Banking Dynamics, Market Discipline and Capital Regulations

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Abstract

This paper builds a quantitative model of the banking sector to analyze potential aggregate impacts of the minimum capital requirements and counter-cyclical capital buffer (CCyB) in Basel III capital regulations. We contribute to the growing literature analyzing the impact of CCyB by augmenting a standard banking model in two ways: (i) allows banks to default due to un-diversifiable risk based on the assumption of incomplete markets with respect to credit risk of bank loans and (ii) incorporates market-based funding with its equilibrium price reflecting individual-bank specific default premium as market discipline. The model is calibrated to large banks in Canada in 2017 when the required CCyB was 1.5 percentage points above other capital requirements. A simulation of the model through a Great-Financial-Crisis like episode suggests that counter-cyclical capital buffer that lowers the buffer from 1.5 percentage points to zero in the crisis period qualitatively smoothes aggregate loan dynamics and attenuates bank failures during the crisis. However, the result also suggests a limited quantitative importance of such policy in the aggregates. Across the distribution of banks over their capital ratios, low capitalized banks benefits more from the policy than their high capitalized peers do. When the required buffer increases to 5 percentage points above other capital requirements, the quantitative effectiveness of CCyB during the crisis improves. We also find that market discipline lowers bank default risk on average during the crisis but increases it for market-based-funding reliant banks that tend to be larger and better capitalized.

Keywords: Financial institution, Capital requirement, Market discipline, Bank heterogeneity
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1 Introduction

In the aftermath of the financial crisis, a new set of banking regulations emerged, some of which have been set under the label Basel III.[1] This paper looks at the effects of two features of these regulations that pertain to the amount of own capital required of banks —*a minimum capital requirement* and *counter-cyclical capital buffer (CCyB)*. Central to our approach is the existence of two sources of discipline for banks: The regulations posed by the government and the discipline that the market may pose on the banks if they chose to partially finance their activities in the form of unsecured bank debt.

Minimum capital requirement defines the minimum level of bank capital relative to bank assets weighted by risk. Banks are required to hold capital above their minimum capital requirements under normal circumstances. In addition, counter-cyclical capital buffer requires banks to hold more capital during expansions and allows them to use/lower capital in recessions or in times of financial crisis. It is justified as allowing banks to build up capital buffers before a crisis that may stress banking activity and allows banks to draw down their capital to supply credit during a crisis without being overly constrained by a pro-cyclical nature of regulatory requirements. When banks dip below the buffers, they are to rebuild it by reducing discretionary distribution of earnings, including dividend payments and staff bonus payments. In cases of extreme violation beyond the buffers and below the minimum requirements, the bank can be considered essentially insolvent (even if it has positive option value given the limited liability of its owners and the public guarantees of deposits) and the regulatory authorities can take over.

A stated objective of these regulations is to reduce the likelihood of costly interventions by the government (including the use of deposit insurance) when negative shocks hit the banking sector. In addition, CCyB aims to limit socially valuable banking activities (e.g., bank loans) from overly declining due to the pro-cyclical banking regulation during financial crisis when banks would need to reduce loans in the absence of CCyB that lowers the capital requirement in such periods. How does market discipline interact with these regulations? On one hand, market discipline would place pricing and quantity restrictions on uninsured bank funding (e.g., market-based wholesale funding) to limit bank's risk-taking activities during normal times, and hence there would be less need for regulations. On other hand, the restrictions imposed by market discipline could increase the insolvency rate during a crisis, especially, for banks that rely on market-based funding through its higher risk premiums.

The paper measures the potential impacts of these regulations on the economy and their interactions with endogenous market discipline on bank funding. We ask how much bank lending, default and funding change in normal times and during the crisis-recovery episode with and without CCyB by highlighting the interaction between regulations and market discipline for bank funding. To this end, we build a banking industry model that incorporates what we think are the necessary features for the analysis: banks receive insured deposits, make long term risky (both idiosyncratic and aggregate risks) loans, raise market-based uninsured wholesale funding and hold equity (i.e., bank capital). Market-based wholesale funding is a risky short term debt that comes with a premium reflecting bank's own risk of default, i.e., market

[1] See Basel Committee on Banking Supervision (2011).

discipline. We pose heterogeneous banks–differing in size and the composition of funding as well as in the outcomes of their risky investment–as constituting an industry, and explore the behavior of the industry under alternative regulations imposed by a public regulator.

We calibrate the parameters of our baseline model (including those of loan issuance cost, wholesale funding cost, loan maturity rate, loan failure rates, bank asset liquidation rate and the regulatory requirements) to replicate the main properties of the Canadian banking industry and its regulations subject to aggregate shocks. Salient features of the industry are that large banks use more unsecured debt to finance their activities and that the banking industry's holding of higher bank capital over and above the level required by the regulator. Specific properties that we target include averages and variances of capital ratios, loan balances and wholesale funding.

Using the calibrated model, we first ask what the market discipline or higher CCyB requirement does to the banking industry at a stationary state. Second, we conduct impulse-response analysis by observing the transition from the good aggregate state to the crisis state and then back to the good state that generates a 30 percent decline in the stock of loans at the trough from its initial level.

Comparing between stationary states, we find that the banking industry, facing market discipline through the pricing of bank funding, displays lower bank default risk but at the cost of reduced credit supply over that without market discipline, implying a potential trade-off between socially costly bank risk-taking and socially beneficial credit supply. The average capital ratio of banks rises by 80 basis points with market discipline, reducing the bank default rate by one-third, while bank lending declines by 4 percent. When comparing the baseline model with the 1.5 percentage points CCyB and that with 5 percentage points CCyB, both with market discipline, we find the average capital ratio increases by 3 percentage points with the 20 percent increase in bank capital, however no other major changes are observed regarding bank loans, the use of wholesale funding or the default rate.

Impulse-response analysis shows that 1.5 percentage point CCyB under the baseline calibration qualitatively softens the decline in new loan issuance–hence smoothing credit supply over the cycle as intended–but its quantitative importance is small. The issuance declines at the trough by 54 percent under CCyB compared to 59 percent under constant capital requirement (i.e., without lowering the requirement during the crisis or similarly without releasing the buffer of CCyB), the difference of only 5 percentage point. The intuition behind the small difference is twofold: private capital buffer and small required buffer size under CCyB. First, banks hold precautionary private buffer in bank capital above and beyond the level required by regulation, reducing the need for lower capital requirement during the crisis under CCyB. The average total capital ratio of banks in 2017 was 14.8 percent against 13 percent capital requirement including the layer coming from CCyB. Second, the magnitude of the buffer that is removed during the crisis period is small at 1.5 percentage point, further limiting its quantitative impact.

Our model features heterogenous banks. Bank capital ratio is endogenous and thus heterogeneous depending on bank size and funding needs. Reactions to the crisis shock differ, especially, for banks with low capital ratios close to the requirement since CCyB benefits these banks by lowering the requirement during the crisis period. We find in the baseline case that banks with the bottom 10 percent of the capital ratio distribution benefit more from CCyB since the decline in new loan issuance differs between under CCyB and under constant requirement by 10 percentage points in contrast to that of 5 percentage points for the industry average in the baseline model simulation. Hence, we argue that the impact of regulation is heterogeneous and CCyB, if any, helps those with low capital ratio banks.

When analyzing the impact of CCyB with the 5 percentage point buffer instead of 1.5 percentage points as implemented in 2017, we find that CCyB is visibly more effective in softening the decline of new loan issuance. The issuance in this case declines at the trough by 47 percent under CCyB compared to 59 percent under the constant capital requirement, the difference of 12 percentage point. In addition, the probability of bank default increases more under the constant capital requirement at the trough. CCyB, by giving troubled banks more room to operate without being constrained by the capital requirement, increases the chance of their survival over the case without releasing the buffer in the crisis. CCyB with a larger buffer is more effective in doing so. The default probability at the trough is lower with CCyB by 6 basis points when the CCyB buffer is 5 percentage point, where as it is 2.5 basis points under the baseline CCyB. Finally, dividend payout over this crisis episode is smoother when the CCyB buffer is 5 percentage point then under the baseline 1.5 percentage-point CCyB.

Regarding market discipline in the aggregate dynamics through the crisis simulation, we highlight a tradeoff that arises when removing market discipline. On one hand and prior to the realization of the crisis shock , there is the risk-taking channel where removing market discipline induces higher risk taking by banks who would otherwise be constrained from doing so by higher funding cost reflecting their own risk taking. On the other hand and after the realization of the shock, there is the insurance channel where, some banks on the verge of default will still have access to low-rate funding to continue their operation, dampening the impact of these shocks. This raises the charter value of these banks possibly above that of the outside option, thus increasing the probability of their survival. The two channels are closely inter-related and the former amplifies the adverse impact of the crisis shock with more bank defaults that reduce credit supply; whereas, the latter dampens it with less bank defaults and softens the decline in credit supply.

There are two main findings regarding this tradeoff. First, we find that the former channel is stronger and aggregate credit supply reduces more at the impact of the crisis shock without market discipline than with it. One implication of this result is that market discipline qualitatively helps towards the goal of smoothing credit supply through the cycle that CCyB is intended to achieve. Second, up on the realization of the crisis, market discipline tightens the credit conditions leading to higher bank insolvency, especially, for those banks that rely heavily on market-base funding. These banks tend to be larger and better capitalized than the average bank in the model.

Our paper builds on a growing body of the macro-banking literature (see, for example, Gertler and Kiyotaki (2010), Meh and Moran (2010), Repullo and Saurina (2012), Corbae and D'Erasmo (2013), He and Krishnamurthy (2012), Adrian and Boyarchenko (2012), Martinez-Miera and Suarez (2012), Martinez-Miera and Repullo (2017), Corbae and D'Erasmo (2018), Corbae, D'Erasmo, Galaasen, Irarrazabal, and Siemsen (2017), Brunnermeier and Sannikov (2014), Bianchi and Bigio (2018), Davydiuk (2017), Mankart, Michaelides, and Pagratis (2018) and Goel (2019)). One margin we contribute to the literature is the analysis of heterogenous banks. Analyzing banking regulations with bank default and their aggregate impacts would require banks that are endogenously different. For example, if regulations were to differ by bank size, banks would optimally take them into account in their decisions with implications for aggregate credit supply, banking sector risk, interest rates and so on.[2]

Along this line, there are three papers that are closely related to our study. De Nicolò, Gamba, and Lucchetta (2014) analyze how banks' decisions including lending and default change with capital requirement, liquidity requirement and Prompt Corrective Action (PCA) using a partial equilibrium model with heterogeneous banks. They find that PCA dominates the other regulations in terms of lending, bank's value and welfare through forcing banks to reaccumulate capital *ex post* to the required level when their capital ratios are lower than that. In addition, Mankart, Michaelides, and Pagratis (2018) study interactions between the leverage regulation and the capital requirement defined in terms of risk weighted assets in a partial equilibrium heterogeneous bank model. To analyze the substitution between safe assets and risky assets, their model allows banks to hold safe assets while borrowing in the wholesale market. They find that tighter capital requirement incentivizes banks to substitute risky assets with safe assets to reduce risk weighted assets rather than increase equity, whereas tighter leverage requirement increases lending and equity buffers. Goel (2019) analyzes size-dependent banking regulation in a heterogeneous-bank model with bank failures. Our contribution to these closely related papers are two folds. One is the analysis of counter-cyclical capital buffer. Another is the incorporation of bank insolvency risk premium in risky market-based wholesale funding in addition to deposit and equity as sources of funding. One key distinction between these papers and ours is the incorporation of market discipline in the pricing of bank wholesale funding, which allows us to analyze the importance of the interaction between market discipline and regulations.

The reminder of the paper is organized as follows. Section 2 briefly summarizes Basel III capital requirements. Section 3 describes the model. Section 4 discuss the model calibration. Section 5 show how the model solutions look. Section 6 goes over the policy experiments, using the calibrated model. Section 7 concludes.

2 Basel III Capital Requirements

The Basel Committee on Banking Supervision issued a document containing a framework of new post-crisis regulations, Basel III.[3] This section briefly discusses an overview of the capital requirements in

[2] Corbae and D'Erasmo (2013, 2018) provide a model of heterogeneous banks, however they do not analyze counter-cyclical capital buffer with market-based funding.

[3] See Basel Committee on Banking Supervision (2011) for the details of the information presented in this section.

Table 1: Various Capital Requirements for Large Canadian Banks in 2017

	Requirement (% of risk-weighted assets)
Minimum Total Capital	8.0
Capital Conservation Buffer	2.5
Additional Capital for Systemically Important Banks	1.0
Counter Cyclical Capital Buffer	1.5

Basel III.[4] Table 1 summarizes the four layers of capital requirements in Basel III.[5]

The definition of "capital" used in Table 1 is *Total Capital* which, for example, include common shares, retained earnings, preferred stocks, subordinated debt and loan loss provisions.[6]

The first row of the Table 1 is the *Minimum Total Capital* requirement which, for example, include common shares, retained earnings, preferred stocks, subordinated debt and loan loss provisions. Banks need to maintain their capital ratio above the minimum capital requirements at all times. The rest of the rows indicate additional requirements on top of the minimum requirement. Specifically, capital conservation buffer of 2.5% is added. As the name suggests, it is a buffer below which capital can fall in a period of stress while banks should maintain capital above it during normal times. When buffers have been drawn down, banks should rebuild them by reducing discretionary distributions of earnings, such as dividend payouts and staff bonus payments.

In addition, additional requirements are placed as extra loss absorbency for banks that are systemically important.[7] Banks are deemed systemically important based on indicators under several categories: cross-jurisdictional activity, size, interconnectedness, substitutability/financial institution infrastructure and complexity. Systemically important banks are charged with additional 1 to 3.5% of capital, depending on the values of the indicators. In 2017, all six large Canadian banks were deemed domestically systemically important and charged the additional capital requirement of 1%.

Finally, the last row of the table lists the counter-cyclical capital buffer (CCyB) of 0 to 2.5%. This buffer aims to address the risks of system-wide stress that varies with the macro-financial environment. The requirement is turned on by national jurisdictions when aggregate credit growth is deemed excessive

[4]Basel III consists of two broad categories of regulations: one on capital framework and another on liquidity standard.

[5]Numbers in the table are the required percentage of capital with respect to risk-weighted assets. A risk weight is assigned to each asset class by the Basel Committee and represents a degree of riskiness of the underlying asset. Hence, the higher it is the risk, the more capital is required. In our model, banks hold only one type of risky assets, hence, assuming the risk weight of one.

[6]Basel III regulations mainly discuss a narrower definition of capital, i.e., *Common Equity Tier 1 (CET 1) Capital*, consisting of common shares and retained earnings.

[7]These are banks that are deemed to potentially cause system-wide adverse impacts in case of their default. There are both global and domestic systemically important banks. See Basel Committee on Banking Supervision (2013) for discussions of global systemically important banks and Office of Superintendant of Financial Institutions (2013) for domestic systemically important banks in Canada.

and turned off when financial risk materializes. When CCyB is on, banks need to increase up to 2.5% of additional capital. In 2017, CCyB was set at 1.5% in Canada.

In the next section, we present a model that aims to incorporate features addressing regulatory concerns for banks. In this version of the paper, the analysis of the model focuses on the minimum capital requirements and the counter-cyclical capital buffer (CCyB), however, the model provides a framework in which other layers of capital regulations can also be analyzed.

3 Model

We build a dynamic heterogenous-bank model with bank default. Time is discrete and has an infinite horizon. On the funding side, banks receive deposits which are insured and assumed to have zero interest rates. Banks can additionally raise market-based wholesale funding, issue equity and/or dividends. On the asset side, they can issue long-term loans while facing loan-issuance costs that are increasing with the issuance. These loans are risky with the constant interest rate r. Banks can default on their liabilities either when the value of continuing the operation is negative or when they cannot satisfy a set of constraints, including the regulatory requirements. This possibility of bank default gives rise to the bank-default risk premium on the wholesale funding above the risk-free rate r_f. Moral hazard problem with excessive risk-taking with respect to bank default can arise due to the combination of the limited liability for banks and the existence of insured deposit whose interest rate does not adjust to the default probability of banks. Below, we describe the details of the model.

