Capital Regulation and Shadow Finance: A Quantitative Analysis

Hyunju Lee
Department of Economics
Ryerson University

Sunyoung Lee
Department of Finance
Seoul National University

Radoslaw Paluszynski*
Department of Economics
University of Houston

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Abstract

This paper studies the effects of higher bank capital requirements. Using new firm-lender matched credit data from South Korea, we document that Basel III coincided with a 25% decline in credit from regulated banks, and an increase of similar magnitude from non-bank (shadow) lenders. We use our data to estimate the effect of capital requirements on bank credit, and the spillover effect of the reform on non-bank lending. We then build a general equilibrium model with heterogeneous banks and firms that replicates these micro estimates. We find that Basel III can account for most of the observed decrease in regulated bank lending, and about three quarters of the increase in shadow lending. The latter is driven exclusively by general equilibrium effects of the reform.

Keywords: Bank regulation, shadow banks, heterogeneous agents, general equilibrium

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"A banker uses the money of others; as long as he uses his own money he is only a capitalist."

— David Ricardo

1 Introduction

The near-collapse of the financial sector in 2008 led to widespread calls for a global tightening of bank regulation. The resulting Basel III standards have significantly increased the required level of equity that banks must hold to back their risky assets. By the end of 2020, the reform implementation had just been completed in most countries. This opens new opportunities to answer questions about the macroeconomic effects of such changes, theoretically and empirically. One implication of the higher capital requirement is that it may lead to a contraction in the regulated credit market as banks must reduce risky assets on their balance sheets. But how large is this effect and how exactly does that occur? Another potential consequence is that the unmatched demand for risky loans may be channeled through unregulated non-bank (shadow) lenders. Indeed, non-bank financial intermediation has recently been on the rise around the world.[1] To what extent does bank regulation contribute to this trend, and what is the underlying mechanism?

This paper presents a quantitative analysis of the effects of higher capital requirements on lending by regulated banks and by non-bank (shadow) creditors, and on the broad macroeconomy. Using a novel dataset of matched firm-lender credit accounts from South Korea, we document that the Basel III implementation coincided with a 25% decline in lending from regulated banks, and an increase of similar size from shadow lenders.[2] While the former mostly occurred on the *intensive margin*, i.e. within existing bank-firm pairs, the latter was driven by growth on the *extensive margin*, i.e. formation of new lending relationships (partly due to the entry of new shadow lenders). We use the microstructure of our data to estimate the elasticity of bank credit growth with respect to capital requirement. We also estimate the spillover effect of capital requirement on the growth of shadow lending, both on the intensive and extensive margin. Finally, we estimate the degree of within-firm substitution between regulated bank lending and shadow credit. Based on these results, we then build a quantitative general equilibrium model that features heterogeneous banks and firms. An increase in capital requirement affects banks directly by inducing them to reduce risky loans and build a larger equity buffer. But it also indirectly affects potential shadow lenders by widening the general equilibrium interest rate spread and attracting new entrants into the business. Calibrating the model to

[1] See Financial Stability Board: "Global Monitoring Report on Non-Bank Financial Intermediation 2018".

[2] We define a shadow lender as any institution that lends to corporations and is not a regulated bank. In our dataset, most of these are insurance companies, investment funds, etc.

match the structure of the financial sector in the Korean economy, we calculate the transitional dynamics set off by the reform, and redo our econometric analysis on a panel of simulated agents. The model reinforces our empirical findings by yielding statistically equivalent estimates for the effects of capital regulation on both bank and non-bank lending. An the aggregate level, we find that Basel III explains most of the observed decrease in regulated bank lending, and about three quarters of the increase in shadow lending. This result shows that, at least in the case of Korea, the recent rise of shadow finance can be viewed primarily as an unintended consequence of bank regulation tightening, as opposed to alternative forces e.g. the development of "fintech".

Our micro data is a quarterly panel obtained from a major credit bureau in South Korea and covers all credit accounts of public firms in that country, matched with banks and non-bank lenders. To estimate the direct effect of capital regulation on traditional bank lending, we regress credit growth within a bank-firm pair on the log of capital ratio requirement, which varies across time and banks. Our econometric analysis exploits the nature of Basel III implementation in Korea, which was pre-announced and designed to be gradual over time and non-uniform across banks.[3] This allows us to cast the reform effectively as a sequence of exogenous treatments on regulated banks with heterogeneous treatment intensity (where a treatment means being subjected to higher capital requirement). To control for potential confounding factors, we adopt an identification strategy that uses firm and bank fixed effects. Given that borrowers in our data tend to be connected with multiple lenders simultaneously (and vice-versa), these fixed effects control for any heterogeneity in firms' demand or banks' supply. We find that capital requirement has a strong and negative effect on bank lending where a one percent increase in capital requirement reduces the credit growth rate by 0.14 percentage points.[4] Finally, we show that this estimate is robust to various alternative specifications and measurements.[5]

Because the regulation does not directly affect shadow lenders, we design a separate specification to estimate the spillover effect of capital requirement on credit growth in that sector. Concretely, we pool the credit growth data of both regulated banks and non-banks and regress them against an interaction of time dummies and a non-bank dummy. In this way, we measure the extra credit growth coming from shadow lenders over time. We

[3] This stems from more restrictive regulation of Domestic Systemically Important Banks (DSIB), as proposed by the Basel committee.

[4] To get a sense of the magnitude of this number, note that between 2013 and 2019 the Tier 1 capital ratio requirement was raised from 4% to 8.5%, a total increase of 112.5%.

[5] In particular, we also obtain strong and statistically significant results using firm-time fixed effects.

find that credit growth from shadow lenders is up to ten percentage points higher than that from regulated banks starting from 2016, precisely the time when Basel III comes into effect in Korea. In an analogous exercise, we also show that credit growth of Domestic Systemically Important Banks (DSIB) was up to twenty percentage points lower after the reform than the banks without this designation. As a final step of our econometric analysis, we measure the degree of substitution between shadow and regulated credit within a firm, by designing an instrument based on the decline of DSIB credit. We find that a 1 percent decrease in regulated bank credit causes a 1.3 percent increase in shadow credit.

To understand the channels through which higher capital requirement leads to a credit crunch in the regulated bank sector, and a boom in non-bank lending, we build a dynamic general equilibrium model with multiple groups of heterogeneous agents. First, heterogeneous banks seek to smooth out dividend payouts over time and accumulate equity by optimally allocating their portfolio of risky assets (such as corporate loans) and risk-free ones, as well as raising deposits from workers and firms. Every period, a bank's asset value is hit with an idiosyncratic shock (such as a realization of default rate) which puts them at risk of violating the capital regulation. Our innovation in this part is that we introduce the capital requirement in a soft form by assuming that financial authorities impose a dividend tax on banks in case their posted capital ratios are close to the minimum. In equilibrium, banks build an endogenous capital ratio buffer above the required level, and this buffer depends on the equilibrium spread between the interest rates paid on risky loans and riskless deposits. This result explains the reality of modern financial intermediation systems where banks post capital ratios much in excess of the required minimum, and nevertheless violate it occasionally in stress-testing exercises. We show that our model quantitatively replicates the pre-reform distribution of posted capital ratios, and correctly predicts its evolution in response to a higher capital requirement.

Second, the model features heterogeneous entrepreneurs who hire labor and invest in physical capital to fulfill their business ideas. Entrepreneurs with high productivity but low wealth demand loans (and tend to default on them non-strategically), while entrepreneurs with extra funds may deposit them in bank accounts. Our innovation in this part is that we endow such entrepreneurs with an additional choice, namely an option to become a *shadow lender*. This entails incurring a fixed cost and facing the same loan default risk as regular banks do. In exchange, such firms can earn a higher interest rate on the part of their wealth that is not being used in their core business operations. In equilibrium, firms that are not very productive, but own a large stock of wealth, endogenously choose to become a shadow lender. Such firms can be naturally interpreted as the non-bank financial sector of the economy, lending surplus funds to highly productive but not so wealthy firms (e.g. from the manufacturing or technology sectors). Crucially, shadow lenders are not bound by any regulations and can expand in the situation where the reform causes traditional banks to reduce lending.

To close the model, we add heterogeneous workers who accumulate precautionary savings and deposit them with banks. We compute a stationary equilibrium of the model in which all aggregate variables are invariant and the interest rates and wages clear all markets. We use the model to conduct a Basel III reform experiment. We increase the capital requirement by 4.5 percentage points and calculate the new stationary equilibrium. We find that the overall amount of loans extended by regulated banks falls by about 21% (steady-state to steady-state), while total credit from shadow lenders increases by 25%. In response to the new regulation, traditional banks post higher capital ratios over the required minimum by reducing the amounts of loans and deposits. This causes the spread between interest rates on loans and deposits to widen in the new general equilibrium. As a result of this change, shadow lenders grow on both the *intensive* and *extensive* margins. A higher loan rate encourages more entrepreneurs to incur the cost, as well as additional risk exposure, and to lend more of their funds to other firms, while a lower deposit rate discourages firms from storing their financial assets with the banks. That is, the increase in shadow lending is driven exclusively by the general equilibrium effects of higher capital requirements. We validate this channel by showing that the average spread has indeed increased in the data since the reform became binding, by a similar magnitude.

To tie our theoretical framework to the econometric findings, we calculate the transitional dynamics induced by the reform in our model. We pose a reform schedule that mimics the Korean implementation of Basel III and obtain the paths of general equilibrium prices and quantities that correspond to our data sample. Using simulated panels of banks and non-bank lenders, we then run the analogous set of regressions as with our micro data. We find that the model generates both the elasticity of regulated bank credit with respect to capital requirement, and the spillover effect on shadow lending, that fall within the confidence intervals of the original data estimates. As such, our empirical results are supported by a fully independent economic model, and our theoretical analysis is consistent with the micro estimates. At the aggregate level, over the transition, the model explains most of the observed decline in regulated bank credit, and about three quarters of the increase in shadow lending.

Finally, we also investigate the disproportionate effect of Basel III on Domestic Systemically Important Banks (DSIB) uncovered in the econometric part of our paper. The model features two heterogeneous bank groups that are systematically small and large, via separate discount factors, to mimic the existence of DSIBs and non-DSIBs. We find that, while DSIBs face a one percentage point higher capital requirement than non-DSIBs in Korea, this alone cannot account for larger contraction in lending by the former observed in the data, especially at the micro level. We then adjust our model to also feature an alternative policy tool proposed by the Basel Committee, namely "more intensive supervision" of DSIBs. We find that such uneven intensity of regulation, modeled as bank group-specific parameters of the dividend tax, can indeed account for the observed rift between DSIBs and non-DSIBs both at the micro and at the aggregate level, and we quantify it.

While this paper does not directly address the question of optimal capital regulation,[6] our results quantify the crucial channel for this debate. Higher capital requirements presumably make the banking sector safer in the event of a systemic financial crisis, but they also cause bank lending to contract, in particular among the largest banks, and to be replaced with shadow credit. To highlight the importance of this alternative lending source, we conduct a counterfactual experiment where, along with imposing higher capital requirements, regulators also elevate fixed costs to prevent the rise of shadow lending. In this counterfactual scenario, we find that output drops by up to four times as much on the transition, compared to the baseline reform; interest rate on corporate loans increases by up to six times as much, and the increase in the loans-deposits interest rate spread more than doubles. This result illustrates the trade-off that regulators face between promoting financial stability or economic activity.

1.1 Literature review

This paper is related to the literature on the effects of capital regulation on financial intermediation markets. Our model of banks shares many similarities with Bianchi and Bigio (2022). In contrast to their framework, we do not consider the inter-bank market but instead focus on the formation of an endogenous capital buffer over the required minimum. Aliaga-Díaz, Olivero, and Powell (2018) present a model in which banks also post an endogenous buffer over the constraint, although they focus on counter-cyclicity of the regulation rather than its level. Ríos-Rull, Takamura and Terajima (2020) and Faria-e-

[6] This is because our micro data does not cover episodes of financial crises or bank failures that would rationalize the very existence of bank regulation. For this reason, throughout the paper we assume that capital requirements are put in place (and then changed) exogenously.

Castro (2020) further analyze the macroeconomic effects of counter-cyclical buffers. Corbae and D'Erasmo (2021) propose a quantitative model of the banking industry where big and small banks interact. They show that many of the proposals of Basel III can have important effects on the equilibrium distribution of bank sizes and on the allocation of resources. Jamilov and Monacelli (2020) analyze bank balance-sheet-driven recessions through the lens of a model with heterogeneous banks that act as Bewley agents. De Nicolò, Gamba, and Lucchetta (2017), Mankart, Michaelides, and Pagratis (2020), and Goel (2019) further analyze various aspects of optimal regulation using dynamic models with heterogeneous banks. Van den Heuvel (2008), Davydiuk (2019), and Nguyen (2014) all focus on the welfare implications of bank capital regulation. Dempsey (2020) develops a model in which firms may substitute traditional bank loans with non-bank finance. In contrast to our results, he finds this effect to be quantitatively small. Begenau and Landvoigt (2021) propose a model with the possibility of a rise in shadow banking activities in response to a higher capital requirement. They find that this does not necessarily make the financial system more fragile, which warrants a relatively high capital requirement. Our paper contributes to this literature by using micro-evidence from the latest change in capital regulation (Basel III) to quantify its intended and unintended consequences. While the present paper focuses on the supply of credit, in the follow-up project (Lee and Paluszynski, 2022), we investigate the structure of demand for shadow credit in Korea.

On the empirical side, Irani et al. (2021) analyze the market for syndicated corporate loans in the United States and find a strong causal effect of Basel III on the increased shadow banking market share. Relative to their work, our paper analyzes the effects of Basel III on primary bank-firm credit accounts in South Korea, covering the full period of the reform implementation. In the context of residential mortgage loans, Buchak et al. (2018a, 2018b) document that the market share of shadow banks nearly doubled from 2007 to 2015, and they find that regulation accounts for around 60% of it. Our paper shares their interest in the role of shadow banks in loan origination, but we focus on corporate credit extended to all public firms in South Korea. Kashyap, Stein and Hanson (2010), and subsequently Baker and Wurgler (2015) and Kisin and Manela (2016) all show that higher capital requirements have a modest effect on banks' cost of capital. In relation to these studies, we highlight the effects on the quantity of credit, but we also emphasize that the limited response of the cost of capital depends on the general equilibrium response of the shadow lending sector. More generally, our empirical methodology is related to the extensive literature estimating the bank lending channel, starting with Khwaja and Mian (2008), and more recently Amiti and Weinstein (2018), or Morais et al. (2019).

The remainder of this paper is structured as follows. Section 2 provides background information about the Basel III reforms worldwide and their Korean implementation. Section 3 introduces our econometric methodology and discusses the results. Section 4 describes the quantitative model of heterogeneous banks and firms. Sections 5 quantifies the model and presents the main model exercise. Section 6 shows the transition induced by the reform and ties the model's micro-estimation results to our econometric analysis. Section 7 discusses the macroeconomic effects of higher capital requirements. Section 8 concludes.

2 Background

This section describes the data and introduces the motivating observations. We present the aggregate trends in corporate credit markets in Korea (subsection 2.2) and discuss various underlying details (subsections 2.3-2.6). Then, we describe the Basel III reform (subsections 2.7-2.8), and the banks' behavior upon its introduction (subsections 2.9-2.10). This establishes a correlation between the two at an aggregate level. In the rest of the paper, we quantify the extent to which capital regulation explains the trends in corporate credit, both empirically (Section 3) and theoretically (Section 4).

