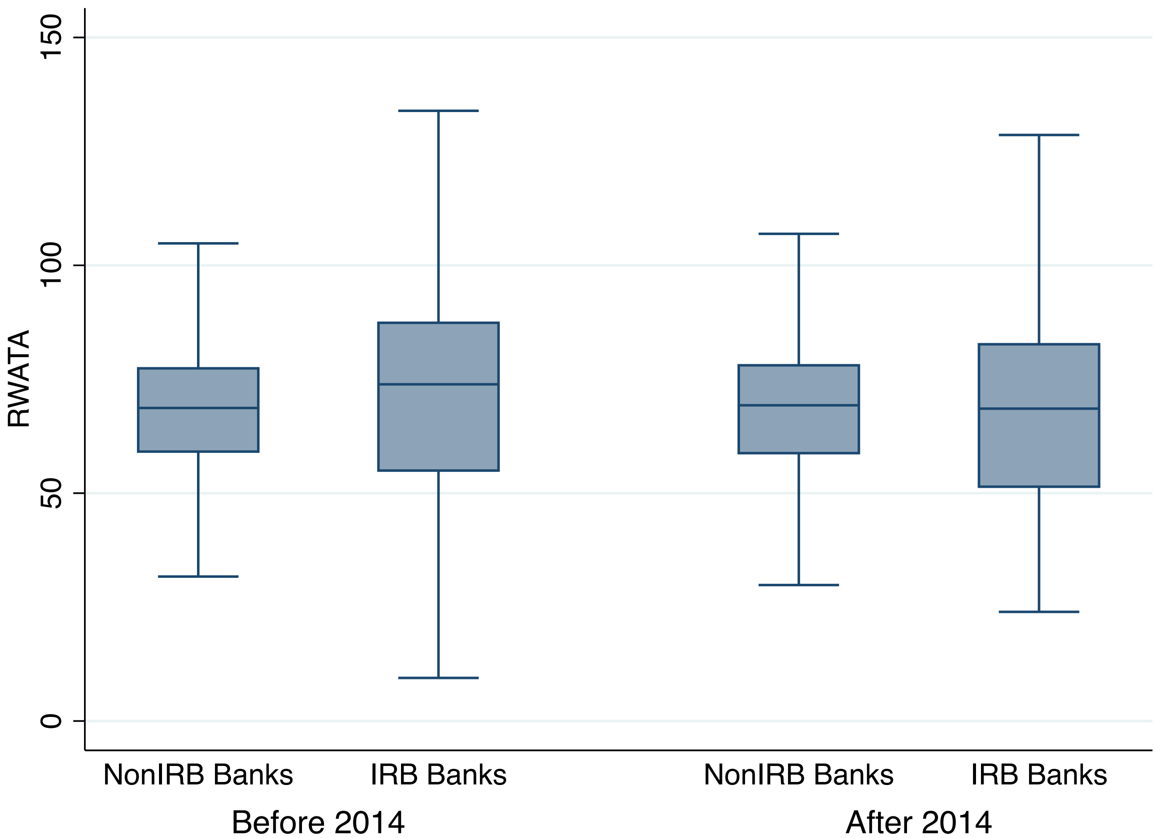


(b) Panel B: Tier 1, Tier 2 & Competition



Note: This figure plots estimates of regulatory capital ratios (RBC and Tier1 & Tier2 RBC) and deposit competition (measured as bankHHI) from the baseline equations (40) and (42). The key controls in Panel A are RBC and bankHHI from the whole sample and subsamples based on the size of RBC (below 25th percentile, between 25th and 75th percentile, and above 75th percentile). The key controls in Panel B are Tier1 RBC, Tier2 RBC and bankHHI from the whole sample and subsamples based on the size of Tier1 RBC (below 25th percentile, between 25th and 75th percentile, and above 75th percentile). Raw estimates are presented in Table 3 and Table 4.

Figure 7: Comparison of RWATA among IRB and nonIRB Banks



Note: This figure shows RWATAs, measured as risk-weighted assets over total assets, for IRB banks and nonIRB banks before and after 2014.