3.1 Environment

Banks differ both exogenously and endogenously, where the endogenous differences comes from their choices and resulting endogenous individual bank states. There are two exogenous types of banks, indexed by $i \in \{S, L\}$. S banks receive a smaller value deposits and face higher risk in their loans, i.e., higher average loan failure rate and higher volatility of the loan failure rate, compared to those of L banks. We denote ξ_i^d, μ_i^δ, and σ_i^δ as the deposits, the average and the standard deviation of loan failure rate, δ, for type i banks, respectively. This exogenous bank type is stochastic and follows a Markov process, $i' \sim \Gamma(i'|i)$, where the prime indicates the next period.

Both types of banks face the same loan issuance cost function, $f_n(\ell, n, \chi_1^n, \chi_2^n)$, where ℓ and n denote the existing long-term loans and the new loan issuance, respectively. χ_1^n and χ_2^n are the parameters of the function. f_n is increasing and convex in n so that the choice is well defined, while the marginal cost of n, $\partial f_n/\partial n$, is decreasing in ℓ to capture the banking technology that is increasing returns to scale in bank size. We also assume that banks face increasing and convex cost in raising wholesale funding, denoted by $f_b(b', \chi_1^b, \chi_2^b)$, where b' represents the wholesale funding borrowed this period to be paid back in the next period.

In addition, there is a two-state persistent aggregate shock, z, following a Markov process, $z' \sim$

$\Gamma(z'|z)$. The two states are the "normal" ($z = G$ for good) and "crisis" states ($z = B$ for bad). The loan-failure-rate probability, $\pi_i(\delta|z)$, worsens in the crisis state over that of the normal state for all banks such that the average loan failure rate increases during the crisis periods, i.e., $\mu^{\delta}_{i,B} > \mu^{\delta}_{i,G}$) where $\mu^{\delta}_{i,z}$ is the average loan failure rate for bank type i in aggregate state z.

As the idiosyncratic loan-failure shock on bank loans, δ, realizes, some banks default when their δ is high enough. These banks are either unable to pay back their liabilities while satisfying regulatory constraints (i.e., an involuntary default) or find its outside option more attractive (i.e., a voluntary default). As existing banks default, the same number of new banks enter and start their operations with small a and ℓ, maintaining the population of banks constant over time.

Banks's decisions to issue new loans and raise market-based funding are subject to bank capital regulation in the form of a minimum capital requirement. That is, the ratio of bank equity to risk-weighted assets needs to be above a certain level, $\theta(z)$, where we interpret the dependence of θ on the aggregate shock z to capture the nature of dynamic capital requirements such as the counter-cyclical capital buffer. Banks do not necessarily default or enter the liquidation stage when violating the capital requirement. Instead, the regulator restricts the banks from issing dividends.[8] When these additional restrictions do not prevent a bank to continue losing its capital, the bank will be resolved and liquidated, i.e., the involuntary default. This happens at some threshold $\underline{\theta}$ such that $\underline{\theta} < \theta(z)$.

3.2 Bank problem

Relevant events for a bank unfold in the following sequence within each period. In the beginning of a period, a bank has its liquid asset position, a, and its long term loans ℓ, carried over from the previous period that did not mature or fail, i.e., . (at rate λ per period. Banks issue new loans n, distribute dividends c and raise market-based funding b' at price $q(\ell, n, b', i, z)$.

The timing of events involving bank's decisions are as follows:

1. In the beginning of a period, a bank knows its state and that of the economy, i and z, as well as its funding need position (a) and existing long-term loans (ℓ) as a result of the δ shock realization from the previous period.

2. The bank decides whether to continue their operation or default.

3. If no default, it chooses dividend, new loans, wholesale funding and bank equity (c, n, b' and e, respectively) subject to the capital regulation, $\theta(z)$.

4. If the regulation is successfully met, the bank operates according to its choices. If not, the regulator forces the bank to set $c = 0$.

5. At the end of the period, i', z' and δ' realize.

[8]See, for example, the Prompt Correction Action in the Federal Deposit Insurance Act in the USA at https://www.fdic.gov/regulations/laws/rules/1000-4000.html.

Table 2: Bank Balance Sheet

ASSET		LIABILITY & EQUITY	
Long-Term Loan	$p^n_{i,z}n + p^\ell_{i,z}\ell$	Insured Deposit	ξ^d_i
		Market-Based Funding	$q \cdot b'$
		Equity	e

We define the funding need, a, to be the financial position after receiving loan interest income and between paying off previous deposits and wholesale funding and receiving new deposits and wholesale funding. Figure 1 visualizes the timing of events.

Accordingly, the balance sheet position of the bank after its choices on c, n, b' and e is given by Table 2. Note that q is a discount price of b' and a function of the bank decisions and state as it will be discussed below. In addition, $p^n_{i,z}$ and $p^\ell_{i,z}$ are the implied values of loans which reflect discounted streams of expected income generated by them. Then, the risk weighted capital ratio of the bank is given by $\frac{e}{\omega(p^n_{i,z}n+p^\ell_{i,z}\ell)}$, where ω is the relative risk weight for risky assets. The balance sheet gives the identity that $e \equiv p^n_{i,z}n + p^\ell_{i,z}\ell - \xi^d_i - q \cdot b'$.

Let us denote $V(a, \ell, i, z)$ and $W(a, \ell, i, z)$ to be the value function of the bank before the default decision and that of operating, respectively. We then have

$$V(a, \ell, i, z) = \max\{0, W(a, \ell, i, z)\}, \tag{1}$$

where 0 inside the max operator is the outside option of the bank if defaulted. The continuation value of the bank that does not default further break down into three sub-values depending on the feasible choice set to satisfy different levels of the capital ratio:

$$W(a, \ell, i, z) = \begin{cases} W^O(a, \ell, i, z) & \text{if } \frac{e}{\omega(p^n_{i,z}n+p^\ell_{i,z}\ell)} \geq \theta(z) \text{ is feasible,} \\ W^P(a, \ell, i, z) & \text{if } \frac{e}{\omega(p^n_{i,z}n+p^\ell_{i,z}\ell)} \in [\underline{\theta}, \theta(z)) \text{ is the only feasible region, or} \\ -\infty & \text{otherwise.} \end{cases}$$

W^O represents the value of normally-operating banks with feasible choices that satisfy the capital requirement and W^P the value of banks with positive equity but its capital ratio is in the penalty zone with no feasible choices that satisfy the minimum capital requirement. We define W^O as follows.

$$W^O(a,\ell,i,z) = \max_{b',\ n\geq 0,\ c\geq \max\{\chi^e\ell,\underline{c}\}} u(c) + \beta\mathbb{E}_{i',z',\delta'(i',z')} V\left(a',\ell',i',z'\right) \tag{2}$$

subject to

$$\ell' = (1-\lambda)\left(1-\delta'\right)\ell + n \tag{3}$$

$$a' = (\lambda + r)(1-\delta')\ell + r\ n - \xi_i^d - b' \tag{4}$$

$$\begin{aligned}(1-\phi\cdot I_{c<0})\,c + n + f_n(\ell,n,\chi_1^n,\chi_2^n) + f_b(b',\chi_1^b,\chi_2^b)\\ \leq a + q(\ell,n,b',i,z)b' + \xi_i^d\end{aligned} \tag{5}$$

$$\frac{e}{\omega\cdot(p_{i,z}^n n + p_{i,z}^\ell \ell)} \geq \theta(z) \tag{6}$$

Equations 3 and 4 are the law of motion for the long-term loans and the funding needs position, respectively. The funding needs measure the financial position of income from the loans net of paying back all debt and before receiving new deposits and raising wholesale funding. λ is the maturity rate of existing loans. Equation 5 is the budget constraint. The parenthesis multiplied by c on the left-hand side of inequality 5 includes the proportional cost parameter $\phi \in [0,1]$ for equity issuance. We interpret "negative dividend", $c < 0$, to be equity issuance. $I_{c<0}$ is the indicator function that is 1 when $c < 0$ and 0 otherwise. When $c > 0$, the value in the parenthesis is 1 and between 0 and 1 when $c < 0$, implying that a bank needs to spend \$1 to raise \$$(1-\phi)$ of equity. In addition, the choice range of c is bound below by $\max\{\chi^e\ell,\underline{c}\}$. We assume that there is an overall bounded, $\underline{c} < 0$, in equity issuance and the bound for an individual bank can be tighter proportional to the amount of existing loans, $\chi^e\cdot\ell$ with $\chi^e < 0$. The equity issuance bound for individual banks captures the size effect of issuing equity. Equation 6 is the regulatory capital requirement.

We assume that the preference for dividend, $u(c)$, displays diminishing marginal returns with $u(c) > 0$ for $c > 0$. New loans do not fail for one period to allow for the distinction that the performance of new loans are better monitored by banks than of older ones. The discount price of market-based funding, $q(\ell,n,b',i,z)$, is an equilibrium object that incorporates the bank-specific default risk premium due to market discipline to be discussed in detail in the next section.

Next, the value function of the bank in penalty, W^P, is given as follows.

$$W^P(a,\ell,i,z) = \max_{b',\ n\geq 0,\ \max\{\chi^e\ell,\underline{c}\}\leq c\leq 0} u(c) + \beta\mathbb{E}_{i',z',\delta'(i',z')} V\left(a',\ell',i',z'\right) \tag{7}$$

subject to

$$\ell' = (1-\lambda)\left(1-\delta'\right)\ell + n \tag{8}$$

$$a' = (\lambda + r)(1-\delta')\ell + rn - \xi^d - b' \tag{9}$$

$$(1-\phi)\,c + n + f_n(\ell, n, \chi_1^n, \chi_2^n) + f_b(b', \chi_1^b, \chi_2^b) \tag{10}$$

$$\leq a + q(\ell, n, b', i, z)b' + \xi^d \tag{11}$$

$$\frac{e}{\omega(p^n_{i,z}n + p^\ell_{i,z}\ell)} \geq \underline{\theta} \tag{12}$$

Note that banks are restricted to set $c \leq 0$ in Problem 7 as penalty in violation of the minimum capital requirement.

3.3 Equilibrium price function with market discipline

We introduce market discipline in the form of how wholesale funding is priced with appropriate risk premium, taking into account bank's default risk. We assume that wholesale investors, who have access to unlimited external funding at the risk free rate, have complete information regarding the risk of individual banks and compete among themselves to lend to banks. Under this assumption of market discipline, the only equilibrium price in the model is given by the function $q(.)$ where investors of wholesale funding for each bank make zero profit in expectation over time while banks are solving 1, 2 and 7. This condition leads to $\underline{\delta}^*(\ell, n, b', i', z')$ and $q^*(\ell, n, b', i, z)$ such that the discount price of the funding just reflects the default probability of individual banks plus the adjustment for the liquidation rate of bank assets in the equilibrium discounted by the risk-free rate:

$$q^*(\ell, n, b', i, z) = \frac{1 - \sum_{i',z'} \Gamma^i_{i,i'} \cdot \Gamma^z_{z,z'} \cdot \int^1_{\underline{\delta}^*(\ell,n,b',i',z')} \left(1 - \frac{a'(\delta')+b'+\nu\ell'(\delta')}{b'}\right) \pi(\delta'|i',z')\,d\delta'}{1+r_f}, \tag{13}$$

where $\Gamma^i_{i,i'}$ and $\Gamma^z_{z,z'}$ are the transition probability of the individual state i and the aggregate state z, respectively, r_f is the risk-free rate and $\underline{\delta}$ is the bank's voluntary-default threshold of δ' such that, when $\delta' = \underline{\delta}(\ell, n, b', i', z')$, the two terms inside the max operator in Problem 1 are equal to each other. The term $\frac{a'+b'+\nu\ell'}{b'}$ is the recovery rate from the liquidation of bank assets in insolvency with ν being the liquidation rate of loans. Note that wholesale funding is priced at the risk-free rate, $q(\ell, n, b', i, z) = \frac{1}{r_f}$, when the default probability of the bank is zero.

In our exercises later on when we consider removing market discipline, we assume that wholesale funding price does not incorporate bank's default risk and hence set $q(\ell, n, b', i, z) = \frac{1}{r_f}$ for all banks.

4 Calibration

This section discusses how we set the values for the model parameters. First, we assume the functional form for $u(c)$ to be $u(c) = (c - \underline{c})^\sigma - \underline{c}^\sigma$ where $\sigma \in (0, 1]$. This function has desired properties such that it is increasing and concave and $u(0) = 0$. We also assume the functional form for the loan issuance cost to be $f_n(\ell, n, \chi_1^n, \chi_2^n) = \chi_1^n \cdot \ell + 0.5 \cdot \chi_2^n \cdot n \cdot (n/\ell)^2$. When $\chi_1^n > 0$ and $\chi_2^n > 0$, f_n displays an increasing marginal cost for n (i.e., $\partial^2 f_n / \partial n^2 > 0$), decreases in ℓ (i.e., $\partial f_n / \partial \ell < 0$)[9] and increases proportionally to $\frac{n}{\ell}$.[10] Finally, we assume the loan failure shock δ' to be drawn from the Beta distribution whose two parameters are uniquely identified from the average and the variance of loan failure rate. Hence, we calibrate the mean and the variance of the loan failure rate process.

We simulate the model economy that is stationary to calibrate some parameters by matching the moments from the model equilibrium to those from the data. The model economy that we used for calibration is given by the equilibrium after $z = G$ for a long period of time such that the distribution of banks converges. We formally define this economy as follows:

Definition 1 *For each type of banks i, a stationary economy of the normal time is given by the capital requirement, $\theta(z)$, the realization of aggregate shocks, $z_t = G \ \ \forall t$, a measure of banks, $\Omega_i^*(a, \ell)$, a price of market-based funding, $q^*(\ell, n, b', i, z)$, and decisions, $\{c^*(a, \ell, i, z),\ n^*(a, \ell, i, z),\ b^{'*}(a, \ell, i, z)\}$, such that*

- $\{c^*(a, \ell, i, z), n^*(a, \ell, i, z), b^{'*}(a, \ell, i, z)\}$ *solve Problems 1, 2 and 7;*
- *investors get the market return, $q^*(\ell, n, b', i, z)$; and*
- *the measure, $\Omega_i^*(a, \ell)$, converges to a limit.*

Table 3 summarizes the set of parameters in calibration, their values and descriptions. Table 4 lists the data moments used in the calibration and those generated from the model. There are 13 parameters in Table 3 that are calibrated in the model equilibrium, shown in blue, and 13 moments to match, shown in Table 4. Data moments are from large Canadian banks in 2017.[11] This is a good period for the model calibration of the normal state, as the Canadian economy was consistently in a good state in 2017 with 3% annual GDP growth, while CCyB (or called Domestic Stability Buffer in Canada) was consistently set at 1.5 percentage points above the minimum requirement for these banks. Furthermore, by 2017, Basel III capital requirement was fully implemented in Canada together with CCyB of 1.5 percentage

[9] This property is consistent with the assumption that banks display increasing returns to scale technology in the number of bank branches where loans are issued at each branch location.

[10] That is, $f_n(x \cdot \ell, x \cdot n, \chi_1^n, \chi_2^n) = x \cdot f_n(\ell, n, \chi_1^n, \chi_2^n)$ for $x > 0$, i.e., homogeneous of degree 1 in ℓ and n. This implies that a larger bank pays the same average cost per n as a smaller bank if the ratio n/ℓ is the same for both banks.

[11] In the table, CV stands for coefficient of variation. The data moment for the bank insolvency rate requires a discussion. Large Canadian banks have historically never become insolvent, which make it difficult to have the target moment for bank insolvency. Hence, we expanded the list to all federally regulated banks and calculated the historical insolvency rate to be 0.2% over the last 40-year period. We assume a half of 0.2% for the insolvency rate of the large banks used in this calibration.