2.1 Data description

The main dataset we use in this paper is a panel of firm-lender matched credit accounts for all public companies in South Korea. The data is proprietary and acquired from eCredible Co., Ltd., a major credit bureau in Korea. It comes at quarterly frequency and covers the time period of 2013Q2-2019Q1. Overall, we observe 578 financial institutions matched to 2204 firms, which yields a total of 402,098 active observations at the bank-firm-time level. It is an unbalanced panel consisting only of observations with positive amount of credit. All firms included in the data are public and listed in one of the three trading boards in Korea (KOSDAQ, KOSPI, KONEX) at least for one quarter during the sample period. We adjust all credit amounts for inflation using the GDP deflator and express all monetary variables in 2010 Korean won. A non-negligible fraction of the corporate loans market in Korea operates through state-owned banks and financial institutions sponsored by the government. Because such relationships are often based on political decisions rather than market factors, we exclude them from our analysis.

An advantage of our data lies in its extensive coverage of credit provided by Korean non-bank lenders such as the insurance companies, investment or wealth management funds.

Throughout this paper, we define a shadow lender as any institution that engages in legal forms of lending to corporations and is not a regulated bank.[7] In the following subsections, as well as in Appendix A, we provide more details on the nature of our data.

It should be emphasized that our main dataset contains information on realized quantities of credit only, and not on the corresponding interest rates or loan applications. Throughout the paper, we therefore supplement our analysis by using data on average interest rates for corporate loans obtained from the Bank of Korea.

Our secondary dataset comes from the Financial Supervisory Service in Korea, which publishes the balance sheets of financial institutions. For regulated banks in particular, we observe the capital ratios measured according to the latest regulatory guidelines (which we describe in subsection 2.9), along with standard balance sheet items such as loans, deposits and equity. For shadow lenders, the coverage of their balance sheets in this dataset is incomplete because not all such institutions are monitored by the Financial Supervisory Service. In particular, shadow lenders do not have their capital ratios measured.

Using bank and firm balance sheet information, we infer that our data covers 28% of all corporate credit extended by regulated banks, and 37% of all corporate credit (by regulated and special banks, as well as non-banks).[8] As in many advanced countries, banks in our data show a significant level of concentration. For example, three and six largest banks take 51% and 70% of commercial banks' aggregate equity, respectively.[9]

A final remark about the data is in order. In contrast to lenders, the firms in our dataset show up in a de-identified form. This means that, in our empirical work, we can use fixed effects to control for any intrinsic firm characteristics. However, we are unable to match our records with an external database on firm financial statements.

[7]We view this definition as more general than the concept of a shadow bank. As Section 2.5 shows, the non-bank lenders in our data are a collection of heterogeneous institutions, many of which are non-deposit-takers and hence should not be referred to as banks.

[8]The former is obtained by summing up corporate credit from domestic commercial banks in our data, and dividing it by the sum of all corporate loans in KRW from domestic commercial bank balance sheets. The statistics is a simple average over the quarters from 2013Q2 to 2019Q1. The latter is based on the Bank of Korea, Financial Statement Analysis, Balance Sheet. Debt is calculated as the sum of short- and long-term borrowings and bonds. Annual data from Bank of Korea is compared to the average total credit in our data within a year over quarters. The reported figure is a simple average over the years of 2013-2019.

[9]More specifically, six largest banks indicate Domestic Systemically Important Banks (DSIB) from 2016 to 2019. See subsection B.5 for more details.

2.2 Aggregate credit in years 2013-2019

Using our main credit data, we now describe the aggregate trends in total credit provided by regulated banks and shadow lenders over the sample period.

Figure 1 presents the evolution of credit extended to corporations by regulated banks and shadow lenders. During the time period covered by our data, the total credit from regulated banks dropped from 160 to 120 trillion Korean Won (KRW), which constitutes a 25% decline in five years. At the same time, the total credit originating from shadow lenders moved in the opposite direction, rising from just under 120 trillion KRW to 170 trillion at its peak. The noticeable dip in shadow credit at the end of the sample period, accompanied by a rebound in regulated bank lending, is attributed to the concurrent adjustment in risk weights by the Korean financial supervisors. Concerned about the sharp decline in bank provision of corporate credit, the authorities announced sweeping changes in regulatory measures in January 2018. The new measures included a shift in risk loadings from corporate to household loans,[10] introduction of household sectoral

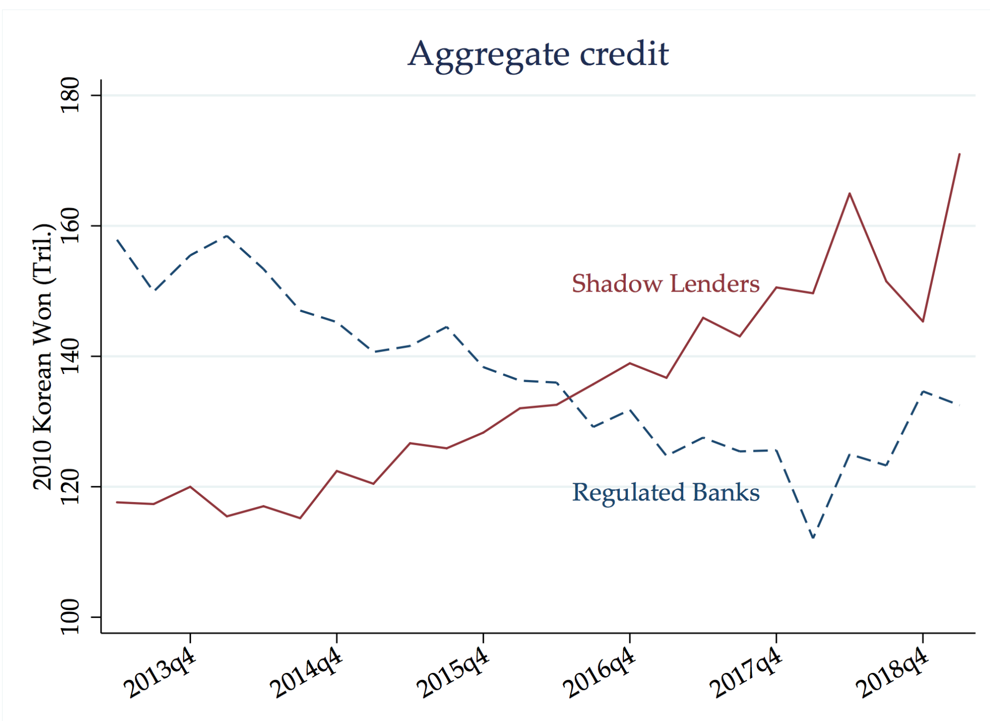


Figure 1: Total credit by regulated banks and shadow lenders

[10]There is a loan-to-deposit ratio regulation in Korea, applicable to commercial banks since 2012, which mandates that KRW loans to deposit ratio be less than 1. Under the new regulation announced in 2018, 1 KRW of household loans is weighted as 1.15 KRW, while 1 KRW of corporate loans counts as 0.85 KRW.

countercyclical capital buffers, and further increasing of the risk weights on high-LTV (loan-to-value) mortgages.

2.3 Prior trends

A natural question that arises from the inspection of Figure 1 is whether these empirical patterns started together with the introduction of Basel III. An alternative explanation could be that they are simply a part of a longer trend that precedes the reform. Unfortunately, we cannot answer this question with our micro data because the sample begins in 2013Q2 and is not available for earlier time periods.[11] Nevertheless, to investigate this issue we obtain alternative aggregate series from FISIS and the Bank of Korea, going back to at least 2008, and plot them in Figures 19 and 20 in Appendix A.2. The analysis of this data shows that the empirical patterns documented in Figure 1 are *a new development*. In particular, lending by regulated banks was growing fast since 2006 and then began a dramatic decline around 2014. On the other hand, lending by non-banks already had a slight upward trend since 2008, but this trend sharply accelerated in 2015 when Basel III was about to become binding in Korea.

2.4 Intensive and extensive margin decomposition

To shed more light on the trends documented in Figure 1, in Appendix A.3 we decompose credit growth into intensive and extensive margins for both bank credit and for shadow credit. The intensive margin measures credit growth within existing firm-lender relationships. The extensive margin on the other hand includes changes in credit due to entry or exit of firm-lender relationships. Two observations stand out from the decomposition. First, most of the decline in regulated bank credit occurred on the intensive margin, i.e. within existing relationships. Second, most of the growth in shadow credit occurred on the extensive margin, especially starting from 2016Q1 which is when Basel III was enforced with penalties in Korea (see Section 2.8). This means that the formation of new firm-lender relationships mostly drove the observed increase in shadow lending.

2.5 Evolution of shadow lender types over time

Appendix A.5 provides a decomposition of shadow lender types over time in terms of their number and total credit. We define a non-bank (shadow) lender as any institution that provides credit to corporations and is not a regulated bank. As such, the shadow

[11] For legal reasons, the credit bureau is obliged to remove old records after a certain amount of time.

lenders that we observe in our data span various financial institutions such as mutual finance firms, wealth management funds, or insurance companies who supply roughly half of all such credit. Related to Section 2.4, we also observe growth in the number of shadow lenders over time. Specifically, their number is roughly constant until 2016 and then starts to increase, which coincides with the introduction of penalties for non-compliance with Basel III (see Section 2.8). By 2019, there are around one hundred new shadow lenders that first appear in our sample during the course of Basel III implementation in Korea.

2.6 Credit types

In our data, we observe all types of credit accounts separately such as loans, securities, and off-balance sheet items. In our baseline analysis we use the total credit, i.e. a sum of all credit accounts that we observe. In Appendix A.6, we describe each credit type and its composition in more detail. Roughly speaking, loans comprise the vast majority of regulated bank lending, although a significant portion of the change in years 2013-2019 occurred through a decline in off-balance sheet items. On the other hand, most of the shadow credit is extended through securities issuance, but the bulk of the recent change is actually due to the growth in loans.

2.7 Basel III

We now turn our attention to the recent changes in bank regulation, the effects of which we seek to quantify in this paper. The Basel Committee on Banking Supervision reached an agreement in 2011 on the new global framework for capital requirements, the so-called Basel III. While Appendix B.1 provides more details, here we flag the key takeaway. The new rules for minimum capital requirements, scheduled for implementation in years 2013-2015, effectively raised the statutory requirement for Tier 1 capital from 4% to 8.5% of a bank's risk-weighted assets. On top of that, an additional buffer was to be imposed on Systemically Important Banks (SIB), details of which were to be set and implemented by national authorities of each country.

2.8 Basel III implementation in Korea

In South Korea, Basel III was formally introduced on December 1st 2013 but the actual implementation was gradual. In particular, any penalties for not meeting the minimum capital ratios were applied to commercial banks starting from January 1st 2016. Table 1 presents the schedule of capital requirements over the course of Basel III implementation.

Regulated banks were subjected to a minimum Tier 1 capital ratio gradually increasing from 4 to 8.5 percent. In addition to these baseline levels, a separate buffer was created for Domestic Systemically Important Banks (DSIB), described by the variable H_{it}. The introduction of this buffer was also gradual and stretched over four years. On the other hand, the counter-cyclical capital buffer has not been activated in Korea (remains at 0%).

Table 1: Minimum Tier 1 capital ratio requirements

Period	Requirement (%)		Note
Until 2012	4		Basel II
From 2013	4.5		Basel III guideline
From 2014	5.5		(no penalties)
From 2015	6.0		
From 2016	6.625	$+ H_{it} \times 1/4$	Basel III
From 2017	7.25	$+ H_{it} \times 1/2$	(with penalties)
From 2018	7.875	$+ H_{it} \times 3/4$	
From 2019	8.5	$+ H_{it}$	

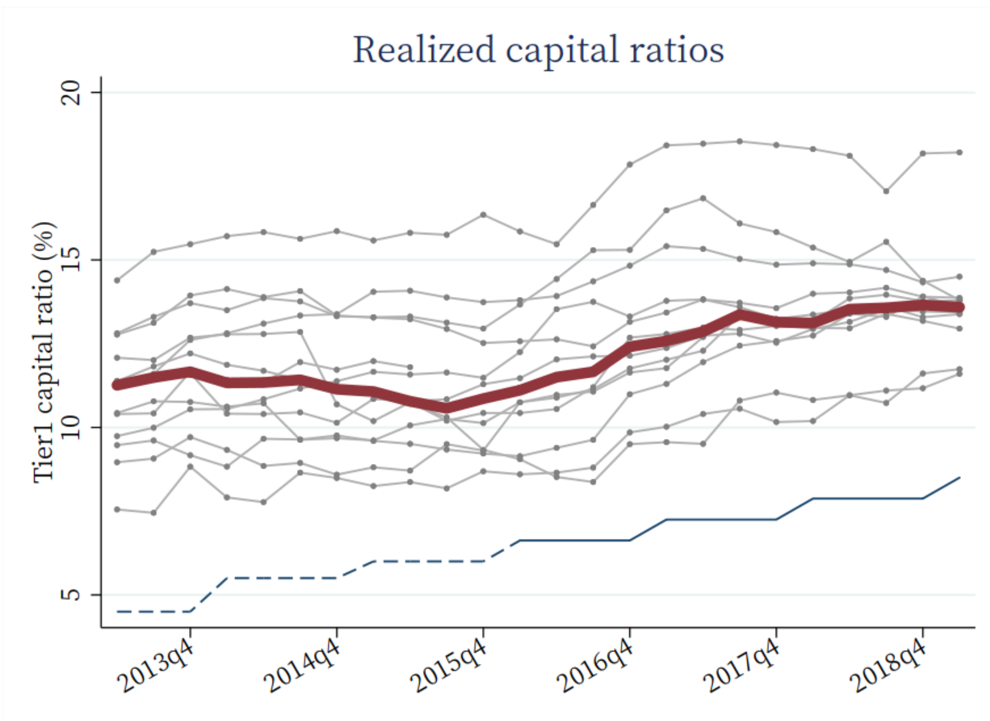
Note: H_{it} is the sum of Countercyclical Capital Buffer and Domestic Systematically Important Banks (DSIB) capital. Alternative measures of capital ratio requirements are discussed in Appendix B.2.

The Korean implementation of Basel III also introduced a range of penalties for non-compliance with the capital requirements. Such non-compliance can occur factually, or as a result of conducting a stress test. In the event of violating a posted capital requirement, the financial authorities are entitled to influence the distribution of profit of the non-compliant bank. In particular, this may involve restrictions on the payout of dividends and a forced accumulation of retained earnings. Appendix B.3 presents a schedule of restrictions that are a function of realized capital ratios. Essentially, the larger the violation, the larger the fraction of posted profit is placed under restriction.

Finally, it should be noted that while Basel III also mandated important changes to the leverage and liquidity regulations, they are unlikely to have biased our estimates for the case of Korea, as we explain in Appendix B.4.

2.9 Bank capital ratios over time

We now analyze bank balance sheets over the time period of interest. Figure 2 presents the evolution of realized bank capital ratios, with the median marked by a solid red line. At least three interesting observations can be made about this graph. First, there is a wide dispersion in realized capital ratios among the banks.[12] Second, and related to the first point, all capital ratios are well above the currently applicable minimum requirement. While this may seem paradoxical, it does not mean that the regulation is non-binding. In fact, even banks with relatively high posted capital ratios occasionally fail stress tests and may be deemed as non-compliant with the regulation. Consequently, banks tend to form an endogenous capital buffer over the required minimum which depends on their specific assets structure. Finally, the distribution of capital ratios is generally stable in years 2013-2015, and then goes on an upward trend starting from 2016. This is consistent with the background facts we describe in Section 2.8, which show that the enforcement of new capital regulation only started in Korea at the beginning of 2016. As a robustness check, Figure 26 in Appendix B.2 shows that the same trend is present for alternative measures of bank capital ratios.