Table 3: Model Parameters

Parameter	Value	Description
$\chi_1^n,\ \chi_2^n$	0.0004, 0.0005	$f_n(\ell, n; \chi_1^n, \chi_2^n) = \chi_1^n \ell + 0.5\chi_2^n n(n/\ell)^2$
$\chi_1^b,\ \chi_2^b$	0.0182, 0.0016	$f_b(b; \chi_1^b, \chi_2^b) = \chi_1^b + 0.5\chi_2^b b^2$
ξ_L^d/ξ_S^d	2.0888	Relative size of deposits by type
ϕ	0.3652	Proportional cost of equity issuance
$\chi^e,\ \underline{c}$	$-0.7242 \cdot \xi_L^d,\ \ -0.8221 \cdot \xi_L^d$	Equity issuance limit: $\max\{\chi^e \ell, \underline{c}\}$
λ	0.488	Maturity rate of long-term loans
r	0.07	Bank lending rate
r_f	0.005	Risk-free rate
β	0.9139	Subjective discount factor
σ	0.9932	$u(c) = (c + \underline{c})^\sigma - (\underline{c})^\sigma$
ω	0.6104	Risk weight on risky loans
$\Gamma^z_{z=G,z'=G},\ \Gamma^z_{z=B,z'=B}$	0.99, 0.80	Aggregate state Markov probability
$\Gamma^i_{i=S,i'=S},\ \Gamma^i_{i=L,i'=L}$	0.90, 0.90	Bank type Markov probability
$(\mu^\delta, \sigma^\delta)_{S,G}, (\mu^\delta, \sigma^\delta)_{S,B}$	$(0.0527,\ 0.0034^{0.5}),\ \ (0.0791,\ 0.0034^{0.5})$	Loan failure rate for $i = S$
$(\mu^\delta, \sigma^\delta)_{L,G}, (\mu^\delta, \sigma^\delta)_{L,B}$	$(0.0366,\ 0.0022^{0.5}),\ \ (0.0549,\ 0.0022^{0.5})$	Loan failure rate for $i = L$
$\underline{\theta}$	0	Regulatory threshold
ν	0.7587	Liquidation rate of bank loans

points (p.p.), implying that the minimum requirement for large Canadian banks was 13% in total capital which would go down to 11.5% if CCyB were released in an economic downturn.[12] Hence, we assumed in calibration that $\theta(z = G) = 0.13$ and $\theta(z = B) = 0.115$.

The values of the parameters in black in Table 3 are set outside the model equilibrium calculation. The value of λ was set so that the ratio of new loans to existing loans are as observed in the data. The loan interest rate r is 7%, within the range observed in the data. The risk-free rate r_f matches the overnight rate in early 2017 at 0.5%. ω is the risk weight for the regulatory capital ratio. We derived the implied risk weight, using the information from the regulatory reports on the average risk-weighted assets, the average regulatory capital and the average capital ratio of the banks. The transition probability from the normal state to the crisis state is set at 1%, implying the crisis occurs once every 100 years on average. The bank type transition probability from one type to another is assumed to be symmetric at 20%. Both the average and the variance of loan failure rate of small-deposit banks are assumed to be three times higher than those of large-deposit banks. Across the aggregate states, the average loan failure rate increases by 50% from the normal state and the crisis state, a comparable number to the increase of the non-performing loans to total loans during the last financial crisis period from 2008 in Canada. Finally, the regulatory threshold in the capital ratio for involuntary liquidation is set at 0%.

Table 4 shows that the two sets of moments targeted in the calibration exercise. Overall, they match well, except for a few moments on dividends. We note that the data moment of capital ratio was 14.8 percent, well above the required regulatory ratio of 13 percent. This shows that banks hold capital with

[12] The requirement for 13% in total capital includes the minimum total capital requirement, the capital conservation buffer, the domestic systemically important bank (DSIB) add-on and CCyB.

Table 4: Calibration: Model and Data Moments in the Initial State

	Data	Model
Bank Insolvency Rate	∼0.10%	0.12%
Capital Ratio	14.80%	14.64%
New Loans/Deposit	1.18	1.02
Existing Loans/Deposit	2.39	2.09
WSF/Deposit	2.34	1.98
Equity/Deposit	0.24	0.29
Dividend/Deposit	0.04	0.09
CV(New Loans/Deposit)	0.49	0.35
CV(Loan Balance/Deposit)	0.23	0.27
CV(WSF/Deposit)	0.26	0.25
CV(Equity/Deposit)	0.23	0.20
CV(Dividend/Deposit)	0.26	0.81
CV(Capital Ratio)	0.03	0.06

a private buffer above and beyond the regulatory requirement. The model captures this moment well despite the risk aversion parameter that is close to 1. The incentive for banks in the model to hold an additional capital buffer as insurance come from the non-linearity generated by the cost of equity issuance (i.e., negative dividend) as well as the limit of issuance.

5 Characterization of Model Solution

The set of figures from Figure 2, 3, 4 and 5 show the value function and the decision rules of banks with $\{i = L, z = G\}$, $\{i = S, z = G\}$, $\{i = L, z = B\}$ and $\{i = S, z = B\}$, respectively, at the stationary economy under the baseline policy of 1.5 p.p. CCyB. Focusing on Figure 2, first, Figure 2a show the value function over the endogenous state variables of a and ℓ. The relevant range of a is negative as it represents the funding shortage to finance existing loans. The value increases with both of the state variables almost linearly, given the calibrated value of $\sigma = 0.991$. The area where the value is zero represents bank insolvency states. At the low end of the existing loan balance near the level of funding needs around zero, we observe a kink in the value function or a cliff. This indicates involuntary bank insolvency where the bank still has a positive value in keeping the operation but does not satisfy the capital requirement as it faces the equity issuance limit.

New loan issuance in Figure 2b has a hump shape over the existing loan dimension as the marginal cost of issuance decrease from the low level of the existing loan balance up to the level where the increasing marginal cost arising from the convexity of the cost function with respect to n take over and the new issuance starts to decline. The borrowing in wholesale funding in Figure 2c increases slightly as ℓ increases but no decline like seen in n, due to the need to finance the higher level of the existing

Table 5: Various Policies for the Capital Requirement and Market Discipline

Cases	Description
1.5 p.p. CCyB (Baseline)	$\theta(z = G) = 0.130$ and $\theta(z = B) = 0.115$
Constant Requirement	$\theta(z) = 0.130 \; \forall \; z$
5 p.p. CCyB	$\theta(z = G) = 0.165$ and $\theta(z = B) = 0.115$
Constant Requirement	$\theta(z) = 0.165 \; \forall \; z$
1.5 p.p. CCyB (Baseline)	$\theta(z = G) = 0.130$ and $\theta(z = B) = 0.115$
1.5 p.p. CCyB (No Market Discipline)	$q = \frac{1}{1+r_f}$, $\theta(z = G) = 0.130$ and $\theta(z = B) = 0.115$

loans. Figure 2d show the discount price of the wholesale funding. The bank insolvency risk premium can be observed along the insolvency line at the higher levels of ℓ, seen as declining q. Furthermore, dividends in Figure 2e show similar patterns as the value function. Finally, Figure 2f displays the capital ratio which increases as ℓ or a increases. The value function and decisions of banks shift with i and z, as seen in Figure 3, 4 and 5.

6 Policy Experiments

This section presents quantitative results of various experiments, using the calibrated model. Specifically, we show the comparison of the stationary economy, as specified in Definition 1, under different cases listed in Table 5. In addition, we derive the impulse-response functions with respect to the aggregate state turning into the crisis state after the stationary economy.

6.1 Stationary economies

The upper panel of Table 6 provides the banking sector statistics in averages under the cases listed in Table 5. All numbers, except for those shown with %, are normalized by the value of deposits. When comparing the baseline and the 5 percentage point policy, no major difference emerges in the loan supply side. Only observable changes are the higher capital ratio and equity as required in the latter, as well as the resulting lower market-based wholesale funding that is replaced by increased equity.[13] Comparing the baseline and one without market discipline, the table show that the insolvency rate in the baseline is one-third lower than that in no market discipline as banks take extra risk without paying the appropriate premium. Capital ratio is also higher in the baseline as banks hold a private buffer to avoid in expectation that, when in trouble, the price of wholesale funding will increase. Loans and wholesale funding are both higher in the no discipline economy while equity and dividends are the same as in the baseline. All

[13] We do not consider tax benefits that come from the interest payment on debt.

Table 6: Comparison of Model Moments under Various Policies and Market Discipline

	1.5pp CCyB (Baseline)	5pp CCyB	1.5pp CCyB (No Market Discipline)
Bank Insolvency Rate	0.12%	0.11%	0.19%
Capital Ratio	14.64%	17.59%	13.85%
New Loans/Deposit	1.02	1.02	1.06
Existing Loans/Deposit	2.09	2.09	2.16
WSF/Deposit	1.98	1.93	2.11
Equity/Deposit	0.29	0.35	0.29
Dividend/Deposit	0.10	0.10	0.10

these imply a potential trade-off between higher loan supply that potentially benefits the economy and higher risk-taking in the banking sector that is costly for the society.

6.2 Impulse-response analysis

The starting points of impulse-response analysis are given by the stationary economy as in Definition 1. Starting from this initial state, the simulation of the aggregate shocks follow the path such that $z_{t=1} = G$ (the initial normal state), $z_{t=2} = z_{t=3} = B$ (two periods of the crisis state) and $z_{t>3} = G$ (recovery to the normal state thereafter). Although the simulation controls the realizations of z shocks, banks have the expectation at time t that the shock at time $t+1$ is drawn from $\Gamma^z_{z_t, z_{t+1}}$ given z_t.

The crisis shock transmits to the banking sector by shifting the distributions of banks. Figure 6a and 6b display the distribution in the stationary economy by bank type i (blue for small and orange for large) and the shift of the distribution from the stationary economy (blue) to the one after the crisis shock occurs (orange), respectively. As the loan-failure rate worsens in the simulation, banks lose more loans on their balance sheet and banks' funding needs increase (i.e., a becomes more negative). As a result, the entire distribution of banks shifts towards lower loan levels and more funding needs (more negative a). The impulse-response functions are constructed by taking the cross-sectional average of the banking sector as the shocks work through the economy. In addition, we show the heterogeneous impacts by observing the two sub-groups defined at the initial state and following them through out the simulations. They are the average of the banks belonging to the 90th percentile of capital ratios and above, and the average of another group of banks belonging to the 10th percentile of capital ratios and below. Hence, below we show three sets of impulse-response functions for each variable of interest.

6.2.1 1.5 p.p. CCyB versus constant capital requirement

The impulse-response functions of the crisis-recovery scenario under the baseline CCyB of 1.5 p.p. and the constant capital requirement during the crisis are displayed in Figure 7a, 7b, 8a, 8b, 9a, 9b and 10a for new loan issuance, existing loan balance, wholesale funding, equity, capital ratio, bank insolvency rate and dividend, respectively. Regarding the vertical axis unit, bank insolvency and capital ratio are shown in percentage, and all other figures are in percentage deviation from the overall average in the initial state of the stationary economy. The units along the horizontal axis are the model period in years.[14]

One of the main questions regarding CCyB is its potential benefit in softening the decline of loan supply during the crisis period. We qualitatively observe this from the overall movement in new loan issuance at $t = 2$ from the middle panel of Figure 7a. The path of the new loan issuance under the baseline CCyB (shown in red) declines during the crisis periods less than that under the case of the constant requirement (in blue). The quantitative implication is small when observing the average of the overall banking industry: a decline of 53.5 percent with CCyB versus 58.5 percent under the constant requirements, the difference of 5 percentage points that is small relative to the overall decline of the new credit supply.

The bank heterogeneity over capital ratios matters in the dynamic impacts of CCyB over the simulation period. For banks with low capital ratio (the bottom panel), the decline in the credit supply is softened more pronouncedly by the release of CCyB during the crisis period: the difference of 10 percentage points between CCyB and the constant requirements. This observation is intuitive since the banks with low capital ratios are those that tend to be more constrained by capital regulation, and hence benefit more from the relaxation of the requirement during the crisis, Figure 9a. Another way to support this intuition is in the dynamics of bank default probability, Figure 9b. All banks increase their default probability during the crisis under the two policies but CCyB benefits banks with low capital ratio as the increase in default is subdued relative to that under the constant capital requirement.

In contrast, those with high capital ratios in the initial state show little difference in credit supply or default probability between the two policies during the crisis. Again, this result is intuitive given these banks are not constrained by capital regulations as they hold an ample private buffer that put them well above the required capital ratio.

6.2.2 5 p.p. CCyB versus constant capital requirement

The main finding from Section 6.2.1 regarding the CCyB policy during 2017 in Canada is that its quantitative implication in softening the credit supply reduction during the crisis is quantitatively small. How does this result depend on the size of the required buffer in CCyB? If CCyB required larger buffer during the normal times and banks were to have access to this larger room in the capital ratio during

[14]Note that all series go back to the average of the stationary economy as $t \to \infty$.

the crisis times, would bank credit supply be more smoothed over the crisis-recovery period than the result obtained from the 1.5 p.p. CCyB policy? To answer this question, we use the calibrated model and change the CCyB policy from 1.5 p.p. to 5 p.p., implying that the capital requirement in the normal times is 16.5% and 11.5% in the crisis times.

We start the simulation from the initial state with 5 p.p. CCyB shown in Table 6. The impulse-response functions under this CCyB policy and the constant capital requirement at 16.5% during the crisis are displayed in Figure 11a, 11b, 12a, 12b, 13a, 13b and 14a for new loan issuance, existing loan balance, wholesale funding, equity, capital ratio, bank insolvency rate and dividend, respectively. From Figure 11a, we do observe a larger difference between the two policies in period 2 such that the fall in credit supply is softened with CCyB, compared to what we observe in Figure 7a under 1.5 p.p. CCyB. The issuance in this case of the larger regulatory buffer declines at the trough by 58.5 percent under CCyB compared to 46.5 percent under constant capital requirement, the difference of 12 percentage point, much larger impact compared to the finding of 5 percentage point from Section 6.2.1. Hence, the size of regulatory buffer matters for the effectiveness of CCyB through the crisis cycle.

Among other variables, one noticeable difference from the 1.5 p.p. CCyB is the default probability, the comparison of Figure 9a and Figure 13a. The peak of the default probability occurs at $t = 2$ in both figures but it is lower under 5 p.p. CCyB at 0.28 percent compared to 0.42 percent under 1.5 p.p. CCyB. The larger reduction in the requirement under the former during the crisis helps banks avoid default. At he same time, the difference between CCyB and constant requirement in bank default is also larger under 5 p.p CCyB than under the baseline, comparing Figure 9 and Figure 13. Under 1.5 p.p CCyB, CCyB reduces the default rate only by 2.5 basis points over constant requirement compared to 6 basis points under 5 p.p. CCyB. We conclude that the size of the regulatory buffer matters for smoothing the banking sector dynamics through the crisis period, while no major difference in credit supply is observed at the initial state between CCyB with low and high regulatory buffers.

6.2.3 Transition from 1.5 p.p. CCyB to 5 p.p. CCyB in the normal time

Previous sections discussed the benefits of a larger buffer in CCyB in the dynamics of a crisis-recovery episode together with no visible difference in credit supply in the stationary economy before a rare crisis shock. How about the transitional cost associated with the policy change from 1.5 p.p. CCyB to that of 5 p.p.? It is conceivable that the transition involves cost to banks through raising more equity, reducing dividend and possibly a temporary reduction in credit supply. This section analyze this question. We do this transitional analysis without a realization of crisis shocks and keep the economy at $z = G$ throughout the transition. Specifically, we take the baseline model with 1.5 p.p. CCyB and start the simulation at $t = 1$. At $t = 2$, a change in the regulation from 1.5 p.p. CCyB to 5 p.p. CCyB is announced for the implementation in the following period at $t = 3$.[15] Results are shown in Figures 15

[15] In Canada, there is a 6-month implementation lag after the announcement.

to 18a.

Figure shows that new loan issuance will fluctuate at the announcement period ($t = 2$) and thereafter. At the announcement period, banks increases credit supply preemptively to generate more revenue for retained earnings in the following period to facilitate the transition as they perfectly expect a tighter regulation at $t = 3$. To this end at $t = 2$, dividend takes at dip to issue more loans, equity and capital ratio start to rise for smooth transition into the new regulation regime for $t > 3$ periods. At the same time, bank default probability rises slightly at $t = 2$ as those banks near the default threshold find the transitional cost to be too great to keep the operation. At the implementation period, $t = 3$, new loan issuance declines to start the normalization process into the new regime as dividend starts to rise, equity continues to rise and finally capital ratio reaches its new norm with bank's private buffer at 17.6 percent that is well above the new requirement at 16.5 percent. The analysis in this section shows that such chance in the buffer size of CCyB could generate credit supply fluctuation in addition to cost to banks through temporary lower dividend and equity issuance during the transition.

6.2.4 1.5 p.p. CCyB versus constant capital requirement, without market discipline

We highlight a tradeoff that arises when removing market discipline. On one hand and prior to the realization of the crisis shock , there is the risk-taking channel where removing market discipline induces higher risk taking by banks who would otherwise be constrained from doing so by higher funding cost reflecting their own risk taking. On the other hand and after the realization of the shock, there is the insurance channel where, some banks on the verge of default will still have access to low-rate funding to continue their operation, dampening the impact of these shocks. This raises the charter value of these banks possibly above that of the outside option, thus increasing the probability of their survival. The two channels are closely inter-related and the former amplifies the adverse impact of the crisis shock with more bank defaults that reduce credit supply; whereas, the latter dampens it with less bank defaults and softens the decline in credit supply.

Figure 19a to 22a display the IRFs comparing the banking sector dynamics with and without market discipline, both under 1.5 p.p. CCyB over the same crisis-recovery shock sequence in Section 6.2.1. There discuss two main findings regarding the tradeoff mentioned above. First, we find that the first channel is stronger and aggregate credit supply qualitatively declines more at the impact of the crisis shock ($t = 2$) without market discipline than with it as shown in Figure 19a. One implication of this result is that market discipline qualitatively helps towards the goal of smoothing credit supply through the cycle that CCyB is intended to achieve.

Second, during the crisis, market discipline tightens credit conditions and induce more insolvencies for banks relying on market-based funding. These banks are larger and better capitalized than the average bank in the economy. The upper panel in Figure 21b displays this. Banks in the top decile of capital ratios are larger. Given that the deposits are exogenous, these banks need to rely more on market-based funding to become large, exposing themselves to adverse funding market conditions during the crisis. From the figure, the increase in bank insolvency is much higher at $t = 2$ in the economy with market discipline.

7 Conclusions

This paper builds a structural model framework for banking sector dynamics that can analyze Basel III capital regulations, including minimum requirements and counter-cyclical capital buffer. The model incorporate bank default based on the credit risk on the loan book where banks face market discipline in raising wholesale funding. The risk is amplified due to maturity mismatch with respect to long-term loans and short-term funding where the short-term wholesale funding is priced for individual-bank default risk due to market discipline. There is moral hazard that miss-aligns banks' risk-taking and default from the regulator's perspective, due to the use of insured deposit as well as the limited liability framework.

The model is calibrated to match cross sectional means and dispersions of banking sector statistics for large Canadian banks in 2017. Policy experiments using the calibrated model produce impulse response functions to a crisis shock episode. They show that CCyB with low regulatory buffer qualitatively works as intended to soften the decline in bank credit supply during a crisis, but it does not generate a quantitatively important difference in the credit supply during the crisis when compared with an alternative policy of the constant capital requirements through the cycle. Heterogenous responses to the crisis shock are observed, where CCyB is more effective in softening the decline in credit supply and avoiding default for low capital ratio banks close to the regulatory constraint.

When a hypothetical policy of 5 percentage point CCyB is analyzed with the same crisis scenario, CCyB show higher quantitative importance in softening the decline of bank credit supply and lowering bank default during the crisis, showing the importance of the size of regulatory buffer in CCyB. In the transition from 1.5 percentage point CCyB to 5 percentage point CCyB, the model predicts a fluctuation in new credit supply which may be a concern for regulatory authorities. Banks will also bear the cost in terms of lower dividend or equity issuance during the transition.

We also discussed the importance of market discipline in potentially reducing the impact of the crisis shock on credit supply as banks expect the funding constraint can be tighter during the crisis and self insure for the possibility. In addition and as a potentially socially costly effect of market discipline, we showed that market discipline tightens the credit conditions during the crisis for larger banks that rely on market-based funding and induce more bank insolvencies than in the economy without market discipline.

Future work would benefit from making loan and deposit rates endogenous such that general equilibrium impacts from these policies can be assessed.

Figure 1: Timing of Events

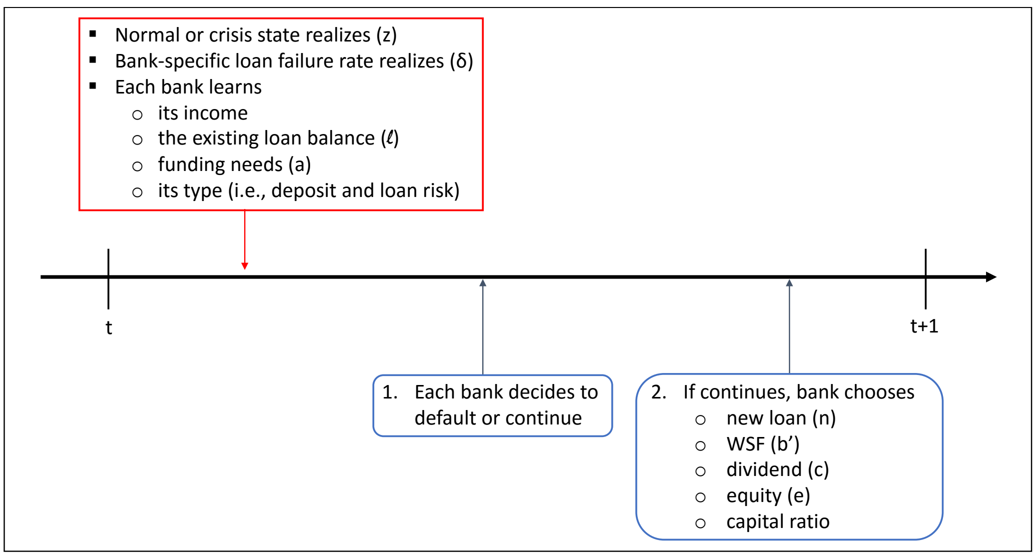
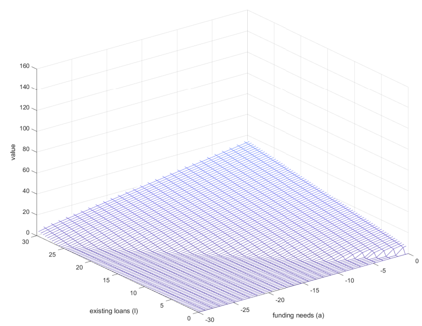
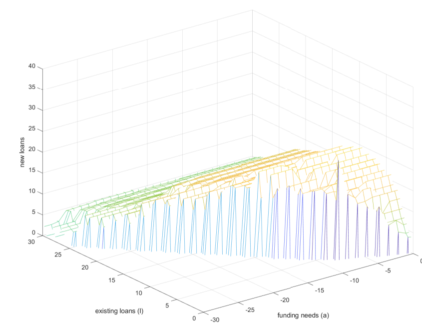


Figure 2: Value Function and Decision Rules of Banks in the Normal State under 1.5-p.p. CCyB for Large Banks

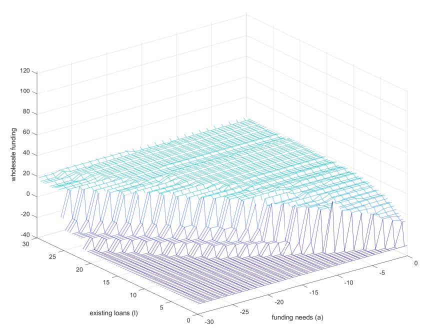
(a) Value Function



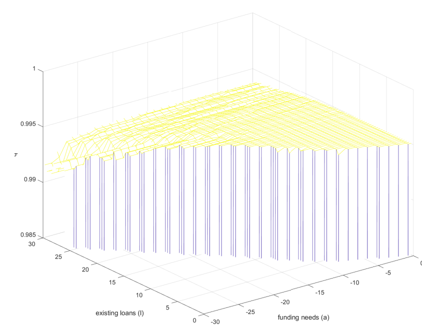
(b) New Loans



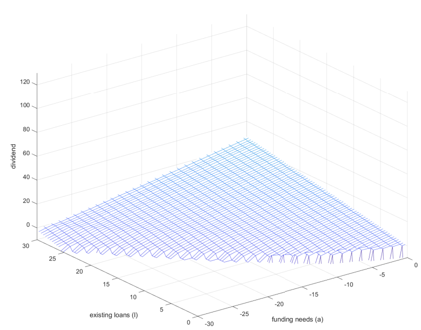
(c) Wholesale Funding



(d) Discount Price of WSF



(e) Dividend



(f) Capital Ratio

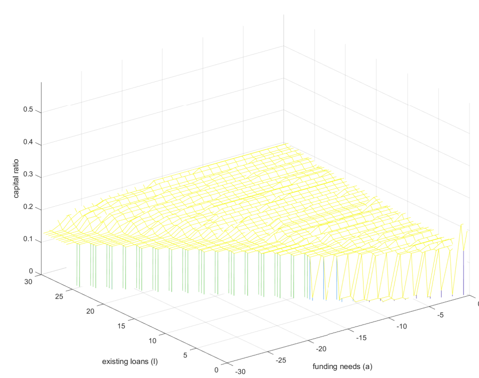
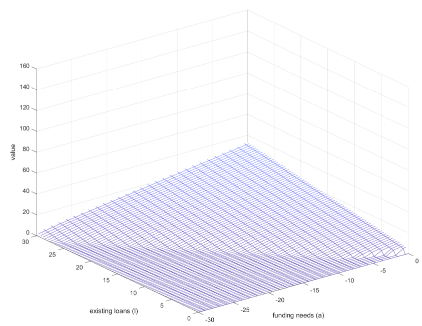
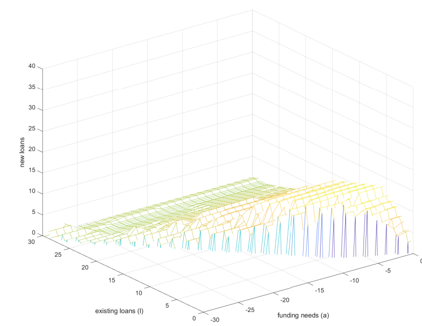


Figure 3: Value Function and Decision Rules of Banks in the Normal State under 1.5-p.p. CCyB for Small Banks

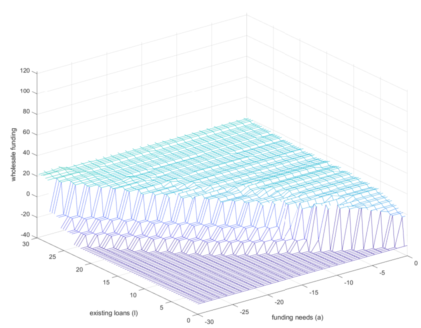
(a) Value Function



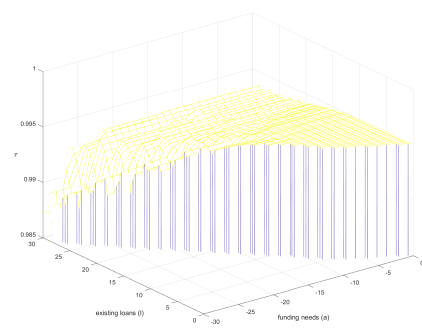
(b) New Loans



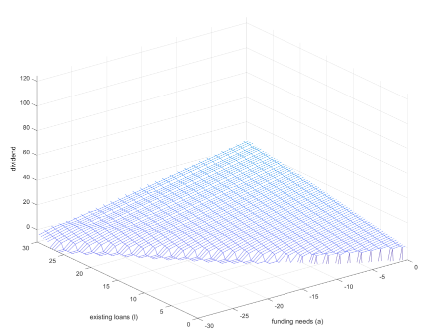
(c) Wholesale Funding



(d) Discount Price of WSF



(e) Dividend



(f) Capital Ratio

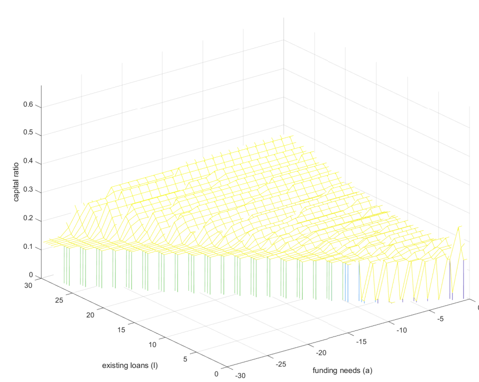
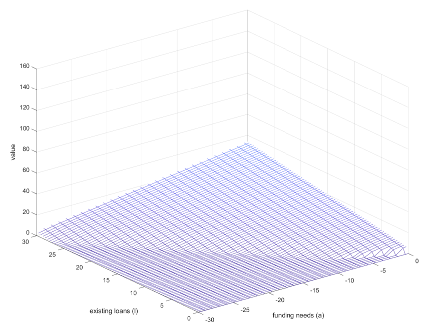
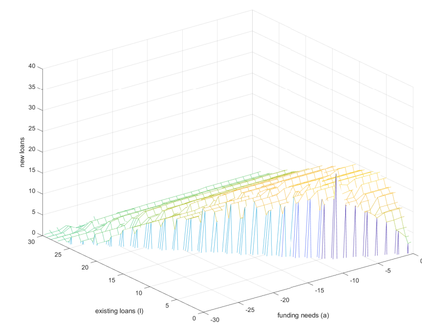


Figure 4: Value Function and Decision Rules of Banks in the Crisis State under 1.5-p.p. CCyB for Large Banks

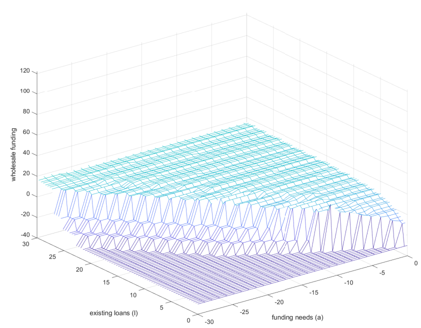
(a) Value Function



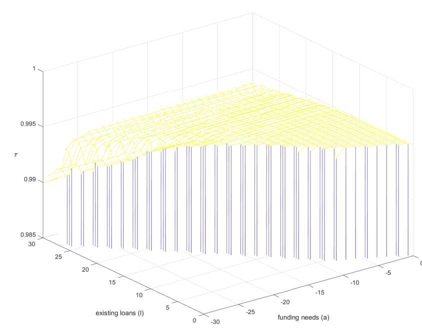
(b) New Loans



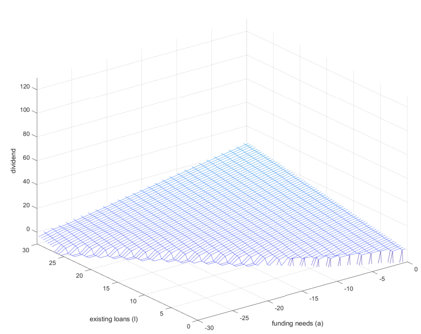
(c) Wholesale Funding



(d) Discount Price of WSF



(e) Dividend



(f) Capital Ratio

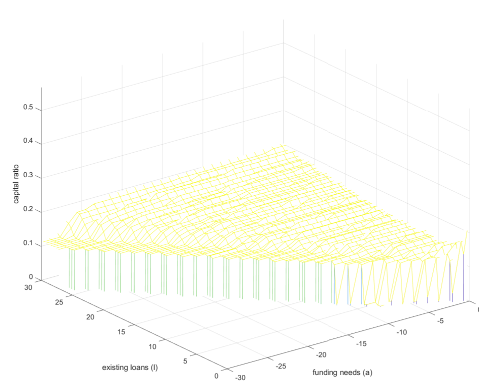


Figure 5: Value Function and Decision Rules of Banks in the Crisis State under 1.5-p.p. CCyB for Small Banks