Note: Each connected gray line represents the realized capital ratio of a domestic bank. Solid red line is a median realized capital ratio of each quarter. Solid navy line is minimum Tier 1 capital ratio requirements since 2016, and dashed navy line is “guideline" minimum capital ratios as in Table 1.

Figure 2: Realized bank capital ratios over time

[12]The figure only includes domestic banks. This is because the branches of foreign banks operating in Korea are subject to Basel III implementation from their home country.

2.10 Decomposition of bank equity over time

How much of the observed changes in bank capital ratios was due to an increase in equity, rather than a reduction in lending? In Appendix A.7 we show that banks did raise their capital, and it mostly occurred through retained earnings rather than external equity or hybrid bond issuance. In the remainder of this paper, we will quantify the effect of capital requirement tightening on bank lending and own equity accumulation while abstracting from the possibility of raising external equity.

3 Econometric analysis

So far, we have documented a strong correlation between the aggregate trends in corporate credit markets and changes in bank capital regulation. In this section, we employ econometric tools to show that higher capital requirements do, in fact, have a causal effect on the provision of corporate credit by both regulated banks and shadow lenders. Specifically, we estimate the elasticity of regulated bank credit with respect to the capital requirement, as well as a spillover effect of the reform onto shadow lending. To do so, we use our micro data to control for various confounding factors that could affect the demand and supply of credit at an individual firm-lender pair level.

3.1 Elasticity of bank lending with respect to capital requirement

We start by estimating the elasticity of regulated bank credit growth with respect to capital requirement. Specifically, we regress the change in total log credit extended by bank j to firm i in quarter t on log of Tier 1 Capital Ratio[13] required of bank j in quarter t, along with firm i and bank j fixed effects, and a vector of controls X_{ijt}.[14]

$$\Delta \ln total\_credit_{ijt} = f_i + f_j + \beta \ln min\_cap\_req_{jt} + \Psi X_{ijt} + \varepsilon_{ijt} \tag{1}$$

Our analysis exploits the fact that Basel III was a global policy reform, which provides plausibly exogenous variation in Korea's bank regulation.[15] As a result of the Korean

[13] We use Tier 1 Capital Ratio requirement in this regression, but results are robust to other types of capital ratios such as Common Equity Tier 1 or Total Capital Ratio, as Appendix C shows.

[14] In the baseline specification (Table 2, columns 3 and 4), we use the bank-firm relationship variable constructed as the lagged fraction of credit out of total firm credit, $credit_{ij,t-4} / \sum_j credit_{ij,t-4}$. In Appendix C.1 we run analogous regressions with additional control variables such as detrended GDP, stock market indices or the volume of manufacturing sector exports.

[15] The schedule was announced back in 2013 and was largely consistent with the Basel Committee's implementation guidelines. This implies that it was invariant to current economic conditions and therefore

implementation of Basel III, this variation in capital requirement policy ($min\_cap\_req_{jt}$) occurred on two margins: across time, and across banks. The variation across time is due to the fact that the capital requirement was being raised gradually over the years, and only starting from 2016 (Table 1). Effectively, the reform was broken into a sequence of small reforms. The variation across banks arises from the core idea of Basel III, that a group of Domestic Systemically Important Banks (DSIB) are required to hold an additional capital buffer. The introduction of this one-percentage-point buffer was also spread out over time.

To separate the impact of policy change from the usual confounding factors, we use a fixed effects identification strategy.[16] For example, a reduction in regulated bank credit could be driven by unobserved heterogeneities in firms' demand for loans, or in banks' supply of loans, that are unrelated to the regulation. To control for the former, we include firm fixed effects in our specification and rely on the observation that a typical firm in the data simultaneously borrows from multiple lenders.[17] Intuitively, a decline in credit will be attributed to a firm's idiosyncratic demand if that firm tends to reduce its borrowing from many banks at the same time. Analogously, we add bank fixed effects to control for any confounding heterogeneities in the lenders' loan supply that are unrelated to the regulation and rely on the observation that a typical lender simultaneously transacts with multiple firms.[18]

Table 2 presents the results of estimating equation (1) in several variants: with and without controlling for bank-firm relationships, as well as including or not the foreign banks in the sample.[19] We find that our results are very consistent across these different specifications, and the estimated elasticity is strongly significant and amounts to around -0.14. To provide a sense of the magnitude of this estimate, suppose that before any reform takes place, the level of credit is constant. Then, an increase in bank capital requirement from

plausibly exogenous (note that the Counter-cyclical Capital Buffer was never activated in Korea).

[16]This is a standard approach used in the literature. Irani et al. (2021) is one of the latest papers that uses fixed effects at loan-year and bank level to control for unobserved factors, and Khwaja and Mian (2008) is a classic paper that pioneered firm-lender matched studies. Subsection 3.5 discusses potential concerns related to our approach.

[17]Specifically, across all periods, a median firm borrows from 4 lenders at the same time.

[18]Specifically, across all periods, a median regulated bank lends to 19 firms and a median shadow lender lends to 5 firms at the same time.

[19]Foreign banks are technically subject to the Basel III requirements in their own country of origin, which may not be exactly the same (or may not be implemented at the same time) as in Korea. In Appendix C, we also use the foreign banks to perform a placebo test. We run the analogous regression on a sample limited to foreign banks only and we find no statistically significant effect of the change in Korean capital requirement on bank credit growth.

4% (as it was under Basel II) to 6.625% (under Basel III, as of 2016) would cause about a 7% *contraction* in credit for a generic firm-bank pair. Analogously, if the regulators in Korea thought that the reforms implemented so far are insufficient and decided to further raise the Tier 1 capital requirement from 8.5% to 9%, then they can expect it to cause a further 0.8% decline in corporate credit that would otherwise be constant.

Table 2: Effects of minimum capital requirements on credit growth

VARIABLES	(1) Δ ln total_credit	(2) Δ ln total_credit	(3) Δ ln total_credit	(4) Δ ln total_credit
ln min. capital req.	-0.135***	-0.138**	-0.140***	-0.143***
	(0.0433)	(0.0469)	(0.0426)	(0.0461)
Constant	0.144*	0.143	0.356***	0.368***
	(0.0777)	(0.0841)	(0.0822)	(0.0891)
Observations	83,559	77,733	83,559	77,733
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Relationship controls	No	No	Yes	Yes
Sample	All	Domestic	All	Domestic
R2	0.0699	0.0722	0.0919	0.0954

Note: Sample period: 2013Q2-2019Q1. For the results in this table, the capital requirement prior to 2016 is assumed to be 4% (the "guideline" requirements prior to 2016 were not legally binding). All standard errors (in parentheses) are clustered at the bank level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

3.2 Effect of reform on large and small banks

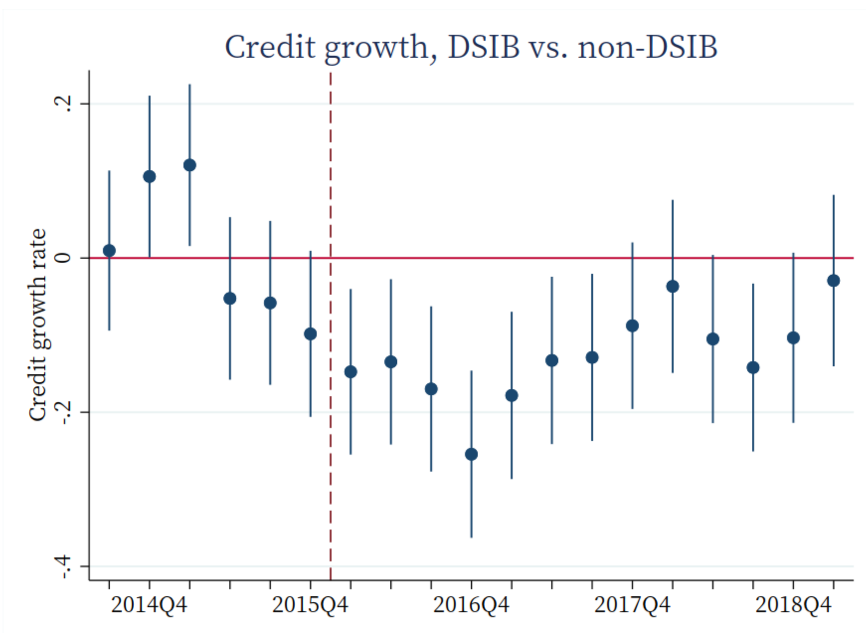
To allow for the firms' idiosyncratic demand for credit to be time-varying, we further add firm-time fixed effects[20] in the main regression and show that the significantly negative effect of capital requirements on credit growth holds. With firm-time fixed effects, this regression measures the difference in credit provision between Domestic Systemically Important Banks (DSIB), which are subject to an additional capital requirement, and the rest. In order to confirm that the estimation is not due to the DSIB specific trends relative to non-DSIB ones, we show in Appendix Figure 27 that two bank groups display parallel trends in credit growth before the reform. The estimation results, available in Appendix C.1, confirm that the elasticities estimated in the main specification are not due to a mere time trend that is unrelated to the regulation (reaffirming our claim from Section 2.3 that the trends in Figure 1 are *a new development*).

[20] As in Jiménez et al. (2012) or Blattner, Farinha, and Rebelo (2020).

To further analyze the effect of the additional capital requirement on credit provision by the large banks, we measure the interaction of time fixed effects and the DSIB dummy. Compared with equation (1), we replace the capital requirement variable on the explanatory side with time fixed effects and we also interact them with a dummy variable for DSIB status.[21] Specifically, the regression we run is

$$\Delta \ln total\_credit_{ijt} = f_i + f_j + f_t + \gamma_t \cdot DSIB_j + \Psi X_{ijt} + \varepsilon_{ijt} \tag{2}$$

where f_i, f_j, and f_t are firm, bank, and time fixed effects, respectively, while $DSIB_j$ is an indicator that takes the value of 1 if bank j is designated as DSIB and 0 otherwise.[22] We summarize the results of this regression in Figure 3 which plots the evolution of coefficients γ_t over time, together with 95% confidence interval. The estimates demonstrate that at the beginning of the sample period, there is no statistically significant difference between DSIBs and non-DSIBs in terms of the credit growth rate. The decline in credit



Note: Each dot measures marginal credit growth of DSIB compared to non-DSIB in each quarter, which is γ_t of equation 2. Each line is a confidence interval. All measures are relative to the first time period, 2013Q2. Dashed vertical line is 2016Q1, indicating the beginning of the reform.

Figure 3: Credit growth of DSIBs vs. non-DSIBs

[21]However, it is noteworthy that the selection of DSIBs is not random. Every year, Korean regulators announce the selection of DSIBs based on various measures, but the same set of banks are selected as DSIBs over the entire sample period. Therefore DSIB dummies do not vary over time in our sample.

[22] The omitted time dummy is the first sample period (2013Q2) so that γ_t measures the policy effects relative to 2013Q2.

growth for DSIBs becomes significant only after the introduction of the Basel III regulation in 2016Q1 (vertical red line), consistent with the main estimation in Table 2. In Section 6.4 we use our model to understand the forces that drive this empirical result.

3.3 Spillover effect of the reform on shadow lending

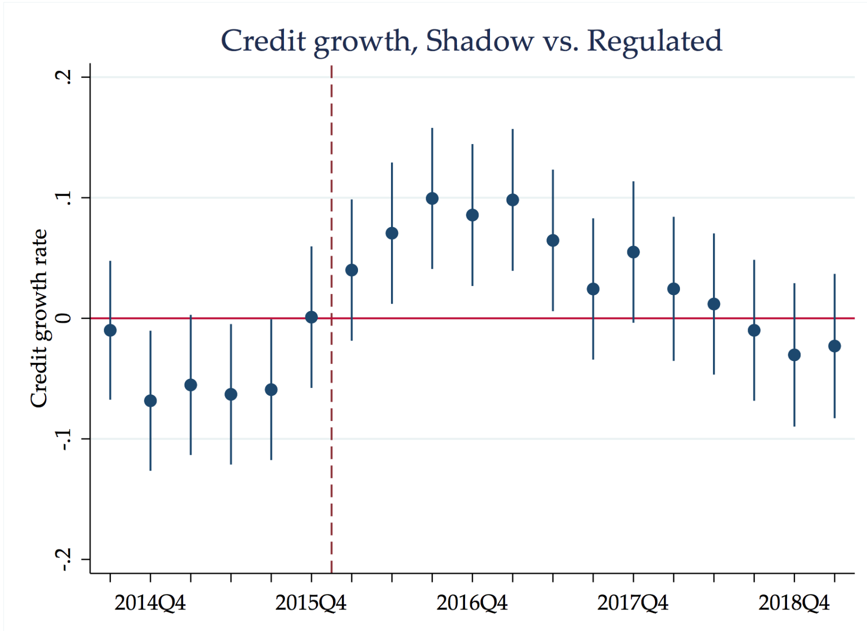
The results presented so far are limited to the sample of regulated bank loans. This is due to the fact that only these banks are formally subject to Basel III requirements and have their capital ratios formally measured. We now turn our attention to the measurement of a spillover effect from the regulation onto the provision of shadow credit. Figure 1 reveals an obvious correlation between the two, but is there evidence to believe that the change in bank regulation actually leads to more credit extended by individual shadow lenders? To answer this question, we modify our baseline specification to include all lenders available in our dataset. We use a specification analogous to regression (2) where, compared with equation (1), the policy variable is replaced with time fixed effects interacted with a dummy variable for whether institution j is a shadow lender. Specifically, we regress

$$\Delta \ln total\_credit_{ijt} = f_i + f_j + f_t + \gamma_t \cdot Shadow_j + \Psi X_{ijt} + \varepsilon_{ijt} \tag{3}$$

where f_i, f_j, and f_t are firm, bank, and time fixed effects, respectively. $Shadow_j$ is an indicator which takes the value of one if institution j is a shadow lender, while γ_t are the coefficients for the interaction of time dummies with the shadow dummy.[23] We summarize the results of this regression in Figure 4 which shows the evolution of γ_t over time, along with 95% confidence intervals. Prior to 2016, i.e. before the penalties for noncompliance with Basel III came into force in Korea, credit growth from shadow lenders was on average lower by up to 7 percentage points at the firm level (although hardly distinguishable from zero). This result changes dramatically in 2016, when credit growth from shadow lenders becomes up to 10 percentage points higher on average and in a statistically significant way compared to credit growth from regulated banks. This effect gradually dissipates over time and by 2018 the difference in growth provided by the two lender types is statistically indistinguishable.

In Appendix C.3 we also estimate the spillover effect of the reform on the *extensive margin* of shadow lending relationships and show that both the existence and formation of such relationships becomes much more likely precisely when Basel III comes into effect.

[23]Similarly as remarked in footnote 22, γ_t here measures the policy effects relative to 2013Q2.



Note: Each dot measures marginal credit growth of shadow lenders compared to regulated banks in each quarter, which is γ_t of equation 3. Each line is a confidence interval. All measures are relative to the first time period, 2013Q2. Dashed vertical line is 2016Q1, indicating the beginning of the reform.