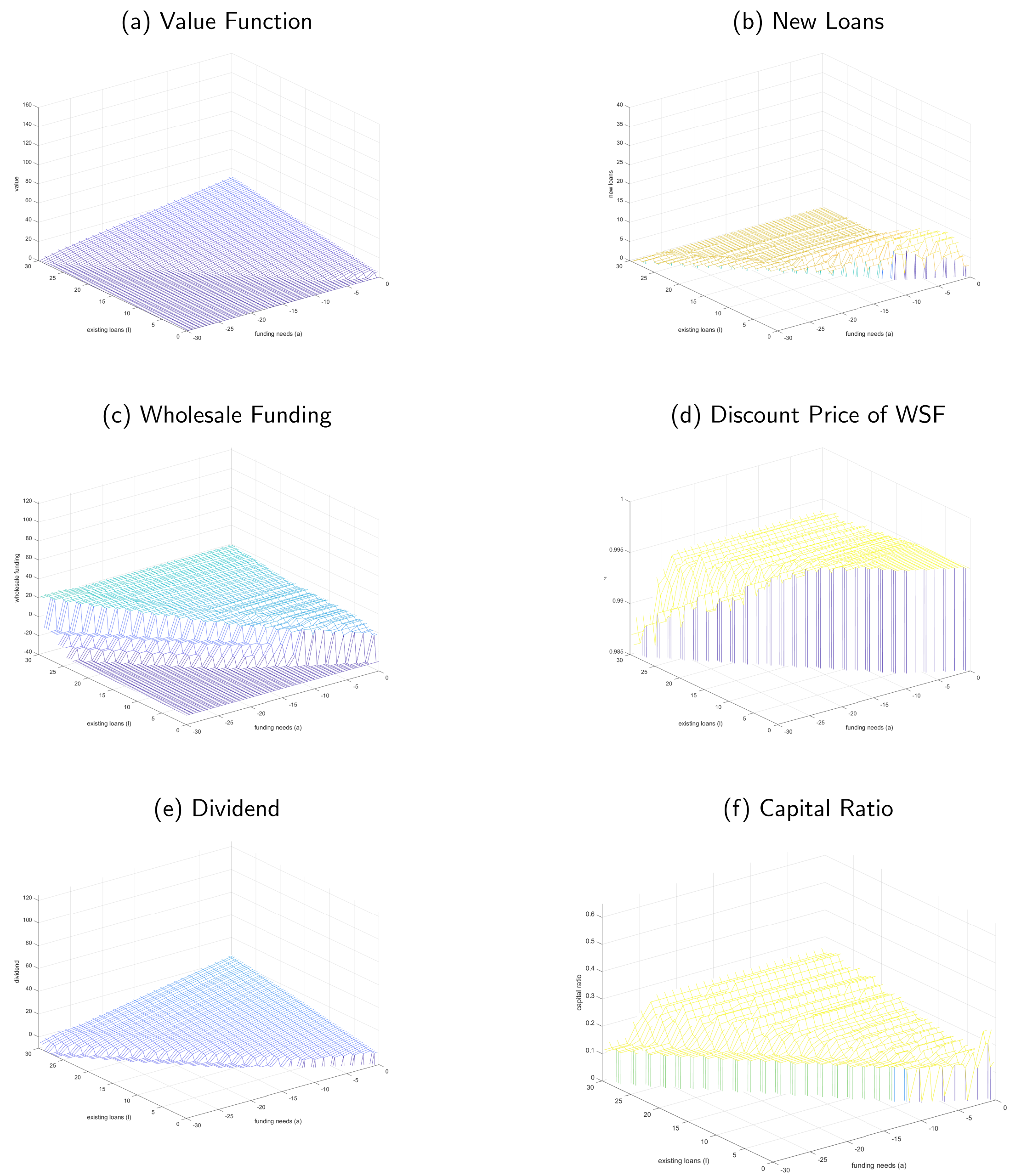
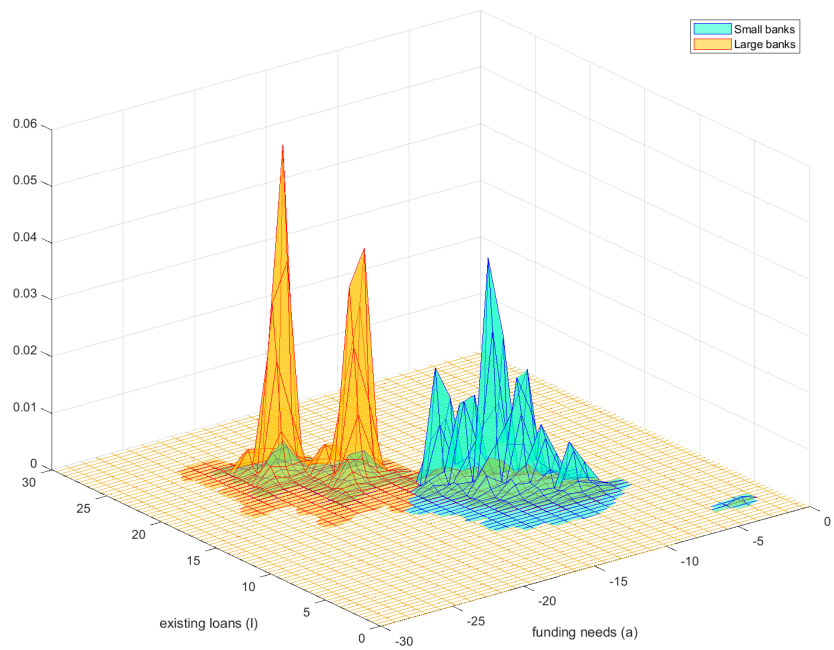


Figure 6: Distributions of Banks under 1.5-p.p. CCyB

(a) Bank Distributions by *i*



(b) Bank Distributions Before and After the Shock

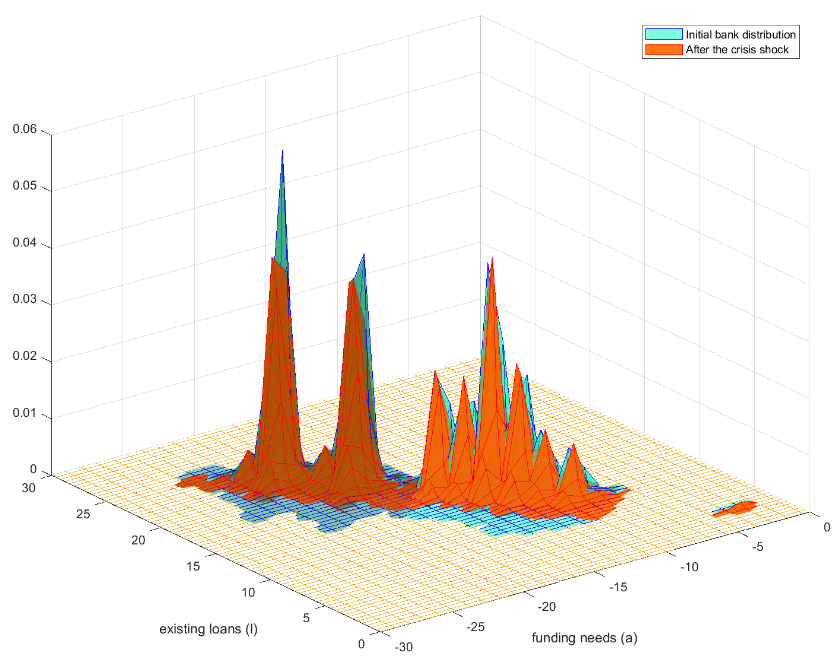
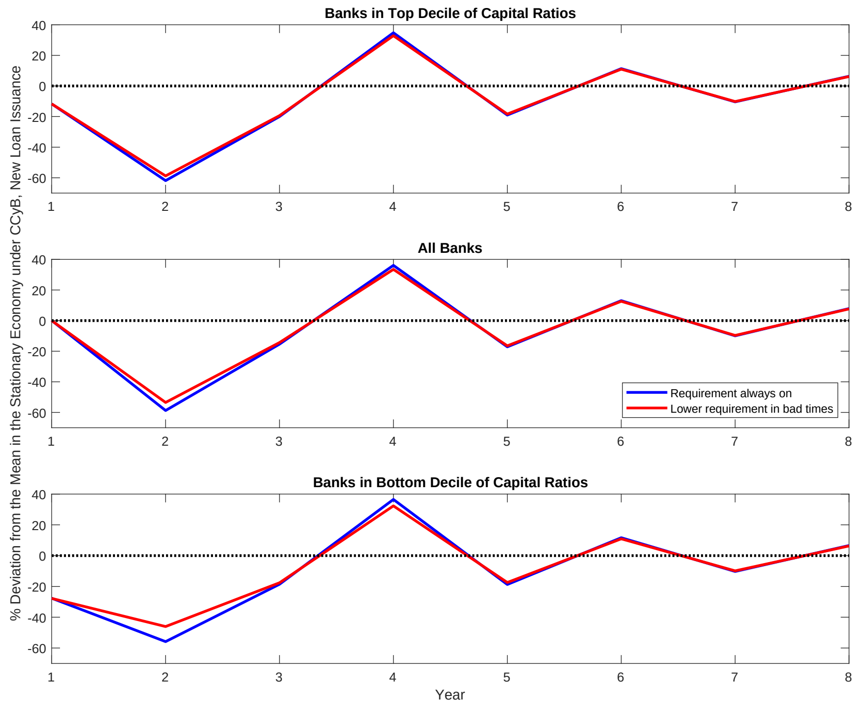


Figure 7: Impulse Responses of New and Existing Loans by Initial Capital Ratio: 1.5-p.p. CCyB vs Non-State Contingent

(a) New Loans



(b) Existing Loans

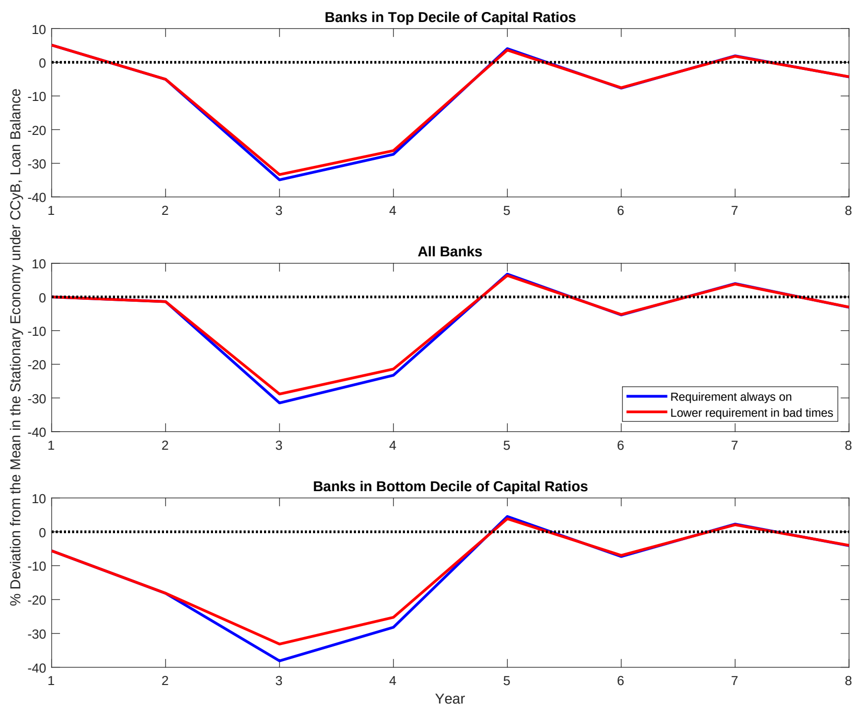
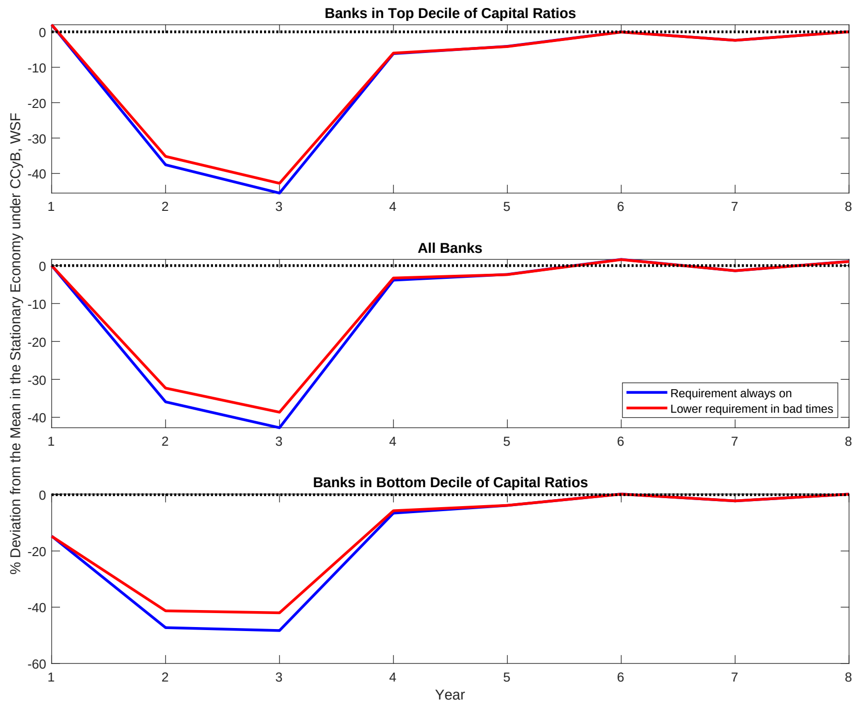


Figure 8: Impulse Responses of WSF and Equity by Initial Capital Ratio: 1.5-p.p. CCyB vs Non-State Contingent

(a) WSF



(b) Equity

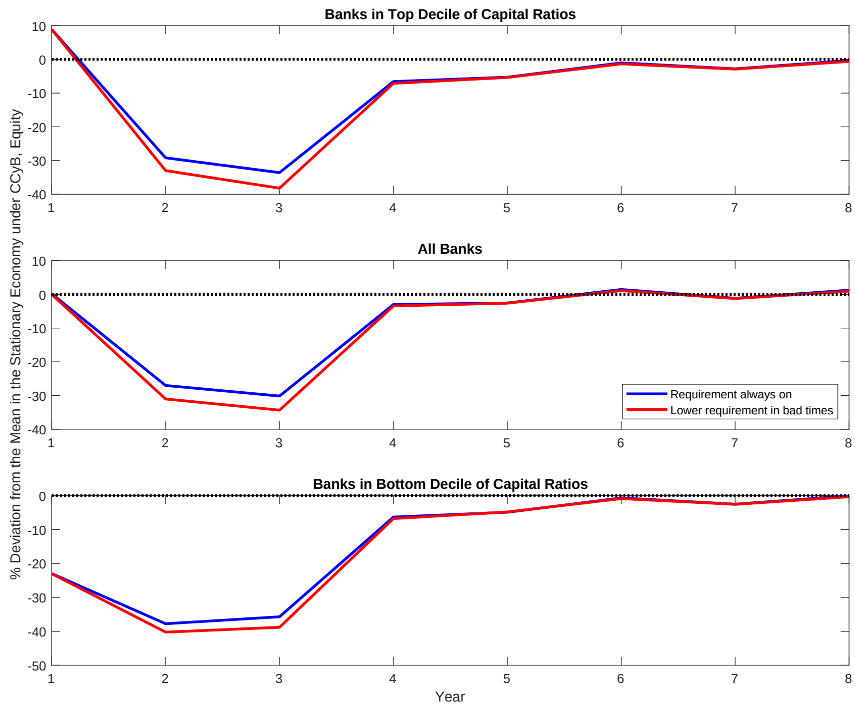
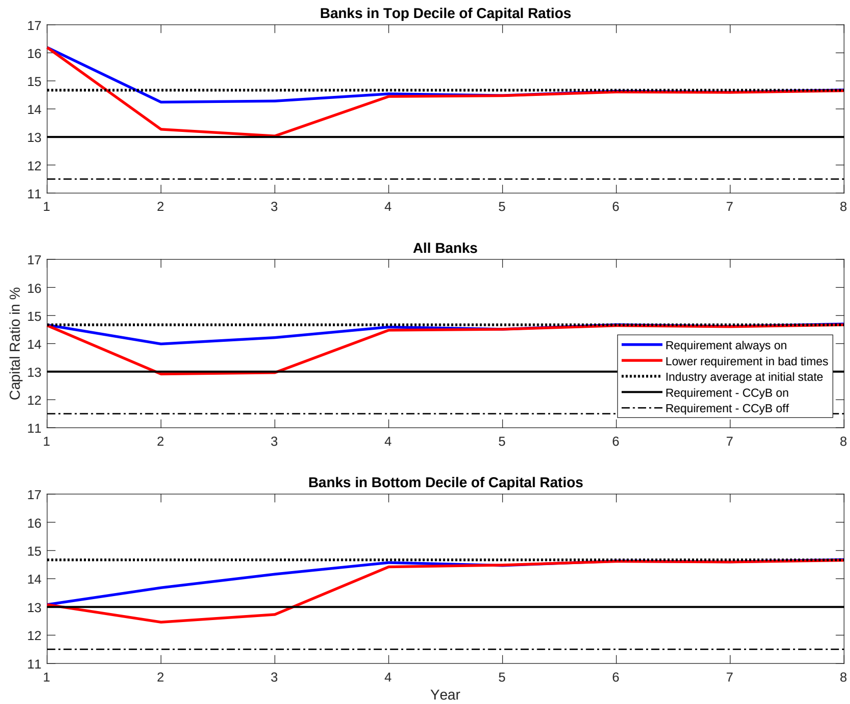


Figure 9: Impulse Responses of Capital Ratio and Default Probability by Initial Capital Ratio: 1.5-p.p. CCyB vs Non-State Contingent

(a) Capital Ratio



(b) Bank Default Probability

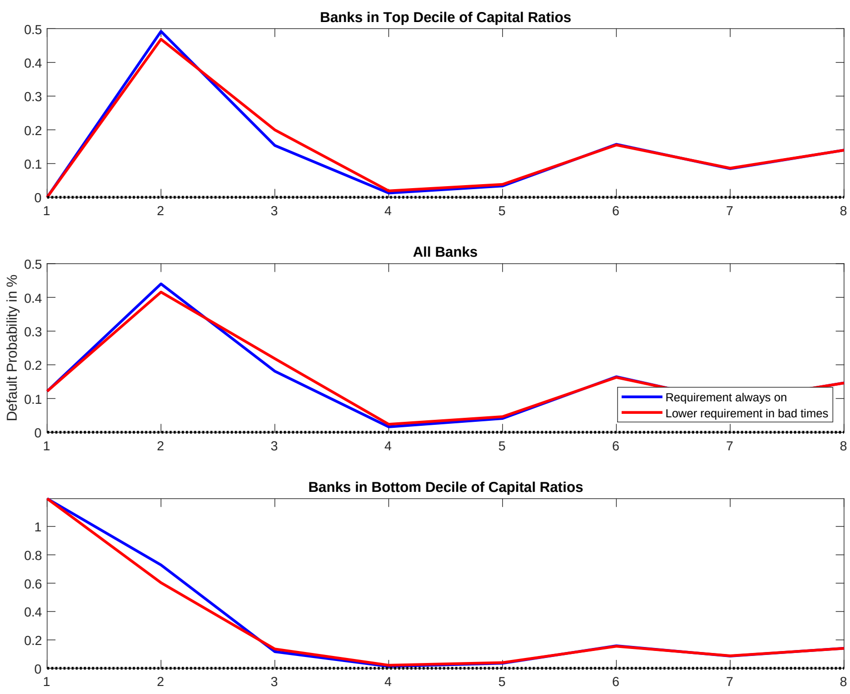


Figure 10: Impulse Responses of Dividend by Initial Capital Ratio: 1.5-p.p. CCyB vs Non-State Contingent

(a) Dividend

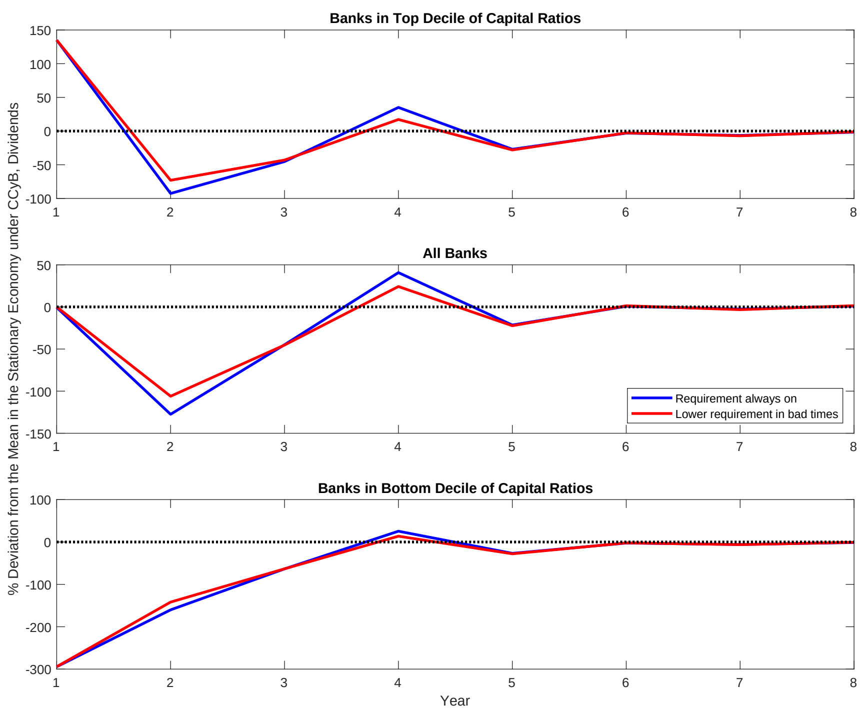
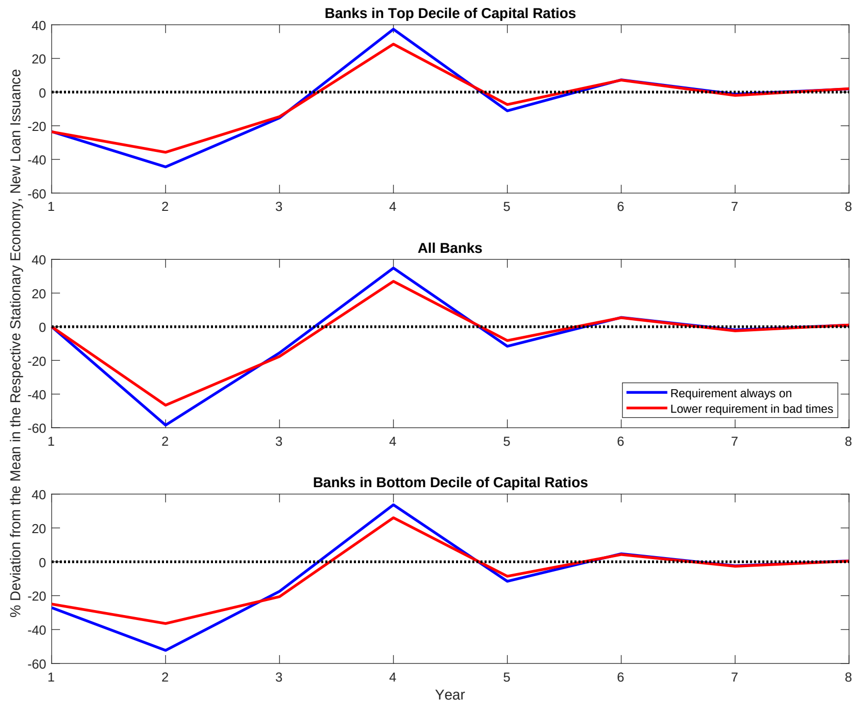


Figure 11: Impulse Responses of New and Existing Loans by Initial Capital Ratio: 5-p.p. CCyB vs Non-State Contingent

(a) New Loans



(b) Existing Loans

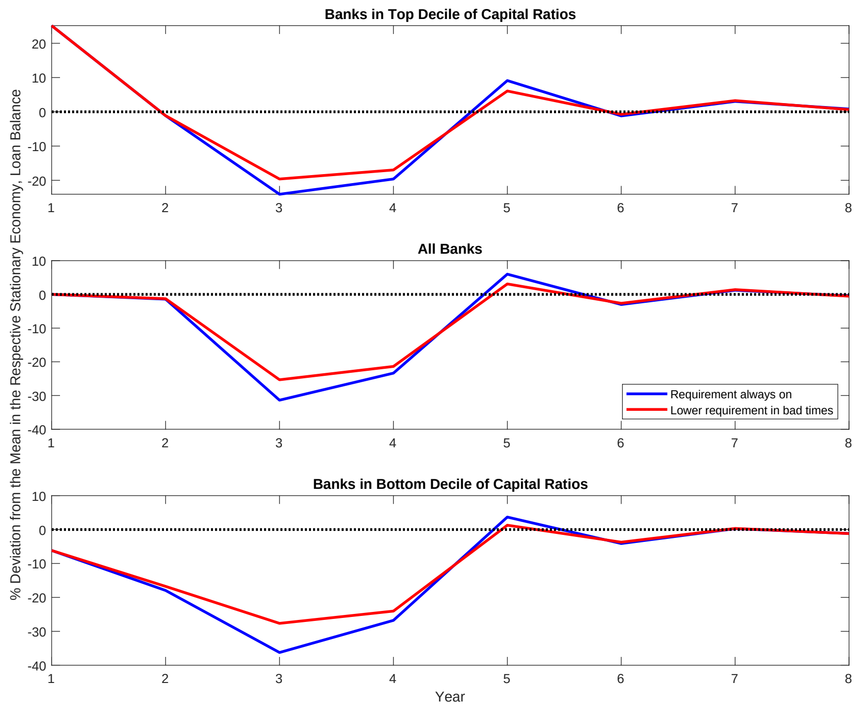
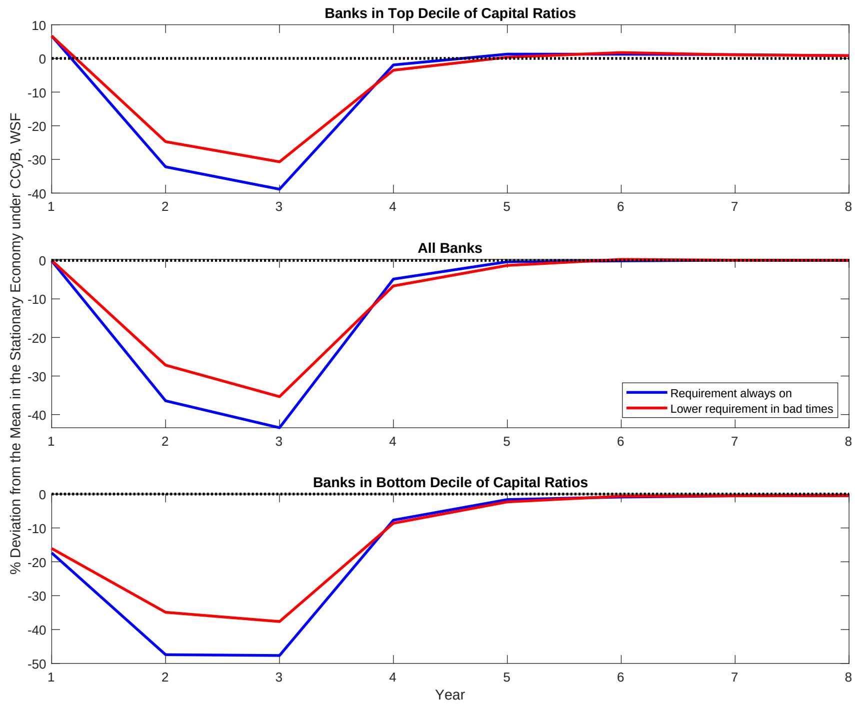


Figure 12: Impulse Responses of WSF and Equity by Initial Capital Ratio: 5-p.p. CCyB vs Non-State Contingent

(a) WSF



(b) Equity

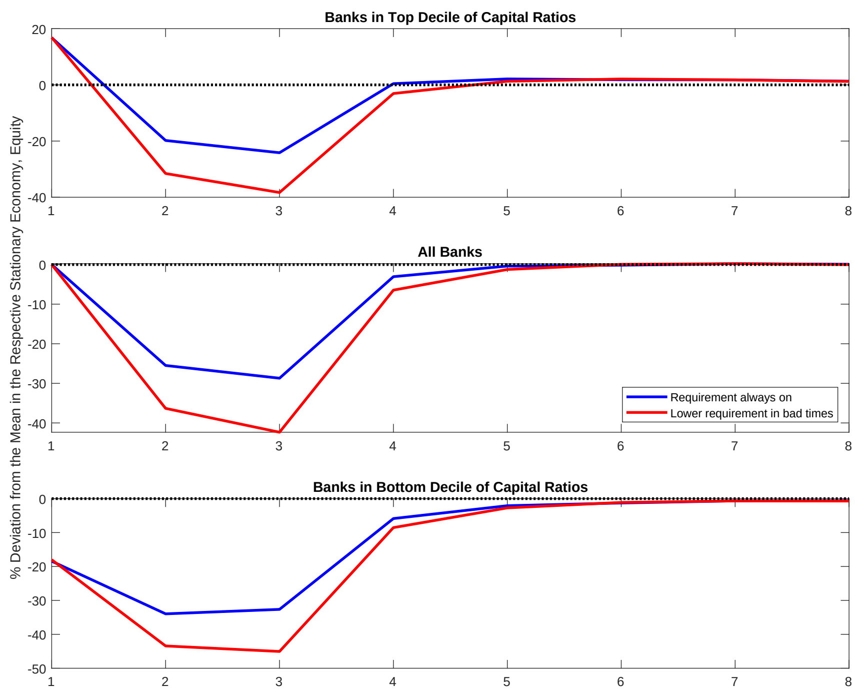
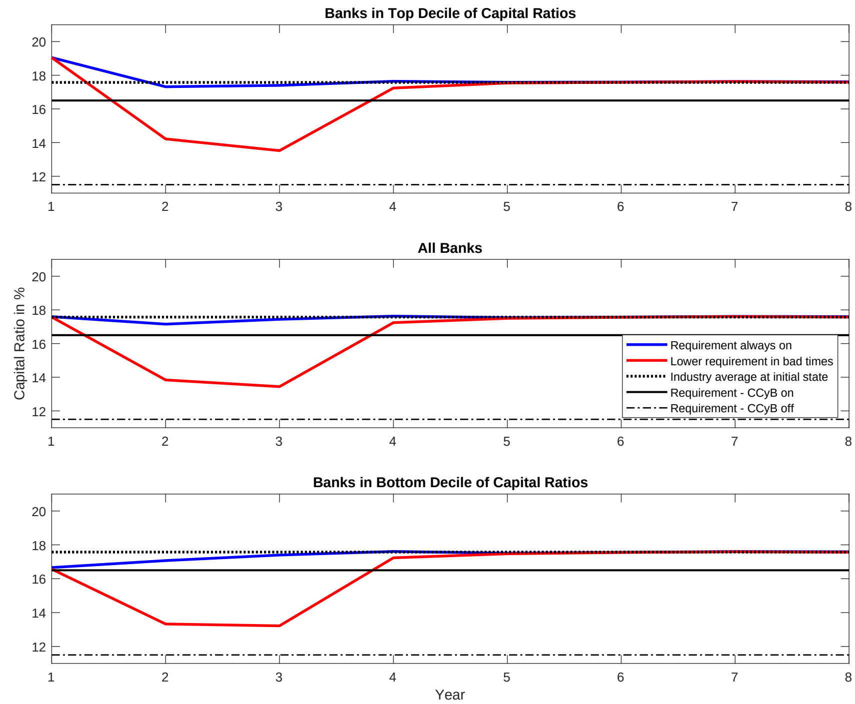


Figure 13: Impulse Responses of Capital Ratio and Default Probability by Initial Capital Ratio: 5-p.p. CCyB vs Non-State Contingent