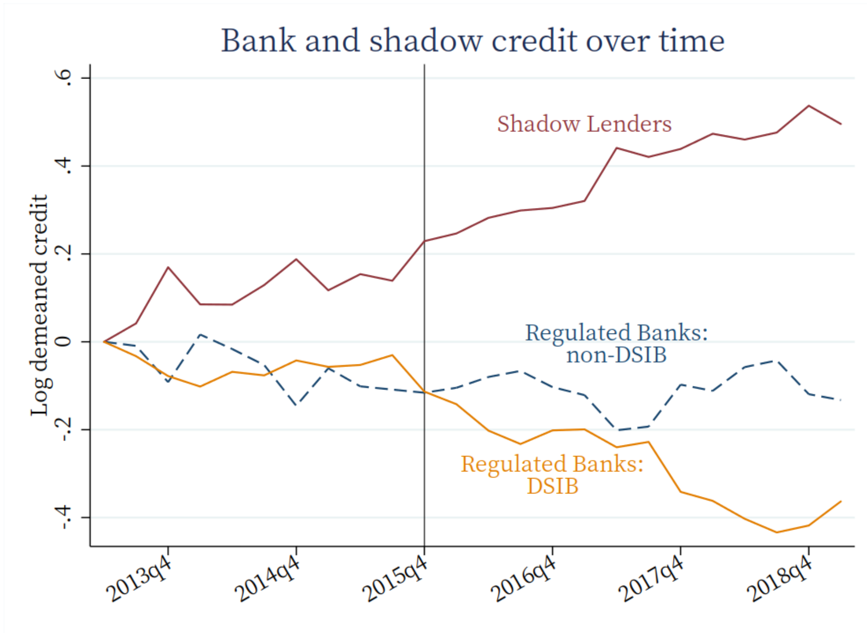
Figure 4: Estimated interaction effects of time and shadow dummies

3.4 Substitution effect between bank and shadow lending

As a final piece of our econometric analysis, we investigate the degree of substitution between regulated bank lending and shadow lending within a firm. So far, we have presented the results showing a strong and negative elasticity of bank lending with respect to capital requirement, and the spillover effect onto shadow credit. A natural question that follows is to what extent are these results driven by the sheer substitution between the two credit sources within a firm.

In order to estimate the substitution effect, we first narrow our sample down to a subset of firms that borrow from all three types of lenders, namely DSIB, non-DSIB, and shadow lenders. Figure 5 summarizes the changes in credit extended by the three types of lenders within an average firm relative to the initial period (2013Q2).[24] It shows that relative

[24]More specifically, we only keep the firm-quarter observations that borrow from all three types of lenders. This amounts to about 86% of total lending amounts. Then, we de-mean each log credit by subtracting the average amount in logs at firm-quarter level. Next, we aggregate the de-meaned figures by taking a simple average across firms within each quarter. Finally, from the aggregate de-meaned figures, we subtract the 2013Q2 level in order to compare changes of each measure over time. These steps are similar to those of Khwaja and Mian (2008), but extended to three types of lenders.



Note: Sample is restricted to firms that borrow from all three types of lenders. Observations are demeaned at firm-quarter level, and normalized to the initial period 2013Q2. By construction, in each period the lines sum up to zero.

Figure 5: Substitution effect of shadow, DSIB, and non-DSIB credit

to the initial period, an average firm in 2019Q1 borrowed over 50% more from shadow lenders, and it borrowed around 40% and 10% less from DSIBs and non-DSIBs, respectively. The amount of shadow credit is on an upward trend throughout the sample period within a firm, but the increase accelerates especially starting from 2016Q1. Meanwhile, credit extended by both DSIBs and non-DSIBs shows a pattern that mirrors the rise of shadow credit, pointing to the substitution between regulated bank and shadow lending.

Based on these observations, we quantify the contribution of the substitution effect between credit from regulated banks and shadow lenders to the aggregate trends depicted in Figure 1. A natural approach to estimating the substitution effect would be to regress the growth of shadow credit of firm i at time t ($\Delta ln\ shadow\_credit_{it}$) on the corresponding growth of regulated credit ($\Delta ln\ regulated\_credit_{it}$), after controlling for the firm fixed effects (f_i) and other control variables (X_{it}), as equation (4) shows.

$$\Delta ln\ shadow\_credit_{it} = f_i + \beta \cdot \Delta ln\ regulated\_credit_{it} + \Psi X_{it} + \varepsilon_{it} \tag{4}$$

However, this estimation is potentially biased due to the presence of credit demand shocks. For example a firm which experiences a positive demand shock may increase both shadow and regulated credit. To correct this bias, we design a shift-share, or Bartik-like instrumental variable regression (Goldsmith-Pinkham et al. 2020). More specifically, we use the share of DSIB credit among the total regulated bank credit in 2013Q2 as a source of differential "exposure" across firms. This instrument design is motivated by the fact that we observe a divergence of credit growth between DSIB and non-DSIB only starting from 2016Q1, triggered by a policy change that imposes an extra capital requirement on DSIBs. More detailed description of the substitution between DSIB and non-DSIB can be found in Appendix C.4. Hence, in place of the observed growth of regulated credit, we use the predicted value based on the shift share instrument as in equation (5):

$$\Delta ln\ regulated\_credit_{it} = q_i + \gamma \cdot S_i \cdot G_t + \Phi X_{it} + \xi_{it} \tag{5}$$

where $S_i \cdot G_t = \sum_j s_{i,j} g_{j,t}$ is a dot product of initial period credit share by bank j within firm i ($s_{i,j}$) and bank j credit growth rate in time t ($g_{j,t}$), q_i is the firm fixed effect, and X_{it} contains other control variables. Here, β in equation (4) is the main coefficient of interest. The results of this estimation, reported in Appendix C.4, show that a 1 percent decrease in credit extended by regulated banks leads to a 1.3 percent increase in shadow credit.

3.5 Robustness checks and further analysis

Appendix C contains a number of robustness exercises to support our baseline results.

In Appendix C.1, we address a number of potential concerns related to the results in Table 2. In particular, we show that the results are robust to inclusion of time-firm fixed effects, which essentially estimates a cross-sectional elasticity of bank credit supply with respect to the capital requirement. We also demonstrate that: i) the results are robust to inclusion of various macroeconomic control variables; ii) there is no statistically significant "anticipation effect" before the reform becomes binding; iii) the results are not statistically significant when we restrict the sample to foreign banks only (who follow foreign countries' regulation); iv) the results are robust to weighting observations by credit quantity. Next, in Appendix C.2, we also redo all our estimations using alternative measures of bank capital ratio. In all cases, we find consistent and strongly significant estimates although the magnitudes can vary considerably. For the sake of future research, Table 18 provides a concise summary of our estimates for the alternative measures of capital ratio.

4 Model

In this section we develop a dynamic general equilibrium model with frictional financial intermediation to provide theoretical foundations for our empirical results. Time is discrete, indexed by t, and goes until infinity. There is no aggregate uncertainty.

Banks are heterogeneous with respect to their histories of shocks and discount factors.[25] They seek to smooth out an uncertain stream of dividends over time by issuing deposits and investing in both risky assets (such as loans to firms), and riskless ones (such as central bank deposits). Banks are also subject to idiosyncratic shocks to the value of their risky assets (representing loan defaults or fluctuations in investment returns). They are subject to a capital requirement that enters in a soft form via a tax on dividend payouts. Facing stochastic fluctuations in the value of their risky assets, banks have an incentive to maintain a precautionary buffer of equity over the minimum level required by the regulator.[26] A key feature of the model is that due to these frictions in financial intermediation, the general equilibrium price vector consists of two separate interest rates: a lower rate on riskless deposits and a higher rate on risky loans.

We embed the banking sector in a broader economy that consists of two further groups of heterogeneous agents. First, there is a mass of entrepreneurs whose stochastic business productivity follows an autoregressive process. In order to produce, entrepreneurs must invest in physical capital ahead of time which can be financed with debt (up to a borrowing limit) or their own accumulated wealth. Any excess savings may be deposited in the banking sector. As a counterpart of the bank's asset value shock, we introduce the possibility of a non-strategic default on debt for the borrowing entrepreneurs. A crucial innovation in that part of the model is that we equip the entrepreneurs with an option to pay a fixed cost and become *shadow lenders*. In such cases, they continue to produce output according to their own productivity realization. However, any excess savings become risky investments with a higher expected rate of return (just as in the case of banks).

Finally, there are heterogeneous workers who face uninsured idiosyncratic labor risk and accumulate precautionary savings. These savings are deposited in riskless bank accounts.

[25] We introduce permanent heterogeneity in bank discount factors to analyze the effects of size-specific regulation proposed in Basel III. None of the results in the paper depend on this feature.

[26] We assume that banks are closely held and cannot raise external equity. This assumption is supported with the evidence presented in Appendix A.7.

4.1 Timeline and summary

Figure 6 presents a graphic summary of the linkages between the different groups of agents in the model economy. Workers accumulate savings to insure against idiosyncratic labor income shocks. These assets are deposited in bank accounts and earn a deposit interest rate r^d. Banks then use these funds to make loans to businesses, earning an interest rate of r^b, and redistribute the earned dividends evenly among the workers who own them. Some entrepreneurs may find it optimal to save, rather than borrow, in which case they may also add to the stock of deposits in the economy. Finally, entrepreneurs may also choose to become shadow lenders. In that case, they continue to produce and use their own excess funds to make risky loans to other entrepreneurs, earning the interest rate r^b which is higher than r^d. Such entrepreneurs then face the idiosyncratic investment risk (just as banks do). Crucially, shadow lenders are not subject to regulations of any sort.

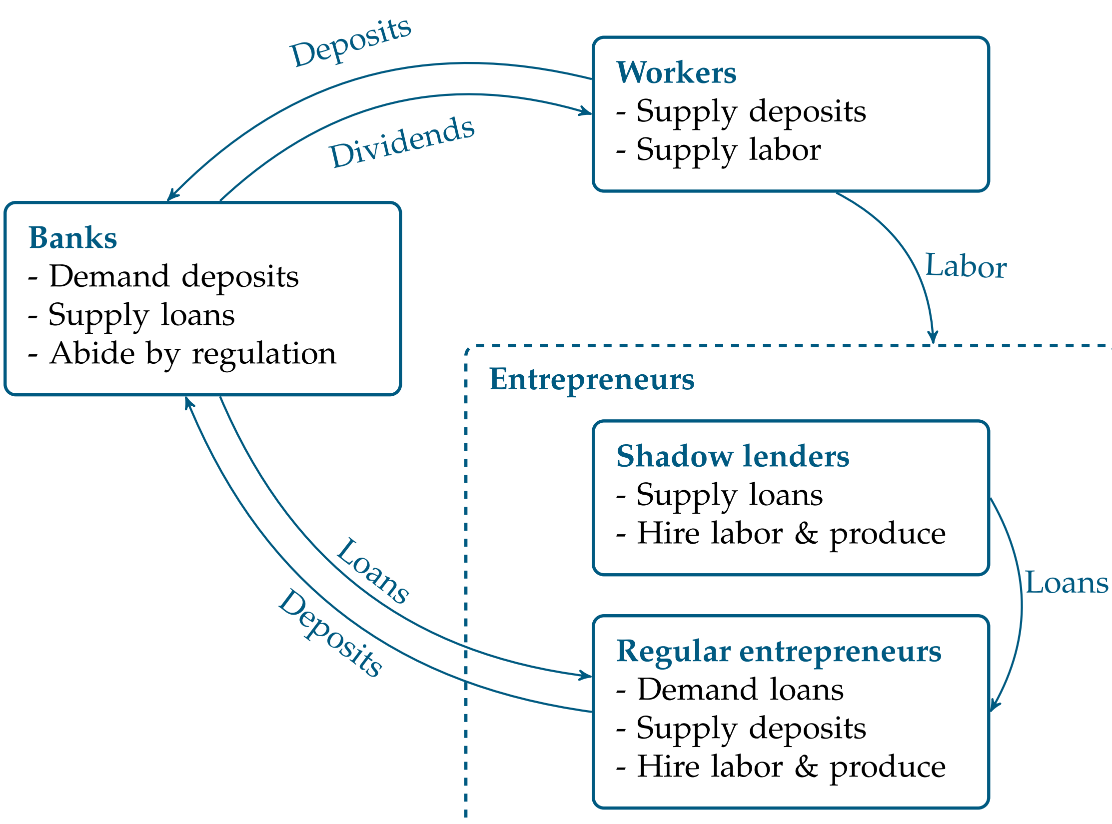
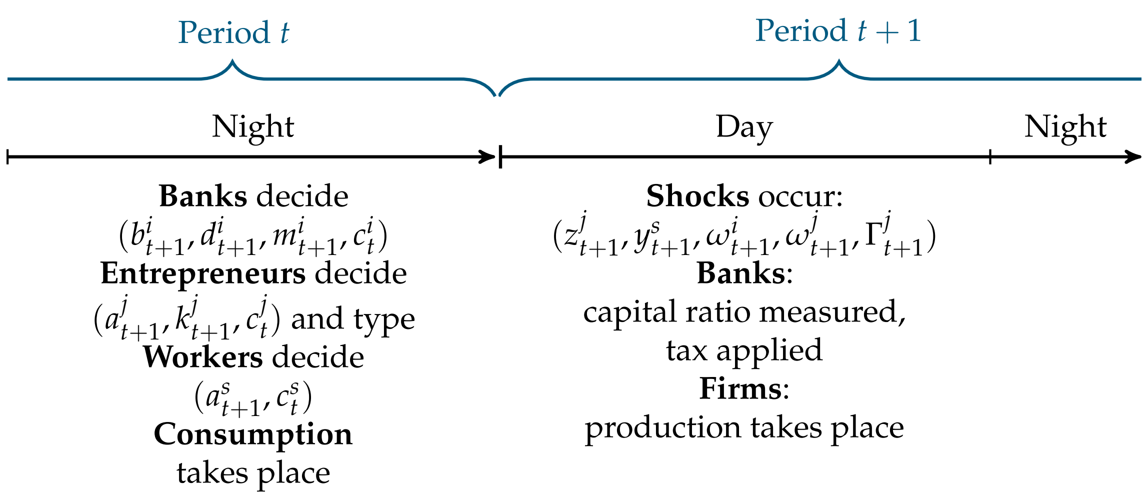


Figure 6: Diagram of linkages in the economy

It should be emphasized that we do not model any direct matching between different agents in our model. The three groups can be thought of as living on separate islands.

Between the islands, there exists a clearing house which posts economy-wide prices, and randomly distributes loan default losses among lenders, such that all markets display no excess demand in the general equilibrium.

Figure 7 discusses the timing of our model. Every period is divided into two stages which can intuitively be thought of as day and night. Night time is a planning period in which all agents decide on their allocations and consume immediately. Then, shocks occur during day time, in particular the shocks to the lenders' risky assets value, as well as the borrower default shocks. Following these realizations, the financial authorities measure banks' posted capital ratios and apply the utility penalties for non-compliance with capital requirements. Finally, day time is when production takes place.



Note: Indexes i, j, and s refer to individual banks, entrepreneurs and workers, respectively.

Figure 7: Timing of the model

4.2 Banks

Preferences The model comprises a continuum of heterogeneous banks with fixed mass λ_b which are indexed by i. Banks have preferences over a stream of dividend payments $\{c^i_t\}$ given by

$$\mathbb{E}_0 \sum_{t \geq 0} \tilde{\beta}^t_i u(c^i_t) \tag{6}$$

where we assume the function $u(\cdot)$ is strictly increasing, concave and twice continuously differentiable. The discount factor is given by $\tilde{\beta}_i \in (0, 1)$ and it is potentially heterogeneous across banks (hence indexed by i). The concavity in the utility function gives banks a dividend-smoothing motive. This assumption is made for convenience of aggregation, but is also empirically relevant as it can represent various frictions in firm financing.

Budget constraint Banks arrive in each period with a single state variable, equity e_t^i. The budget constraint states that they can spend it on dividend payout c_t^i, risky loans investment b_{t+1}^i or risk-free reserves m_{t+1}^i. Banks can also supplement their equity with deposits d_{t+1}^i from other agents in the economy. Formally, the budget constraint is

$$c_t^i + b_{t+1}^i + m_{t+1}^i - d_{t+1}^i = e_t^i \tag{7}$$

Uncertainty Banks are subject to an idiosyncratic shock to the value of their assets, $\omega_{t+1}^i \in [0,1]$, where $\mu \equiv \mathbb{E}(\omega_{t+1}^i)$ is the expected repayment rate of loans. This shock arrives during the first stage of the next period and can be thought of as realization of loan default rates or fluctuations in the market value of risky assets. Banks take as given the current market interest rate on risky loans, risk-free reserves and deposits. As a result, the next period realized equity of a bank is given by

$$e_{t+1}^i = (1 + r_{t+1}^b) b_{t+1}^i \omega_{t+1}^i + (1 + r_{t+1}^m) m_{t+1}^i - (1 + r_{t+1}^d) d_{t+1}^i \tag{8}$$

Regulatory environment Banks are subject to regulations imposed on them by the authorities. In particular, the minimum capital requirement states that

$$\frac{b_{t+1}^i \omega_{t+1}^i + m_{t+1}^i - d_{t+1}^i}{\chi b_{t+1}^i \omega_{t+1}^i} \geq \kappa \tag{9}$$

The numerator in equation (9) represents bank i's realized equity in the first stage of next period, while the denominator contains risk-weighted assets. Corporate loans are the only risky assets in this model, hence they carry a risk weight χ which is a fixed parameter. The constraint states that this ratio must be greater than an exogenously imposed parameter κ. In our actual application in Section 4.6, we impose a soft form of this constraint, allowing banks to violate it while getting taxed on their dividend distribution.

The second regulatory constraint is the minimum reserve requirement which states that banks must hold at least a fraction $\rho \in [0,1]$ of their deposits in the form of risk-free assets.

$$m_{t+1}^i \geq \rho d_{t+1}^i \tag{10}$$

4.3 Entrepreneurs

Preferences There is a continuum of heterogeneous entrepreneurs with fixed mass λ_e in the economy, indexed by j. They have preferences over an uncertain consumption stream given by

$$\mathbb{E}_0 \sum_{t \geq 0} \beta^t u(c_t^j) \tag{11}$$

where we assume the function $u(\cdot)$ is strictly increasing, concave and twice continuously differentiable. The discount factor is given by $\beta \in (0,1)$.

Portfolio choice At the decision stage of each period, an entrepreneur arrives with a cash-on-hand variable x_t^j. This wealth must be spent on current consumption c_t^j, next-period physical capital k_{t+1}^j, or next-period financial asset a_{t+1}^j.

Production technology We assume that every entrepreneur has access to a decreasing returns to scale production function $f(z,k,n)$. This technology transforms k units of physical capital and n units of hired labor into the consumption goods; a fraction δ of physical capital depreciates in the process. We assume that the production function is of the form

$$f(z,k,n) = z^{1-\nu}(k^{\alpha}n^{1-\alpha})^{\nu} \tag{12}$$

Following Lucas (1978), we introduce an entrepreneur-specific fixed factor z with a span-of-control parameter $\nu < 1$. The decreasing returns to scale assumption implied in (12) allows us to obtain a well-defined distribution of firms in the stationary equilibrium. We assume that z is a random variable and follows a Markov process with transition matrix Π_z. In every period, taking as given a realization of z_t^j, a pre-installed level of capital k_t^j, and wage w, each firm hires labor to maximize profit

$$\pi(k_t^j, z_t^j) = \max_n \Big\{ f(z_t^j, k_t^j, n) - w_t n \Big\} \tag{13}$$

Financial asset Each entrepreneur has access to a saving or borrowing technology via a non-contingent financial asset a_{t+1}^j. In the case of savings, $a_{t+1}^j > 0$, the asset pays a risk-free interest rate of r_{t+1}^d. In the case of debt, $a_{t+1}^j < 0$, the interest rate is $r_{t+1}^b > r_{t+1}^d$ and entrepreneurs are only allowed to borrow up a debt limit $\underline{a}_e - \varphi k_{t+1}$ which is partly unsecured and partly collateralized with the newly installed physical capital.

Non-strategic default As an underlying friction that generates fluctuations in the value of the lenders' risky assets, we introduce a non-strategic default shock on borrowers' debt. The shock takes the form of an idiosyncratic binary random variable, Γ_t^j. If $\Gamma_t^j = 1$, which happens with probability ξ, borrower j only repays the secured portion of his debt above $\underline{a}_e$ and his next-period wealth becomes

$$x_{t+1}^j = w_{t+1} + \pi(z_{t+1}^j, k_{t+1}^j) + (1-\delta)k_{t+1}^j + (1 + r_{t+1}^b)\min\{0, a_{t+1}^j - \underline{a}_e\} \tag{14}$$

On the other hand, if $\Gamma_t^j = 0$, which happens with probability $1 - \xi$, borrower j must repay the full debt and his next-period wealth is

$$x_{t+1}^j = w_{t+1} + \pi(z_{t+1}^j, k_{t+1}^j) + (1-\delta)k_{t+1}^j + (1 + r_{t+1}^b)a_{t+1}^j \tag{15}$$

The assumptions of non-strategic default, as well as exogenous borrowing limits and collateral constraints, are deliberate simplifications to keep the entrepreneur side of the model tractable and to focus on the general equilibrium channel linking them to banks. The model can potentially be developed to feature more sophisticated firm behavior.

Shadow lenders At the decision stage of each period, an entrepreneur has an option to become a shadow lender. In such case, he continues to produce output using physical capital, but any excess financial assets $a_{t+1}^j > 0$ are invested in corporate loans and earn the interest rate $r_{t+1}^b > r_{t+1}^d$. On the other hand, these loans are also risky and shadow lenders face the same idiosyncratic shock to their value, ω_{t+1}^j, as regulated banks do. In addition, shadow banks must pay a fixed cost f_S at the decision stage of every period.[27]

An important assumption in our model is that the interest rate on regulated bank loans, and on shadow credit, are equal. While our data does not contain loans-specific interest rates, in a follow-up paper we use alternative sources of information to show that the distributions of interest rates on corporate loans and bonds mostly overlap in 2013 in Korea (Lee and Paluszynski, 2022), providing empirical support for our assumption.

[27]The fixed cost is included in the model primarily for calibration purposes. It is important to note that it is not a statutory cost and can be interpreted as encompassing various search and matching costs that are required of firms to operate as a lender.

4.4 Workers

Preferences There is a continuum of workers of fixed mass $1 - \lambda_e$ in the economy indexed by s. They have preferences over consumption given by

$$\mathbb{E}_0 \sum_{t \geq 0} \beta^t u(c_t^s) \tag{16}$$

where we assume the function $u(\cdot)$ is strictly increasing, concave and twice continuously differentiable. The discount factor is given by $\beta \in (0, 1)$. The workers face an idiosyncratic labor income risk and have access to riskless, one-period non-contingent bonds through which they can borrow and save at the interest rate of r_t^d. In addition, workers receive equal dividend payments from the banks.

4.5 Clearing House

Because we abstract from any direct matching between the different types of agents in our model, we assume the existence of a clearing house that manages the flows of funds and labor. By posting market-clearing general equilibrium prices (r_t^b, r_t^d, w_t), the clearing house balances out demand and supply in each market. It is worth emphasizing, in particular, that the clearing house randomly transforms the distribution *of the fraction of loans* repaid in the process. Specifically, the fraction of loans repaid by borrowers is determined by the non-strategic default shock Γ_{t+1}^j, while the distribution of the fraction of loans repaid to the lenders is given by a continuous random variable $\omega_{t+1} \in [0, 1]$. In equilibrium, however, the quantities of defaulted loans must balance out by setting the proper value of the expected repayment rate $\mu \equiv \mathbb{E}(\omega_{t+1})$.[28] We use this assumption as a reduced-form way to introduce the notion of imperfect risk diversification for the lenders. It should be highlighted, however, that in doing so the clearing house operates mechanically period-by-period and never gains or loses any resources in the process.

4.6 Recursive Formulation

In this section, we express the model in recursive formulation which we will use directly to compute the solution. For notational convenience, we suppress the bank, entrepreneur, and worker superscripts, as well as time subscripts.

[28]Parameter μ is the crucial link between the borrower defaults and lender losses and must be selected separately for each stationary equilibrium, as well as for every period on the deterministic transition path. However, the adjustments to this parameter across different equilibria are minor and do not affect our quantitative results in any noticeable way. See Appendix D for details.

Bank's problem The recursive problem of a bank with discount factor $\tilde{\beta}$ is[29]

$$V^B(e,p) = \max_{c,b',m',d'} u\left(\frac{c}{1+\tau(p)}\right) + \tilde{\beta} E_{\omega'} V^B(e',p') \tag{17}$$

$$s.t.\ c + b' + m' - d' = e \tag{18}$$

$$e' = (1+r^b)b'\omega' + (1+r^m)m' - (1+r^d)d' \tag{19}$$

$$p' = \kappa\chi b'\omega' - \left(b'\omega' + m' - d'\right) \tag{20}$$

$$m' \geq \rho d' \tag{21}$$

In the problem above, equation (18) represents the bank's budget constraint which implies that current equity can be spent on dividend payouts c, risky loans to firms b', central bank reserves m', and it can be supplemented with raising deposits d'. Equation (19) shows that the equity next period will depend on the interest rates on the three portfolio components, as well as the realization of the loan default shock ω'. We introduce the capital constraint in a soft form, by assuming that banks' dividend payouts are taxed for violating the minimum capital requirement.[30] State variable p' in formula (20) captures the deviation of the bank's posted equity next period from the κ-fraction of its risk-weighted assets. A positive value of p' implies that the bank's capital ratio has fallen below the required minimum. The tax operates through a nonlinear function $\tau(p)$, to be specified in the next section. Finally, expression (21) contains the reserve requirement of the bank, i.e. banks must invest at least a fraction ρ of their deposits in risk-free assets.

Banks are heterogeneous with respect to accumulated equity due to each having experienced a unique path of shocks over time. The main result from the model of Bianchi and Bigio (2022) is that banks' policy functions are linear in equity, i.e. big banks are essentially a scaled-up version of small banks. As a result, a stationary distribution does not determine the aggregate level of equity. As we will show in Section 5, this is not necessarily the case in our setup because capital requirements may inhibit the ability of banks to use deposits to leverage up and make an optimal amount of risky investments. The key to achieving this result is to introduce non-homotheticity in the tax function $\tau(p)$ which, as we will argue, is consistent with the core idea of the Basel regulations.

[29] In the quantitative implementation of our model, we introduce two groups of banks, differing in discount factor, to mimic the existence of DSIB and non-DSIB banks in the data. This feature is not necessary for any of the main results.

[30] This assumption captures the reality where, a bank whose capital ratio falls below the required minimum is subjected to various penalties, in particular to restrictions on the distribution of dividends. Importantly, this can occur as a result of a failed stress test even if the posted capital ratio is above the requirement.

Entrepreneurs An entrepreneur in our model enters the decision stage of each period (night time) with two state variables: net worth x, and idiosyncratic productivity of his business idea z. He decides how much to consume or save, which in turn entails a portfolio choice between selecting financial assets and installed capital for the next period. During the realizations stage of the next period (day time), he uses the pre-installed physical capital and hires workers to carry out production. The entrepreneur's income next period will then consist of the sum of his own labor income (we assume it is provided inelastically), profit from running business, undepreciated capital and the gross return on the financial assets.

Problem of a regular firm An entrepreneur who has chosen to be a regular firm solves

$$V^R(x,z) = \max_{c,a',k'} u(c) + \beta \mathbb{E}_{z',\Gamma'} \Big[V(x',z') | z \Big] \tag{22}$$

$$s.t. \quad x = c + a' + k' \tag{23}$$

$$x' = w + \pi(k',z') + (1-\delta)k' + \Big(1 + r(a')\Big)\Big(a' - s(\Gamma',a')\max\{a', \underline{a}_e\}\Big) \tag{24}$$

$$r(a') = r^d \mathbb{1}\{a' \geq 0\} + r^b \mathbb{1}\{a' < 0\} \tag{25}$$

$$s(\Gamma',a') = \mathbb{1}\{\Gamma' = 1, a' < 0\} \tag{26}$$

$$a' \geq \underline{a}_e - \varphi k' \tag{27}$$

where V is the continuation value of a generic entrepreneur who then decides again whether to become a shadow lender or not. Current net worth x can be spent on consumption c, or investment in financial assets a' or physical capital k'. Next period net worth will consist of the entrepreneur's labor income, as well as gross returns on the two types of assets. Equation (25) shows that entrepreneurs face different interest rates on their financial assets, depending on whether they have savings or loans. Firms can borrow up to a limit of $\underline{a}_e - \varphi k'$ and their debt consists of an exogenous unsecured credit line $\underline{a}_e$, and a loan collateralized with the newly installed physical capital. To match the lenders' losses on the extended credit, we introduce a possibility of a non-strategic default on the borrowers' side. An entrepreneur who has borrowed ($a' < 0$) may receive a default shock ($\Gamma' = 1$) next period which occurs with a fixed probability ξ. In such case, he is only liable for repayment of any debt in excess of the unsecured credit line $\underline{a}_e$.[31]

[31] This way of modeling debt is motivated by the fact that, in the data, roughly half of all corporate debt is collateralized. In the quantitative analysis in Section 5, we select the parameters to match this fact. In particular, the parameter $\varphi < 1$ can be interpreted as a fraction of the installed physical capital that can be easily seized and liquidated by the lenders in the case of default.

Problem of a shadow lender An entrepreneur who becomes a shadow lender solves

$$V^S(x,z) = \max_{c,a',k'} u(c) + \beta \mathbb{E}_{z',\omega'} \Big[V(x',z') | z \Big] \tag{28}$$

$$s.t. \quad x = c + a' + k' + f_S \tag{29}$$

$$x' = w + \pi(k',z') + (1-\delta)k' + (1+r^b)\omega' a' \tag{30}$$

$$a' \geq 0 \tag{31}$$

where V is the continuation value of a generic entrepreneur who then decides again whether to become a shadow lender or not. Current net worth x can be spent on consumption, or investment in financial assets a' or physical capital k'. In addition, to operate as a shadow lender, an entrepreneur must incur a fixed cost of f_S. Next period net worth will consist of the entrepreneur's labor income, as well as gross returns on the two types of assets. The key difference relative to a regular firm who saves ($a' \geq 0$) is that the shadow lender can earn interest rate r^b on their financial assets, as opposed to a (potentially lower) rate r^d. The downside of choosing to do so is that a shadow lender faces the same shock to the value of his financial assets, ω', as regulated banks do.