(a) Capital Ratio



(b) Bank Default Probability

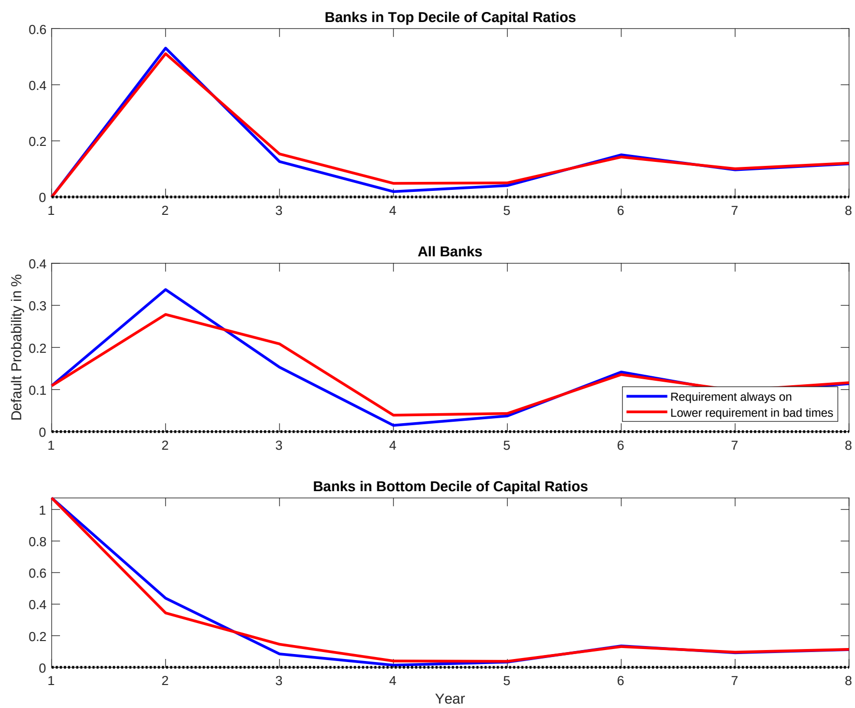


Figure 14: Impulse Responses of Dividend by Initial Capital Ratio: 5-p.p. CCyB vs Non-State Contingent

(a) Dividend

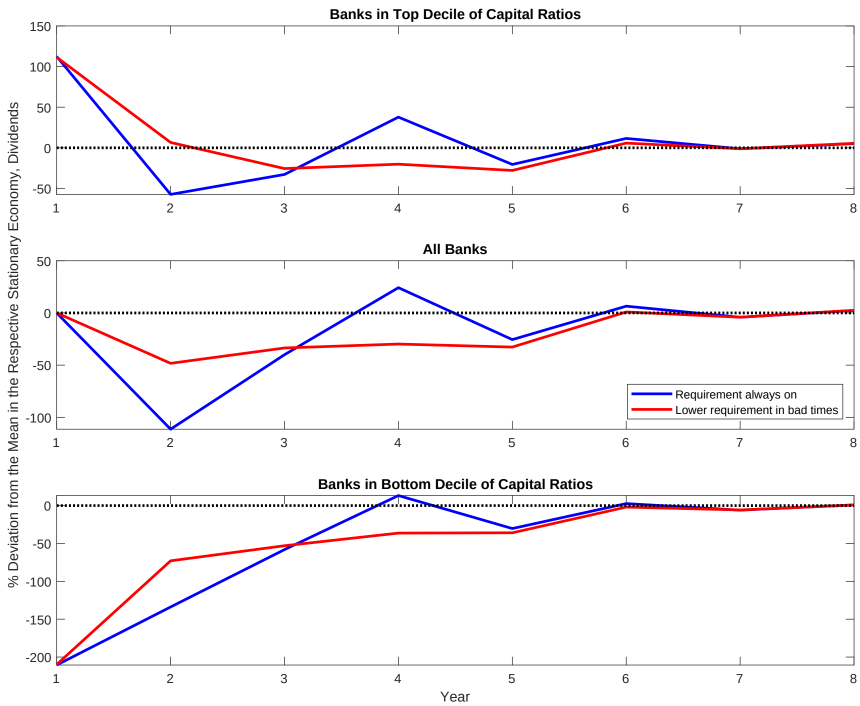
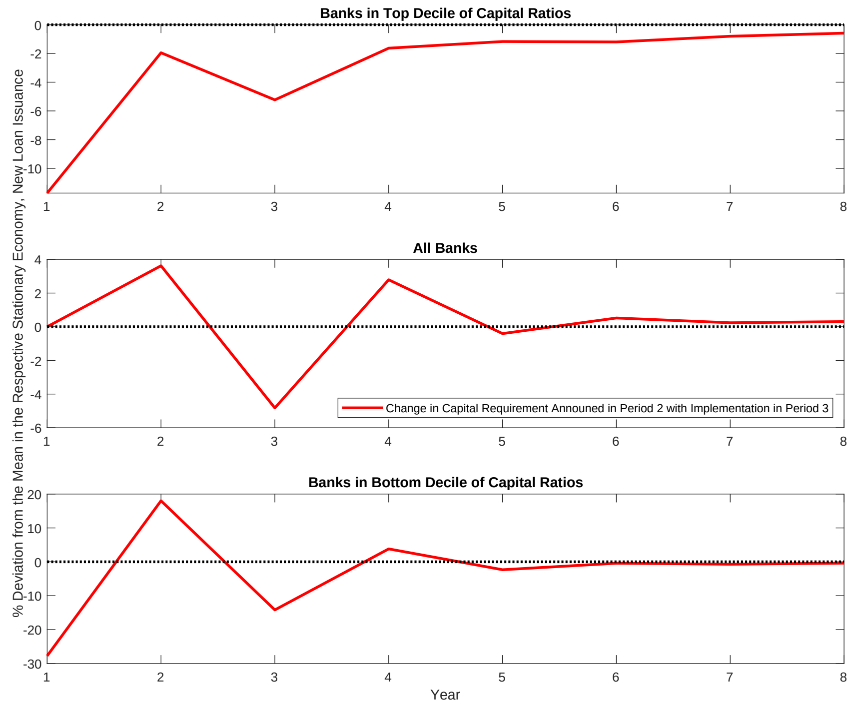


Figure 15: Impulse Responses of New and Existing Loans by Initial Capital Ratio: From 1.5-p.p CCyB to 5-p.p. CCyB, Announcement at Period 2 for Implementation at Period 3

(a) New Loans



(b) Existing Loans

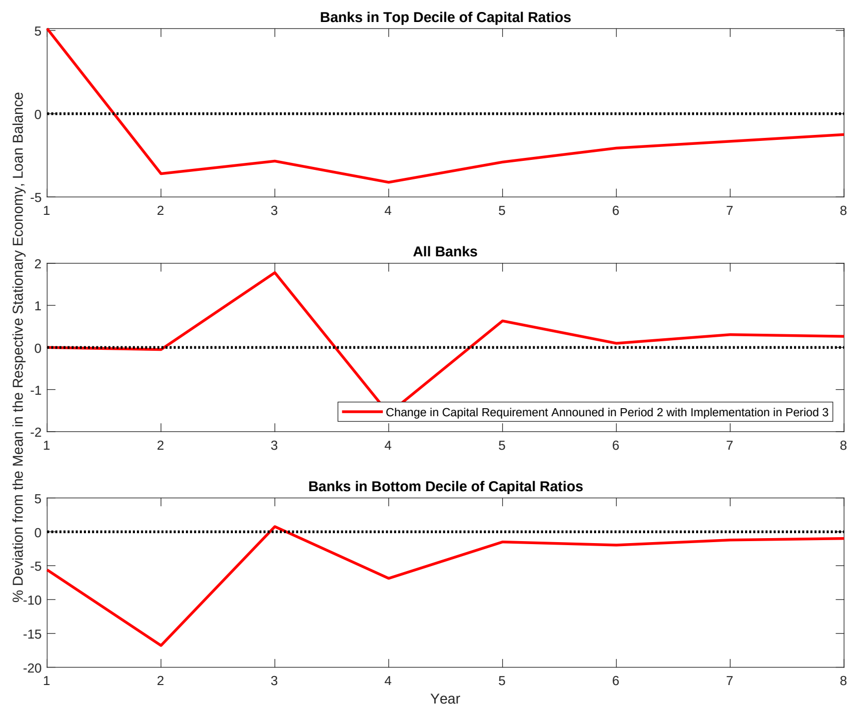
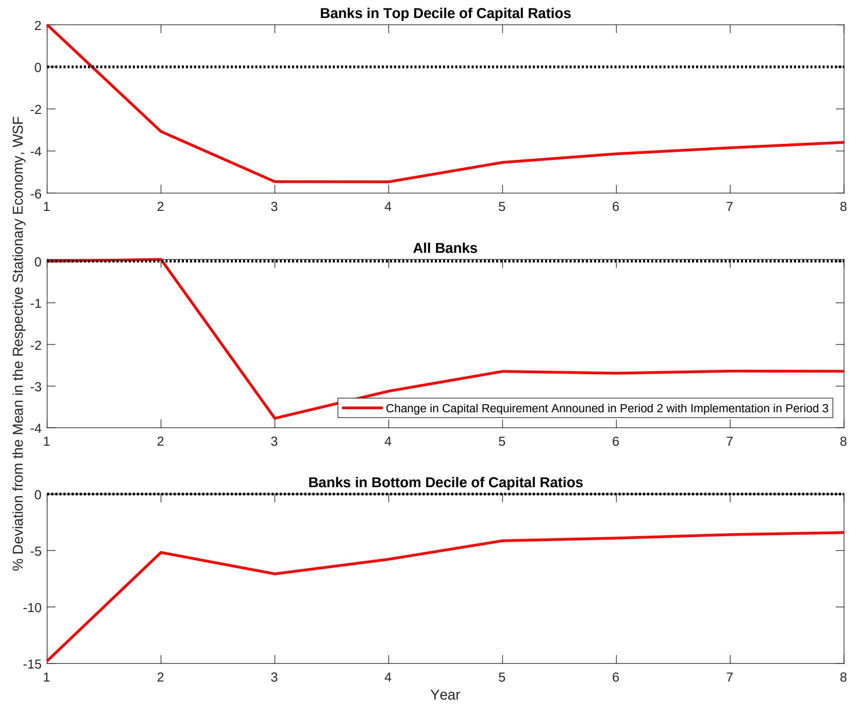


Figure 16: Impulse Responses of WSF and Equity by Initial Capital Ratio: From 1.5-p.p CCyB to 5-p.p. CCyB, Announcement at Period 2 for Implementation at Period 3

(a) WSF



(b) Equity

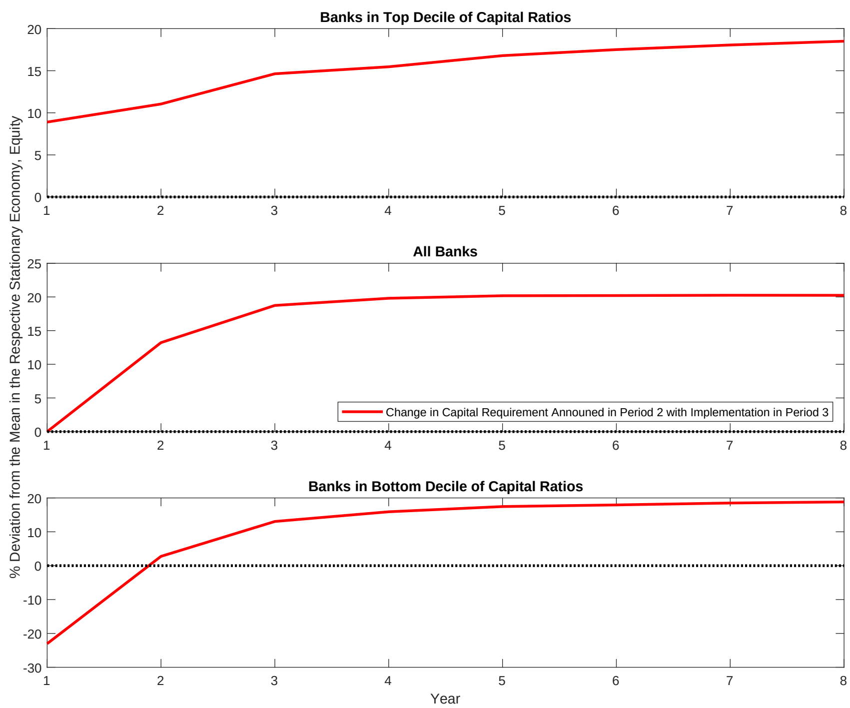
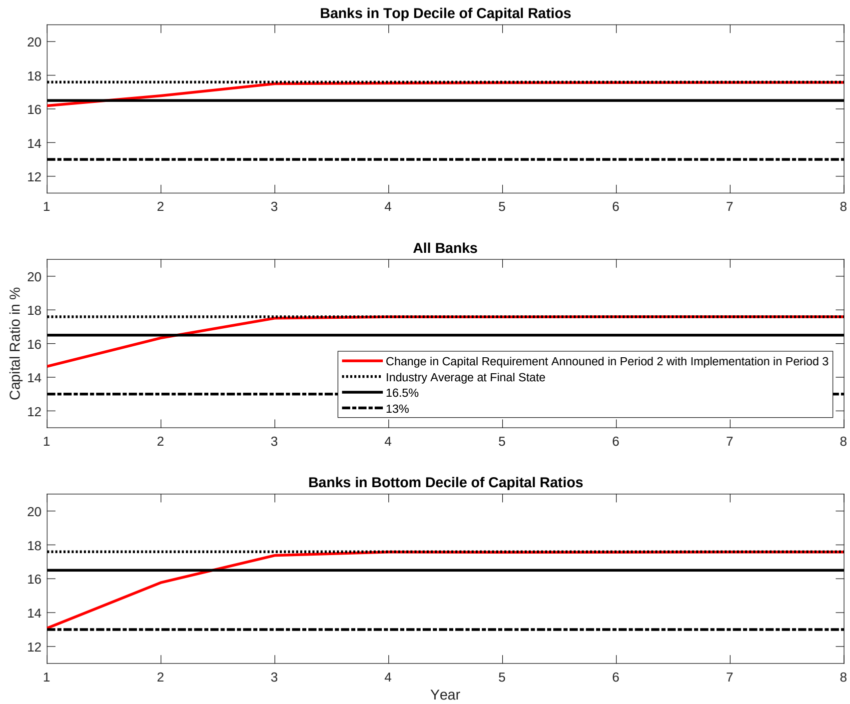


Figure 17: Impulse Responses of Capital Ratio and Default Probability by Initial Capital Ratio: From 1.5-p.p CCyB to 5-p.p. CCyB, Announcement at Period 2 for Implementation at Period 3

(a) Capital Ratio



(b) Bank Default Probability

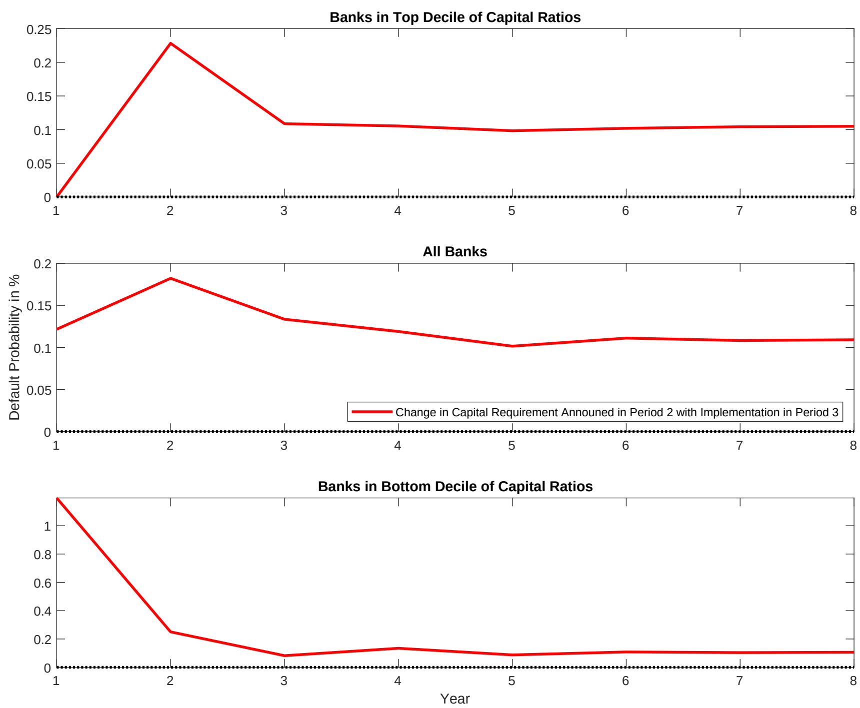


Figure 18: Impulse Responses of Dividend by Initial Capital Ratio: From 1.5-p.p CCyB to 5-p.p. CCyB, Announcement at Period 2 for Implementation at Period 3