Choice to become a shadow lender A generic entrepreneur chooses whether to become a shadow lender or not by comparing the two value functions

$$V(x,z) = \max \Big\{ V^R(x,z), V^S(x,z) \Big\} \tag{32}$$

Notice that through selection into entrepreneur types, the behavior of shadow lenders in equilibrium is also affected by the deposit rate which acts as opportunity cost to them.

Worker's problem The recursive problem of a worker is

$$V^W(x,y) = \max_{c,a'} u(c) + \beta E_{y'} \Big[V^W(x',y') | y \Big] \tag{33}$$

$$s.t. \quad x = c + a' \tag{34}$$

$$x' = wy' + (1+r^d)a' + c_b \frac{\lambda_b}{1-\lambda_e} \tag{35}$$

$$a' \geq 0 \tag{36}$$

Workers in this economy are standard and modeled as in Aiyagari (1994). In order to make the timing of workers' decisions consistent with the other parts of the economy, we pose our recursive problem in terms of a wealth (or cash-on-hand) state variable x. Each worker's labor productivity y follows a stochastic autoregressive process. Uninsurable idiosyncratic labor risk generates a motive for workers to accumulate wealth through savings in risk-free assets a', which are then deposited with the banking sector (and paid the corresponding interest rate r^d). For simplicity, we assume that workers are not allowed to borrow (see Section 4.8 for further discussion of this modeling assumption). Finally, because workers ultimately own all the banks, they receive a lump-sum transfer of the banks' aggregate gross dividend c_b (including the proceeds from taxes), scaled in proportion to the respective measures of these two types of agents.

4.7 Stationary Equilibrium

We finish describing the model by introducing the definition of a stationary general equilibrium.

Definition 1 *A stationary recursive competitive equilibrium consists of policy functions for banks* $\{c_b, b', m', d'\}$, *borrowing entrepreneurs* $\{c_{r-}, a'_{r-}, k'_{r-}\}$, *depositing entrepreneurs* $\{c_{r+}, a'_{r+}, k'_{r+}\}$, *shadow lenders* $\{c_s, a'_s, k'_s\}$, *and workers* $\{c_w, a'_w\}$; *labor allocations for borrowing entrepreneurs, depositing entrepreneurs and shadow lenders* $\{n_{r-}, n_{r+}, n_s\}$, *respectively; value functions of all types of agents* $\{V^B, V^{R-}, V^{R+}, V^S, V^W\}$; *cumulative distribution functions for all types of agents* $\{\Lambda_b, \Lambda_{r-}, \Lambda_{r+}, \Lambda_s, \Lambda_w\}$; *and prices* $\{r^b, r^d, w\}$ *such that:*

1. *Given the general equilibrium price vector* $\{r^b, r^d, w\}$, *the allocations solve the bank's, the regular firm's, the shadow lender's, and the worker's maximization problems.*

2. *Asset and labor markets clear:*

$$\int_{E\times P} b'(e,p)d\Lambda_b(e,p) + \int_{X\times Z} a'_s(x,z)d\Lambda_s(x,z) = \int_{X\times Z} a'_{r-}(x,z)d\Lambda_{r-}(x,z) \qquad (loans)$$

$$\int_{A\times Y} a'_w(a,y)d\Lambda_w(a,y) + \int_{X\times Z} a'_{r+}(x,z)d\Lambda_{r+}(x,z) = \int_{E\times P} d'(e,p)d\Lambda_b(e,p) \qquad (deposits)$$

$$\int_{E\times P} m'(e,p)d\Lambda_b(e,p) = \overline{M} \qquad (reserves)$$

$$\int_{X\times Z} n_{r-}(x,z)d\Lambda_{r-}(x,z) + \int_{X\times Z} n_{r+}(x,z)d\Lambda_{r+}(x,z) + \int_{X\times Z} n_s(x,z)d\Lambda_s(x,z) = 1 \qquad (labor)$$

Three important remarks concern Definition 1. First, while not part of the formal definition of equilibrium, we also need to make sure that the amount of defaulted debt is equal for both borrowers and lenders. We achieve this by selecting the proper value of μ, the expected loan repayment rate, in all stationary equilibria. Second, in the quantitative application of our model, we introduce multiple bank groups that differ in discount factors. Because it is a straightforward extension, we omit this heterogeneity in Definition 1 for conciseness. Finally, we also assume that the central bank's demand for reserves is perfectly elastic with a constant exogenous interest rate r^m.

4.8 Discussion of the model assumptions

This section provides a discussion of some important modeling assumptions.

Household debt Given the nature of our micro data, we focus on modeling the corporate debt only and do not allow workers to borrow. While this assumption is mostly made for tractability, it is also motivated by the facts. Household debt in Korea is considered much less risky by bank regulation than corporate debt. In particular, the risk weight assigned to the former is only one-third of the risk weight assigned to the latter (Kim and Jung , 2019). In the quantitative analysis, we only target a fraction of the banking sector that corresponds to corporate lending.

The role of workers in our environment is to provide a realistic supply of deposits for the banking sector. This part of the model could in principle be replaced with an exogenous schedule of savings (or assumed away), at the expense of the microfoundations.

Shadow lenders In Section 2 we show that, in the data, non-bank lending comes from a wide variety of institution types. In particular, they do not necessarily take deposits or have any formal ties to regulated banks. Furthermore, we do not observe shadow lenders converting into regulated banks or vice-versa. For this reason, we abstract from many aspects of shadow banking that are often emphasized by the literature such as deposit-taking, off-balance sheet entities, or maturity mismatch. Instead, our model proposes a very general theory of non-bank lending and highlights the key new feature that emerges from Section 2, namely the *endogenous formation* of shadow lenders.

No aggregate uncertainty To keep the model tractable, we do not admit any aggregate shocks in the model. Instead, in Section 6 we compute the full transitional dynamics induced by the change in bank regulation. For this reason, we do not model events such as systemic bank crises or government bailouts which are often considered as rationale for higher capital requirements (our micro-data also does not cover any such episodes). Hence, even though in Section 7 we use the model to analyze the macroeconomic consequences of Basel III, our paper does not provide a general statement on the optimal level of capital regulation.

5 Quantitative Analysis

In this section, we describe the calibration of our model and discuss the mechanics of the main policy functions and the stationary distribution. We then conduct an experiment where we increase the capital requirement by a magnitude similar to that of Basel III.

5.1 Functional forms

For the banks, similar to Bianchi and Bigio (2022), we select a standard CRRA utility function of the form $u(c) = \frac{c^{1-\gamma_b}}{1-\gamma_b}$. While banks are typically thought to be risk neutral, their owners plausibly have a consumption-smoothing motive. The consumption in this case can be thought of as a dividend paid out to stockholders. The functional form of the tax imposed for violating the capital requirement is

$$\tau(p) = \phi_0 \exp(p)^{\phi_1}$$

This non-linear specification takes small values for negative realizations of p, and increases sharply if p becomes positive. This has the advantage of producing a highly asymmetric cost while the function itself is differentiable and can be used to solve the model with first-order conditions.[32] It should be emphasized that, under this specification, a bank always faces some positive tax which becomes smaller, potentially negligible, further away from the constraint. In addition to its smoothness properties, this feature allows us to capture the reality of modern financial systems where banks build endogenous buffers over the capital requirement (that potentially depend on the risk profile of their assets), and still tend to fail them occasionally in stress tests.

[32]A functional form like this has wide applications in quantitative macroeconomics. For example, it has been very useful in the sovereign default literature as a proxy for the exogenous costs resulting from a government default (Aguiar et al., 2016).

We assume that both workers and entrepreneurs have the same preferences given by

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma}$$

The stochastic process for entrepreneurs' business productivity is

$$log(z_{t+1}) = \rho_z log(z_t) + \sigma_z \epsilon_{z,t+1}$$

Similarly, the workers' labor efficiency follows the process

$$log(y_{t+1}) = \rho_y log(y_t) + \sigma_y \epsilon_{y,t+1}$$

where both $\epsilon_{z,t+1}$ and $\epsilon_{y,t+1}$ are i.i.d. normal innovations with mean zero and standard deviations of σ_z and σ_y, respectively.

We solve the model numerically using global methods by iterating over policy and value functions of different groups of agents, and then aggregating them to find their stationary distributions. Appendix D.1 discusses the details of the numerical algorithm we use to find a general equilibrium vector of prices (r^b, r^d, w).

5.2 Calibration

To calibrate the model, we select the values for a number of parameters to replicate several empirical characteristics of the Korean banking sector, and its structure and size within the broad macroeconomy. We split the description of our procedure into banks-related parameters, and the remaining parameters.

5.2.1 Banks

In the calibrated version of our model, we assume the economy is populated by two separate bank groups, small and large, which differ by their discount factors $\tilde{\beta}_s < \tilde{\beta}_\ell$ and their (fixed) measures $1 - \lambda_\ell$ and λ_ℓ, respectively. While not needed for any of the main results of the paper, this feature adds realism to the model by mimicking the existence of DSIB and non-DSIB banks in our data.

We calibrate the parameters that govern bank behavior, summarized in Table 3, as follows. The first set of them is chosen independently from the model solution. The capital requirement κ is set to 4%, the pre-Basel III level for Tier 1 Capital Ratio. The risk aversion γ_b is set to 1 following Bianchi and Bigio (2022). The idiosyncratic shock to lenders' risky asset value ω is assumed to follow the beta distribution. An advantage of this assumption is that beta distribution has a bounded domain of $[0,1]$. We pick the two parameters of this distribution, a_B and b_B (where the expected repayment rate is $\mu = \frac{a_B}{a_B+b_B}$), along with the two parameters of the regulatory tax function, ϕ_0 and ϕ_1, the risk weight χ, and the discount factors for the two bank groups $\tilde{\beta}_k$, for $k \in \{s, \ell\}$, in a joint calibration exercise. We target the following moments from the Korean banking sector in years 2010-2013:[33] the ratios of average loans and average deposits to average equity,[34] mean and standard deviation of the realized bank capital ratios, as well as their correlation with bank equity. The former two moments inform the model about the amount of leverage in the banking sector. The latter three moments identify the restrictiveness of dividend tax on violating capital requirements, as well as the degree of non-homotheticity of that function. This

Table 3: Calibration of bank parameters

Parameter	**Meaning**	**Value**	**Source**
γ_b	Risk aversion	1	Literature
ρ	Reserve requirement	0.07	Korean data
κ	Capital requirement	0.04	Basel II
a_B	Shape parameter a	76.84	Joint calibration
b_B	Shape parameter b	0.74	Joint calibration
ϕ_0	Level parameter of penalty	16.98	Joint calibration
ϕ_1	Curvature parameter of penalty	6.94	Joint calibration
χ	Risk weight	0.78	Joint calibration
$\tilde{\beta}_s$	Discount factor - small banks	0.918	Joint calibration
$\tilde{\beta}_\ell$	Discount factor - large banks	0.926	Joint calibration
λ_ℓ	Share of large banks in bank measure	0.34	Korean data
Calibration targets		**Model**	**Data**
E(loans)/E(equity)		9.11	9.13
E(deposits)/E(equity)		8.80	8.77
E(realized cap. ratio)		10.97	10.97
St. dev. (realized cap. ratio)		1.61	1.61
Corr (realized cap. ratio, equity)		0.39	0.39
E(equity_large)/E(equity_small)		4.49	4.49
E(ROE_large)		7.65	7.65

[33]The model moments also depend on interest rates r_b and r_d. Their selection is described subsequently, in Section 5.2.2.

[34]As explained in Section 4.8, we abstract from the riskiness of household debt. For this reason, we only consider the fraction of bank equity that corresponds to the proportion of corporate loans in total lending.

allows us to capture the endogenous equity buffers over the binding capital requirements that are evident in the data (Figure 2). Finally, to pin down the discount factors of the two bank groups, we target the ratio of average equity of large-to-small banks and the average return on equity of large banks. A good fit of the former moment also allows us to externally pin down the measure of large banks λ_ℓ by setting it such that the large banks' share of total bank equity is 69.8% (corresponding to 69.4% for DSIBs in the data).

5.2.2 Workers and entrepreneurs

To calibrate the rest of the economy, we follow the standard approach of adopting some of the parameters from existing literature, and selecting others so that the model replicates several essential features of the Korean economy. The parameters that govern the behavior of entrepreneurs and workers are fairly standard and consistent with existing literature.[35] The discount factor is set to 0.96, and risk aversion is 2. The persistence of both workers' labor efficiency ρ_y and entrepreneurs' business productivity ρ_z are set to 0.8, a typical value in the literature. Similarly, the span-of-control parameter ν is set to 0.8, a standard value among the recent papers on entrepreneurship. We further use the National Accounts data for Korea to infer the depreciation rate δ of 0.075 and the standard deviation of entrepreneurs' business productivity shock σ_z of 0.5.[36] Finally, we set the weight on capital α in the production technology by assuming a labor share of 0.51, an average and fairly stationary value for Korea since the Asian financial crisis of 1997 (data from Penn World Tables). The remaining parameters, which include the standard deviation of workers' labor efficiency shock σ_y, the collateralizable share of capital φ, the unsecured credit line for entrepreneurs $\underline{a}_e$, the fixed cost of operating as a shadow lender f_S, and the measures of entrepreneurs and banks (λ_e and λ_b, respectively), are jointly calibrated to match six empirical moments. The standard deviation is identified by targeting the ratio of corporate bank loans to all corporate deposits, which is equal to 2.14 according to the Bank of Korea data (the missing deposits then come from workers' savings, the size of which is determined by the idiosyncratic labor risk they face). The collateralizable capital share and the unsecured limit are identified by matching the average share of collateralized corporate credit and the overall size of the banking sector relative to the

[35] These parameter values are commonly used in macroeconomic studies modeling the Korean economy.

[36] Specifically, using the OECD National Accounts we first infer the average capital-to-output ratio on the balanced growth path of 2.5. Fixing σ_z at 0.5 in all calibrations allows us to achieve this value approximately (we do not include this target in the moments-matching exercise to economize on computational effort). Second, we set the depreciation rate δ to match the average consumption of fixed capital to GDP, which is around 18% since 2000 according to the OECD data for Korea.

economy,[37] while the fixed cost is pinned down by matching the fraction of shadow loans in total corporate credit of about 43% (which is inferred from the data shown in Figure 1). We further inform the two measures by targeting the average pre-reform loans and deposits interest rates of 3.44% and 1.64%, respectively. Finally, we make sure that the model is internally consistent by setting the default probability ξ so that the total loans defaulted on by the borrowers are equal to the total loans written-off by the lenders. Table 4 summarizes the calibration of the general economy in the model.