(a) Dividend

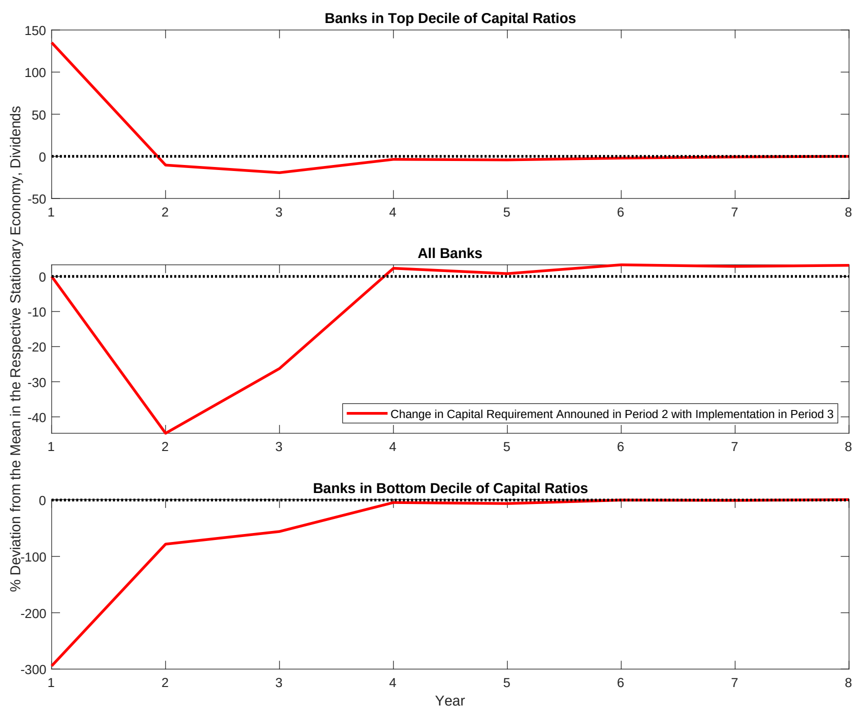
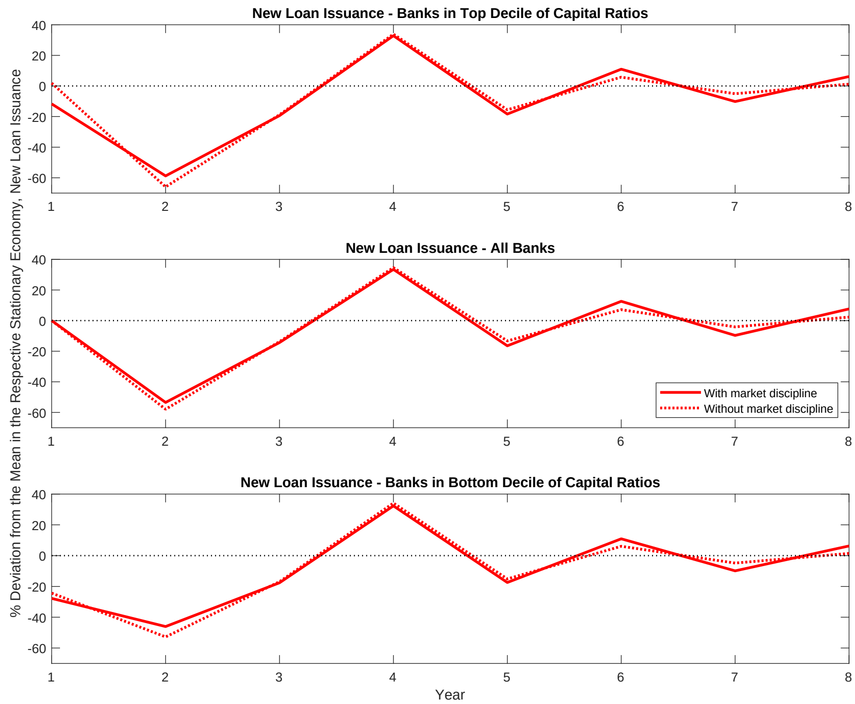


Figure 19: Impulse Responses of New and Existing Loans by Initial Capital Ratio: 1.5-p.p. CCyB with and without Market Discipline

(a) New Loans



(b) Existing Loans

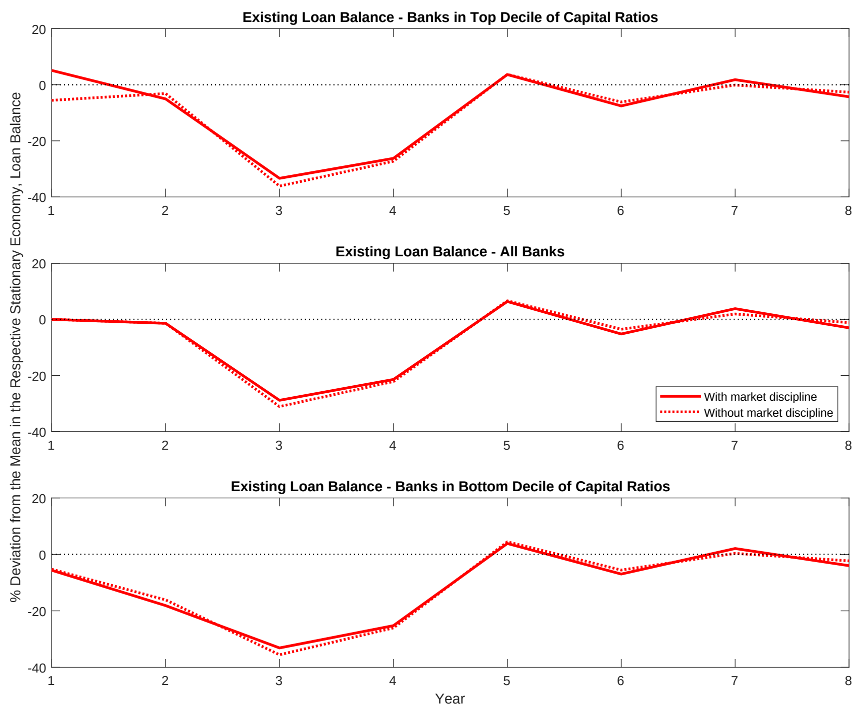
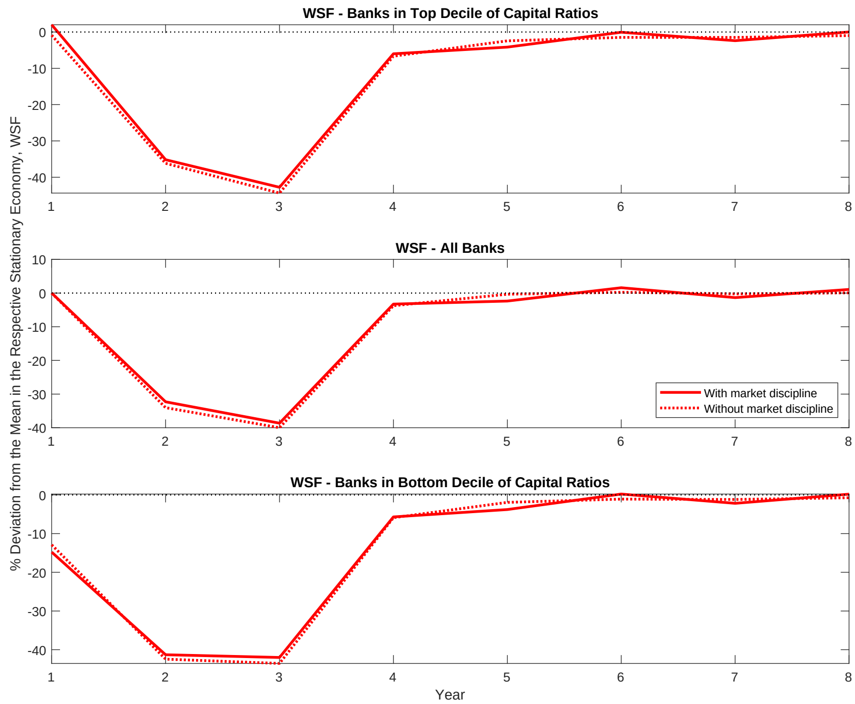


Figure 20: Impulse Responses of WSF and Equity by Initial Capital Ratio: 1.5-p.p. CCyB with and without Market Discipline

(a) WSF



(b) Equity

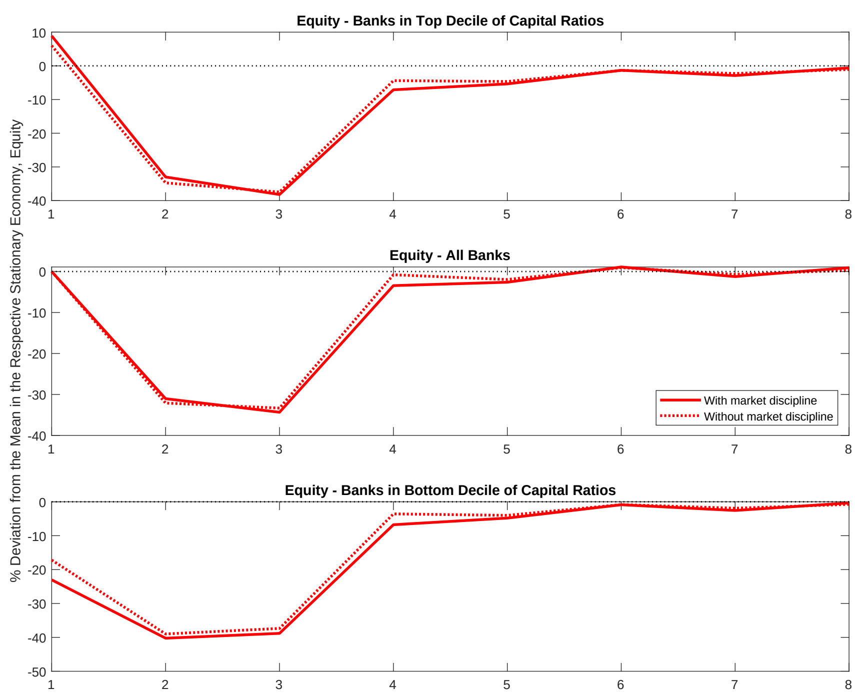
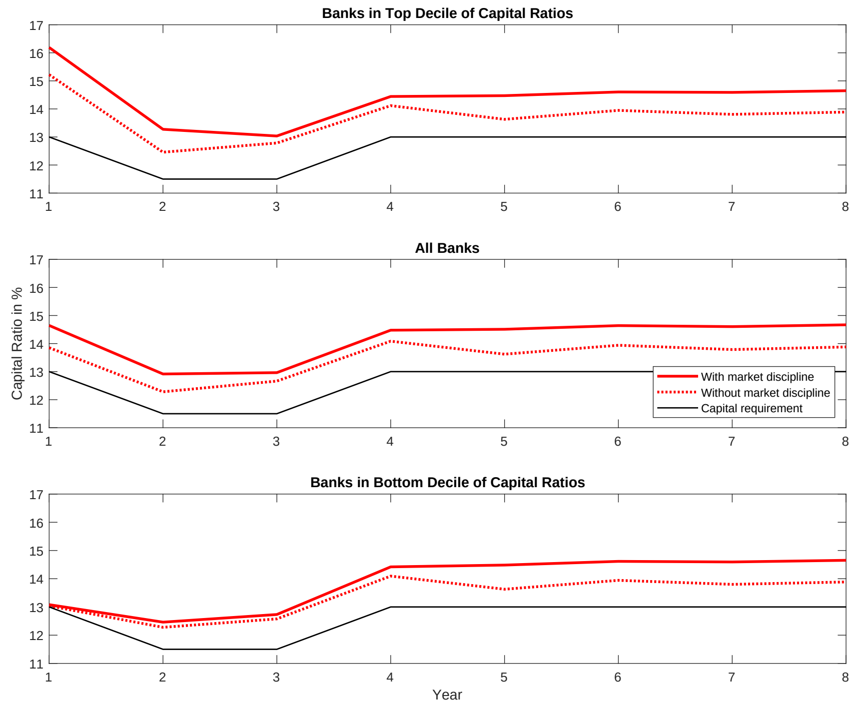


Figure 21: Impulse Responses of Capital Ratio and Default Probability by Initial Capital Ratio: 1.5-p.p. CCyB with and without Market Discipline

(a) Capital Ratio



(b) Bank Default Probability

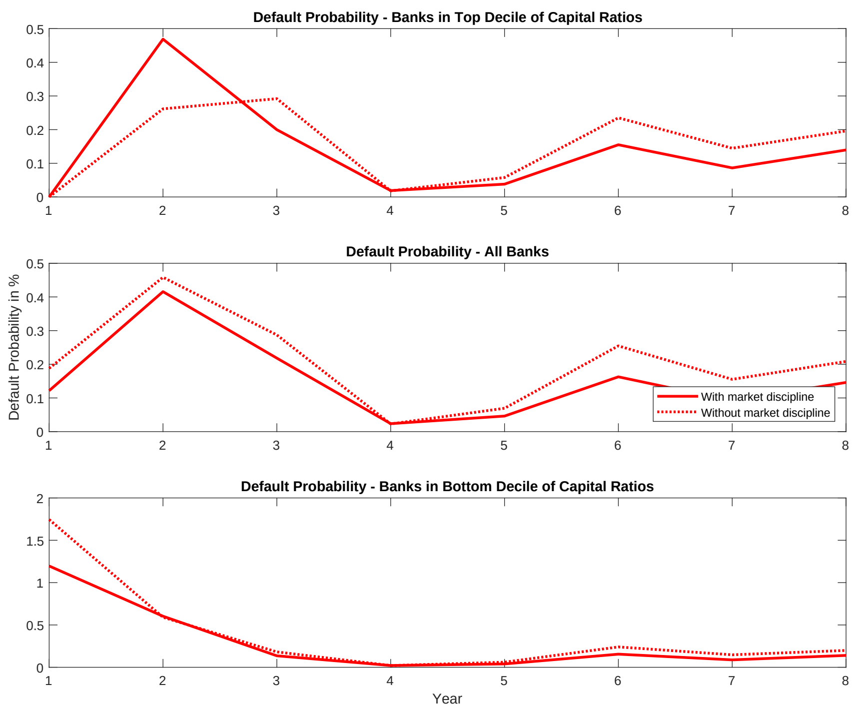
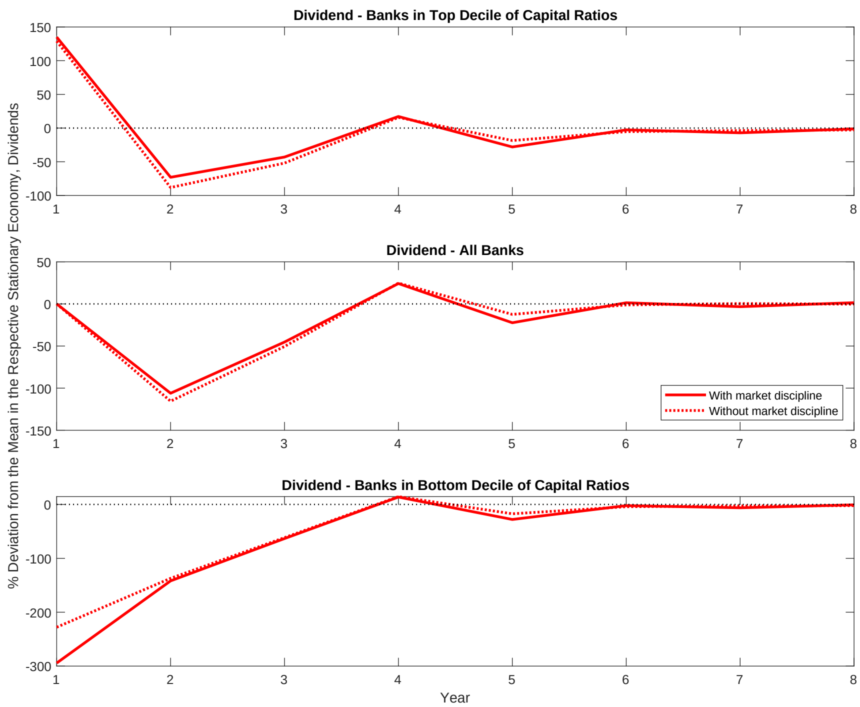


Figure 22: Impulse Responses of Dividend by Initial Capital Ratio: 1.5-p.p. CCyB with and without Market Discipline

(a) Dividend



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