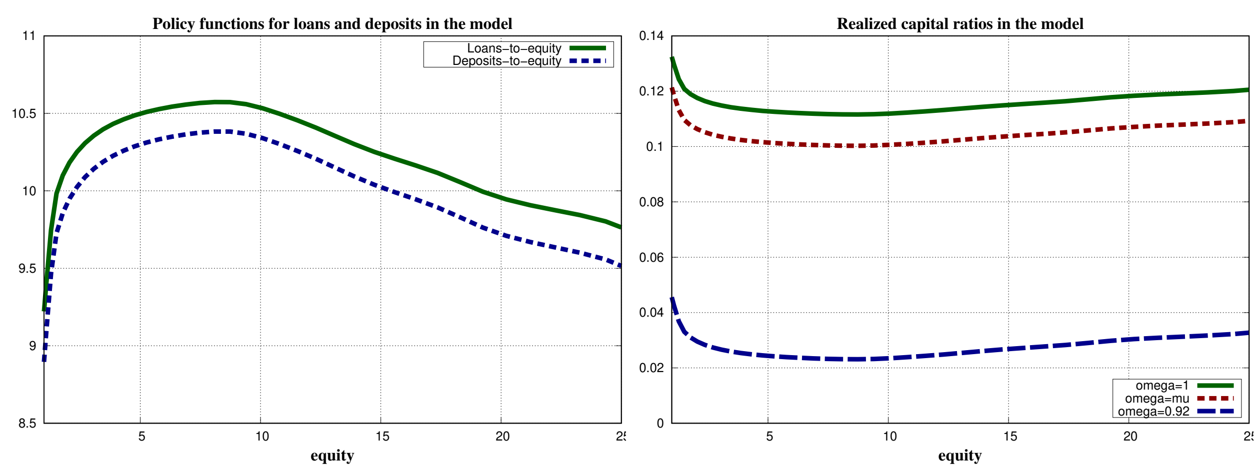
Table 4: Calibration of the parameters of general economy

Parameter	**Meaning**	**Value**	**Source**
γ	Risk aversion	2	Standard value
β	Discount factor	0.96	Standard value
ρ_y	Persistence of worker efficiency	0.8	Standard value
ρ_z	Persistence of firm productivity	0.8	Standard value
ν	Span of control	0.8	Standard value
δ	Depreciation	0.08	Korean data
α	Capital share	0.36	Labor share of 0.51
σ_z	St. dev. of firm productivity	0.5	Capital-to-output
σ_y	St. dev. of worker efficiency	0.11	Joint calibration
φ	Collateralizable share of capital	0.42	Joint calibration
$\underline{a}_e$	Unsecured credit line	−10.19	Joint calibration
f_s	Fixed cost to shadow lending	0.46	Joint calibration
λ_b	Mass of banks	0.001	Joint calibration
λ_e	Mass of entrepreneurs	0.027	Joint calibration
ξ	Default probability	0.02	Joint calibration
Calibration targets		**Model**	**Data**
Corp. bank loans to deposits ratio		2.23	2.14
Share of collateralized corp. loans		0.52	0.54
Bank equity / output ratio		4.43%	4.30%
Fraction of shadow loans		42.69%	42.70%
Interest rate on loans		3.44%	3.44%
Interest rate on deposits		1.64%	1.64%
Defaulted loans balance		0.00	0.00

[37] Because our model ignores household debt, we target a fraction of bank equity that corresponds to corporate loans only. According to the data from the Bank of Korea, total bank equity to GDP in 2013 was 7.6%. Then, with corporate loans taking up 56.5% of all bank lending, we choose to target an aggregate equity to output of 4.3%, correspondingly.

5.3 Model mechanics

Banks decisions We first analyze the mechanics of a bank's decision making in the model, visualized in Figure 8. Panel 8(a) depicts the policy functions for loans and deposits (relative to equity) at different levels of bank equity. The main observation here is that banks' decisions are highly non-linear with respect to equity, with small banks being more leveraged and large banks investing less overall and contributing a larger share from their own capital. This contrasts with the result of Bianchi and Bigio (2022) where all policy functions are linear in equity. The curvature in our model is due to the non-homothetic nature of the regulatory tax function. Small banks must build up equity to create a safe buffer above the requirement.[38] On the other hand, large banks are exposed to a disproportionately higher penalty in the event of a bad shock to loan value and hence prefer to decumulate some of their equity. Indeed, this non-homotheticity is consistent with the spirit of Basel regulations which have mandated that the largest ("systemically important") banks be put under a special supervision and subjected to an additional capital requirement. We capture this mandate with our non-homothetic specification of the penalty function and discipline its parameters by targeting the correlation of equity with realized capital ratios in the calibration.



(a) Loans and deposits (b) Capital ratios

Figure 8: Bank policy functions in the model

[38]The non-monotonicity in policy functions results from the trade-off between the need to accumulate equity, induced by the non-homothetic penalty tax function, and the desire to consume. At lowest equity levels the bank is desperate to build up equity at the expense of consumption. Once it attains a level that provides insulation from punitive tax realizations, it can afford more dividend consumption and higher realized capital ratios.

Capital ratios The effect of capital requirements on bank behavior can be further appreciated by inspecting Figure 8(b) which presents realized capital ratios as function of current equity, for different realizations of the idiosyncratic shock ω. Notice that banks tend to maintain sizable equity buffers over the required minimum, with the average buffer in fact being a targeted moment in our calibration. Hence, for a wide range of likely realizations of the ω shock, capital requirements are seemingly non-binding for most banks.[39] Moreover, while the realized ratios generally increase with the level of equity, there is a notable interval of non-monotonicity due to the trade-off between the need for equity-building and consumption. This non-monotonicity is helpful in achieving the targeted low (but positive) correlation between equity and capital ratios.

Formation of shadow lenders We next consider the behavior of firms in our model, with a focus on the determinants of shadow lender formation in the economy. Figure 9 presents the decision rule of entrepreneurs as a function of the two state variables, wealth and productivity. Intuitively, the firms who have high productivity but do not own enough wealth tend to be borrowers. Holding a productivity level fixed, as the

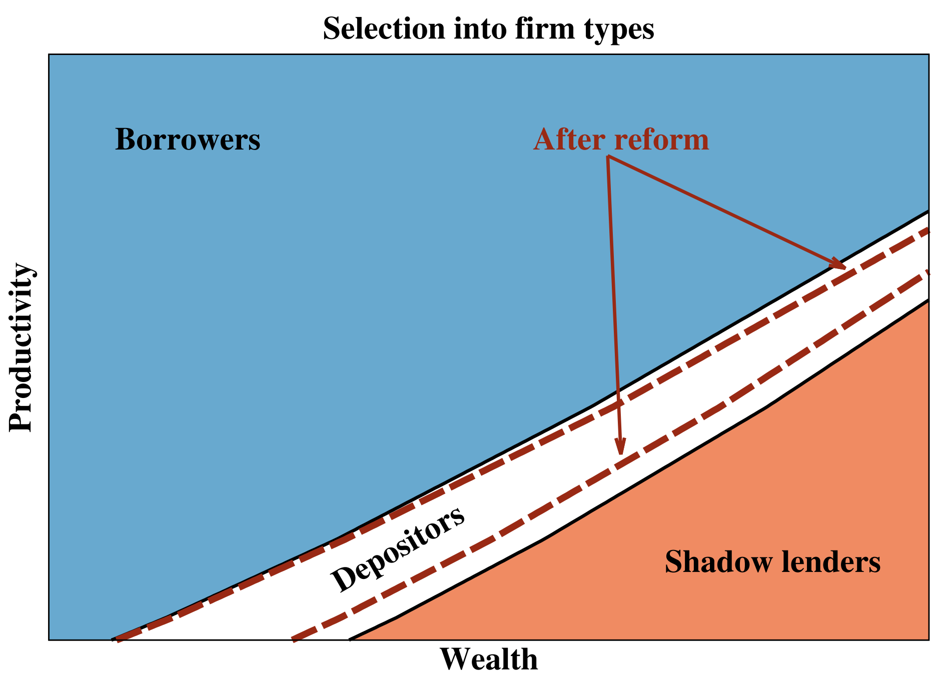


Figure 9: Endogenous selection into borrowers and shadow lenders in the model

[39] In reality, most of the incidents of non-compliance with capital regulation is detected through bank stress-testing. The financial supervisor simulates capital ratios under a range of hypothetical scenarios that aim to mimic large or systemic shocks to the financial system. Because our model does not admit such events, we capture stress-testing in the reduced-form way with our regulatory tax function $\tau(\cdot)$.

wealth of an entrepreneur increases he borrows less and less, until he finally decides to deposit some of the financial assets in a bank account. On the other extreme, the firms who are not very productive but have high wealth tend to become shadow lenders, lending out excess cash that cannot be used productively in their core business. The dashed red lines in the figure illustrate how the two decision thresholds change in the aftermath of a reform that raises the capital requirement for banks. In particular, the outer threshold moves to the left, which implies that former depositors are now becoming shadow lenders.[40] This occurs despite the fact that firms in our model are not directly connected to the banking sector in any way. As the next section will show, these shifts occur due to the changes in general equilibrium interest rates.

5.4 General equilibrium effects of higher capital requirement

Before reform The first column of Table 5 shows the general equilibrium of our model under a baseline capital requirement of 4%. All quantities are expressed relative to average pre-reform bank equity which is normalized to 100. In this benchmark economy, bank loans are roughly 9 times the equity level. Loans from shadow lenders make up

Table 5: Comparison of stationary equilibria before and after the reform

	Before reform	After (PE)	After (GE)	After (GE-CF)
Capital requirement	4%	8.5% (+1%)	8.5% (+1%)	8.5% (+1%)
Banks				
Equity	100.00	9.52	104.76	129.94
Loans	910.56	64.64	722.45	882.49
Capital ratio (%)	10.97	20.42	15.15	15.25
Shadow lenders				
Loans	678.23	678.23	848.68	657.24
Share in all loans (%)	42.69	91.30	54.02	42.69
Share in all firms (%)	6.23	6.23	8.74	5.77
r_b (in %)	3.44	3.44	3.48	3.56
r_d (in %)	1.64	1.64	1.44	1.49
$w \times 100$	29.51	29.51	29.50	29.49

Note: GE-CF refers to the general equilibrium economy in a counterfactual scenario where the rise of shadow credit is suppressed ("No rise of shadow lending"). All post-reform equilibria feature an additional 1% requirement for the large banks (with a higher discount factor).

[40] While the outer threshold always shifts to the left, the direction of the shift of the inner threshold depends on parametrization. This is because a higher interest rate spread that arises as a consequence of the reform (see Table 5) makes it less attractive both to become a borrower and a depositor.

about 43% of all lending and just over 6% of all entrepreneurs choose to engage in this activity. The loan and deposit interest rates which clear the asset markets are the targeted values of 3.44% and 1.64%, respectively. The spread of 1.8 percentage points between them reflects the banks' investment risk, and regulatory frictions such as reserve and capital requirements.

Partial equilibrium We now use our model to analyze the effects of a capital requirement reform. For now, we abstract from any effects along a transition path (which we postpone until Section 6) and instead calculate the new stationary distribution under the requirement of 8.5% (mimicking Basel III).[41] As a first step, the second column of Table 5 presents the partial equilibrium results, i.e. the invariant distribution under fixed prices. Notice that higher capital requirement causes the regulated banking sector activity to collapse in the long run,[42] while credit from shadow lenders remains unchanged. This is because the reform does not affect shadow lenders in any way, and the equilibrium prices are held constant.

General equilibrium The third column of Table 5 summarizes the new general equilibrium in which a price vector is found such that all markets clear.[43] In this equilibrium, average bank equity is about 5% higher than before reform while bank loans fall by about 20%. Naturally, the price vector that supports this equilibrium includes a higher interest rate on loans and a lower interest rate on deposits. These new interest rates in turn change the incentives of entrepreneurs who are discouraged from saving with banks, and instead find it more attractive to engage in shadow lending. In our calibration, the shadow lending sector is very responsive to this change, leading the total shadow loans quantity to increase by 25%, while the fraction of credit extended by such lenders rises to 54% of total. At the same time, the fraction of entrepreneurs who decide to operate as a shadow lender increases from 6% to 9%, i.e. we observe an entry of new firms into the business of shadow lending as a result of the reform, consistent with the evidence from our data.

No rise of shadow lending The last column of Table 5 presents the post-reform equilibrium in the counterfactual scenario in which, along with the baseline reform, the gov-

[41]We also assume that large banks (ones with a higher discount factor) face an 1 percentage point requirement, i.e. 9.5% total.

[42]In Appendix E.5, we show that this decline is caused by a significant increase in the regulatory tax rates faced by the banks due to the calibrated non-linearity in the tax function.

[43]We also need to find a new value of $1-\mu$ in the post-reform equilibrium, the mean fraction of credit that the lenders write off. In practice, the change in this variable needed to make sure that defaulted loans balance out is negligible (relative to the parameters in Table 3), which is why we do not report it here.

ernment also elevates the fixed cost of being a shadow lender f_S, to prevent the share of shadow loans from increasing. This scenario is motivated by the fact that the recent rise of shadow finance has been perceived by many as an unwelcome and potentially destabilizing force.[44] The cost increase of 36% guarantees that the share of shadow loans is the same as in the pre-reform economy (i.e. the government suppresses the boom in this sector). The goal of this counterfactual is to illustrate the role of the general equilibrium response of shadow credit to the capital requirement reform. As Table 5 shows, banks are forced to accumulate much more equity and they lend more, attracted by an even higher interest, while shadow lenders become less numerous and lend less.

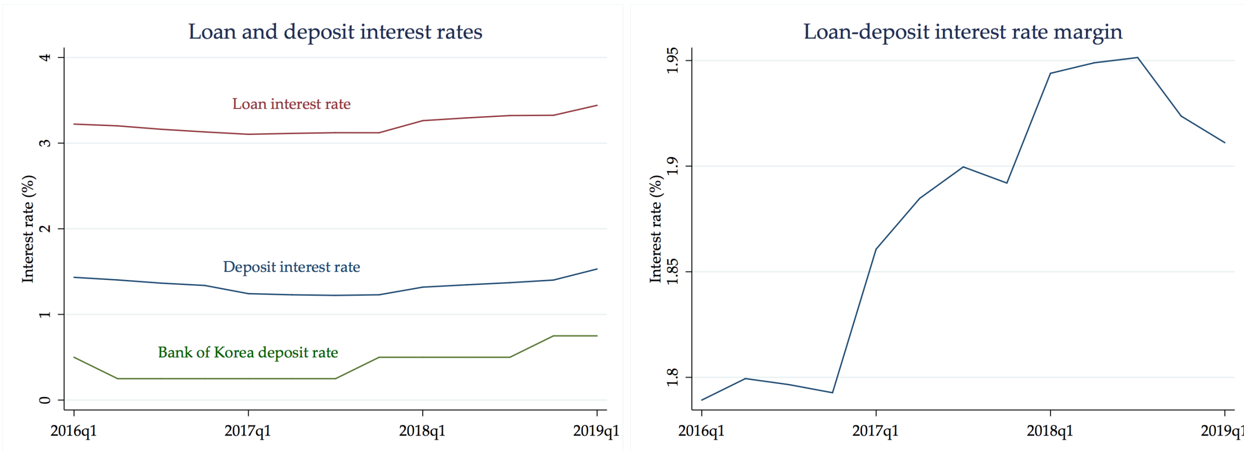
Appendix E provides a more comprehensive macroeconomic analysis of the distributions of banks and firms in the stationary equilibria before and after the reform. It also shows a list of key untargeted moments for the calibrated pre-reform economy and discusses their fit with the data.

5.5 Aggregate interest rates in the data

As is clear from Table 5, the rise of shadow lenders in our model is driven by the change in general equilibrium interest rates that results from the new capital requirement. In this section, we provide empirical validation for this channel by examining interest rate movements in Korea over the time period of interest. Figure 10(a) plots the evolution of loan, deposit and a reference risk-free interest rate in years 2016-2019, while Figure 10(b) calculates the corresponding loan-deposit interest spread. The rates are averages across regulated banks and weighted by their share in total credit.[45] As can be noticed, the rates do not vary significantly during this period, but the spread indeed increases sharply in 2016, right when the reform becomes binding and the largest shifts in the volumes of corporate credit occur. At its highest point, the loans-deposits spread reaches 1.96% which can be referenced against the prediction of our model in Table 5 of 2.04%.

[44]See e.g. "Shadow Banks Need Regulation to Rein in Financial Risks", *Bloomberg*, November 1 2019; or "The clean-up of the non-bank sector needs to begin now", *Financial Times*, April 19 2020. In practice, this could be achieved by tightening the regulation and supervision of other financial sectors such as insurance. As a simplification, we assume that all such efforts collectively materialize in the model as higher fixed cost.

[45]Due to data limitations, these interest rates are only available for regulated banks, and not the shadow lenders. Given our model assumption that loans from shadow lenders are perfect substitutes to loans from regulated banks, this should not be an issue.



(a) Interest rate levels (b) Difference

Note: Data of interest rates from Financial Supervisory Service (fisis.fss.or.kr). All interest rates are weighted by the total credit in data. Sample includes regulated banks, excluding special banks. Bank of Korea deposit rate is Base rate - 100bp, sourced from Bank of Korea.

Figure 10: Interest rates for regulated banks in the data

6 Transitional dynamics: model meets data

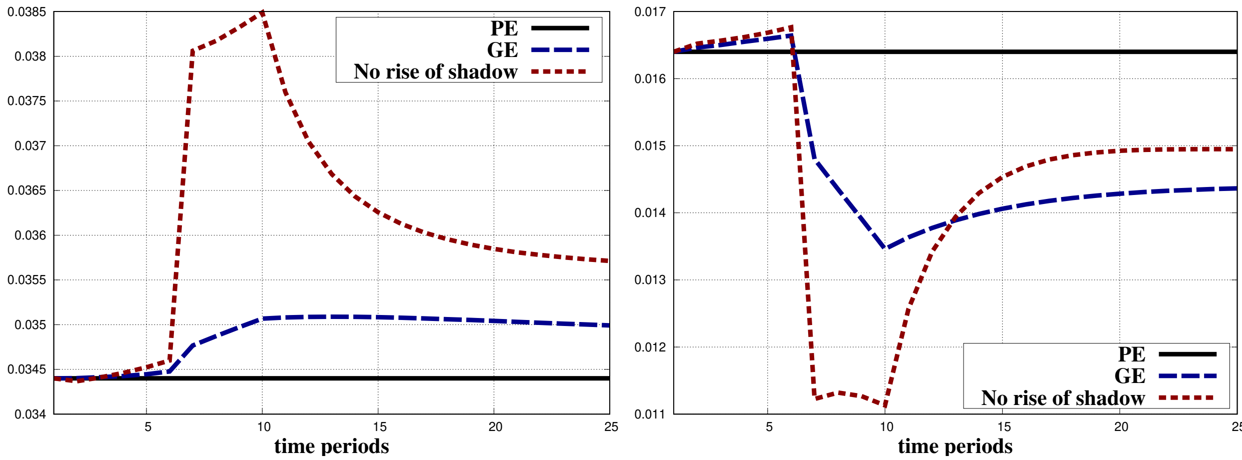
In this section, we link the results from our model to the estimated impact of higher capital requirements on regulated bank lending and shadow lending in Section 3. To do so, we calculate the transition between the two stationary equilibria induced by the reform. As it is standard in the literature, we assume the transition is deterministic, i.e. all agents have perfect foresight as for the future path of prices from the moment they find out about the reform.[46] We make the transition as realistic as possible by assuming that the reform is announced in 2010 and follows the schedule of increases just as described in Table 1 (we ignore the non-binding period prior to 2016). Starting from 2019, the new permanent capital requirement is 8.5%, with an additional one percentage point requirement imposed on the large banks.

6.1 Prices and aggregates over the transition

Figure 11 shows the paths of market-clearing interest rates on loans and deposits over the transition between the two steady states, for the baseline reform as well as the “no rise of shadow lending" scenario. It should be noticed that the spread between these two rates increases slightly more on impact of the reform than what the mere comparison of

[46] Appendix D.2 describes the details of the algorithm we use to compute the transition.

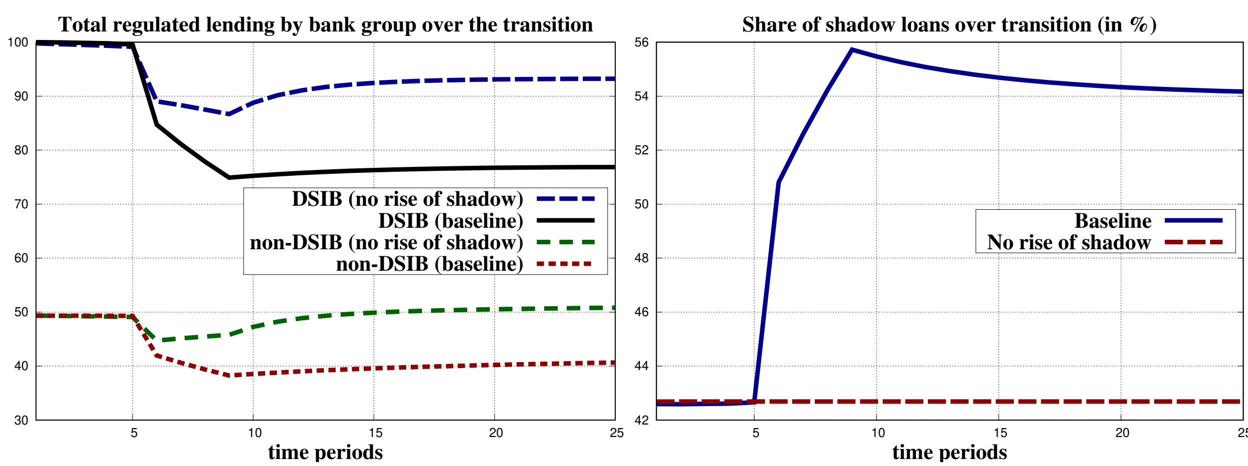
the stationary equilibria in Table 5 suggested (the maximum predicted spread is around 2.16%). The response of prices in the world with no rise of shadow lending is much larger than in the baseline so that regulated banks have incentive to supply enough credit.



(a) Interest rate on loans
(b) Interest rate on deposits

Figure 11: General equilibrium interest rates over the transition

Figure 12 presents the normalized paths of regulated bank lending. Panel 12(a) shows that total lending drops fast for both bank groups on impact of the reform. In the "no rise of shadow" scenario, however, the decline in lending is only about a half of the decline under the baseline reform. On the other hand, panel 12(b) shows that the share of shadow loans in total credit expands to 56% at the peak, before reverting back and gradually converging to around 54% as predicted by the new stationary equilibrium. By construction,

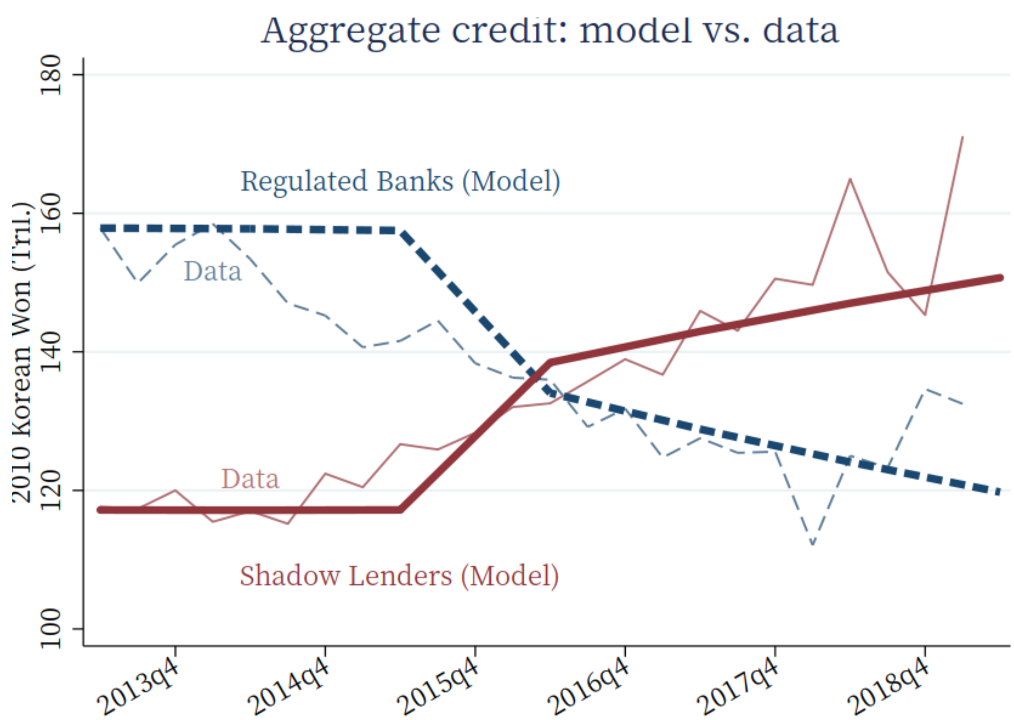


(a) Total bank lending by bank group
(b) Share of shadow loans

Figure 12: Equilibrium lending over the transition

the share of shadow credit is kept constant in the counterfactual scenario (Figure 31(a) in Appendix D.2 shows the sequence of fixed costs needed to generate it).

Figure 13 presents a synthesis of these results by constructing the model counterpart to our main observation from Figure 1. It plots the total credit extended by regulated banks and shadow lenders over the period of the transition path that corresponds to years 2013-2019. For comparison, we include the data series originally shown in Figure 1. The picture conveys our main finding that Basel III explains almost all of the decline in regulated bank lending, and about three quarters of the observed increase in shadow financing.[47]



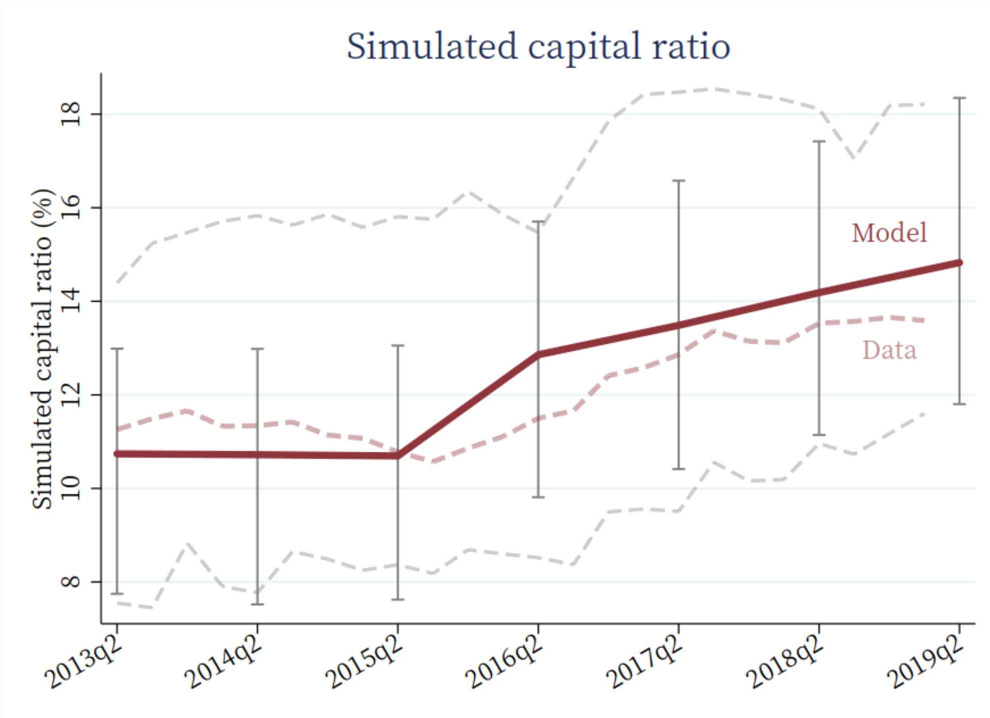
Note: Thick lines depict the transition of total credit from regulated banks and shadow lenders predicted by the model. Thin lines show the data counterpart from Figure 1. Both model-generated series are normalized by the total regulated bank credit observed in the data for 2013Q2. Because the former is in annual frequency, we associate each year in the model with the second quarter.

Figure 13: Total credit from regulated banks and shadow lenders in the model

Figure 14 constructs the model counterpart to our empirical observation on the behavior of bank capital ratios in Figure 2. It plots the distribution of realized capital ratios in the model for the periods of the transition that correspond to years 2013-2019. Recall from

[47] The mismatch in years 2014-2015 indicates that the change in credit provision in anticipation of the reform was potentially stronger in reality than what our model predicts.

Section 5 that the mean and standard deviation of capital ratios are targeted moments in our calibration for the pre-reform stationary equilibrium. As Basel III becomes binding in 2016, the whole distribution of capital ratios moves upwards similarly as in the data, with the median increasing to about 15% (in the data, the median is around 14% in 2019Q1).[48]



Note: The solid red line represents the capital ratio of a median bank. The gray bars stretch from the 5-th to 95-th percentile of realized capital ratios in the simulated sample. Dashed lines represent the data median (red), min and max (gray) capital ratios.

Figure 14: Realized bank capital ratios in the model simulation

6.2 Micro estimates in the model

We now use the model to estimate the impact of higher capital requirements on the credit provision by regulated banks and non-bank shadow lenders. To do so, we simulate a large number of banks along with a large number of entrepreneurs and track them over the transition. Then, we run the model-analogs of regressions (1) and (3), which we used in our econometric analysis, for the corresponding time period, and we compare the results.

[48]One reason for why the median in our model overshoots the data could be because many banks still had elevated capital buffers in the aftermath of the Global Financial Crisis in years 2010-2013, the period of time we are targeting. So, during our sample period, while many banks increased their capital ratios to comply with Basel III, they may have simultaneously reduced their buffers in response to the expansionary phase of the business cycle.

Table 6 shows the estimation results for regression (1) using our simulated bank data. We run several variants of this specification, in particular we include bank fixed effects or not.[49] Similarly as in the data, we find consistent and strongly negative coefficients on the capital requirement. The first two columns show that the size of this coefficient is –0.114, which falls well within the confidence interval of the original estimate of –0.14 found with the micro data (Table 2). It should be emphasized that our model does not use any information from the micro data in its construction or calibration.

Table 6: Effects of capital requirements on credit growth in model simulated data

	General Equilibrium		**Partial Equilibrium**		**No Rise of Shadow**	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Δ ln loans	Δ ln loans	Δ ln loans	Δ ln loans	Δ ln loans	Δ ln loans
ln cap. req.	-0.114***	-0.114***	-0.162***	-0.161***	-0.0294***	-0.0299***
	(0.0020)	(0.0016)	(0.0020)	(0.0017)	(0.0020)	(0.0017)
ω	-1.965***	-0.076	-1.961***	-0.040	-1.777***	0.015
	(0.0594)	(0.0519)	(0.0628)	(0.0530)	(0.0626)	(0.0544)
Constant	2.098***	0.227***	2.162***	0.258***	1.795***	0.022
	(0.0584)	(0.0513)	(0.0619)	(0.0524)	(0.0620)	(0.0540)
Observations	60,048	60,048	60,048	60,048	60,048	60,048
Fixed Effects	Bank	None	Bank	None	Bank	None
R2	0.212	0.0601	0.245	0.105	0.160	0.0045

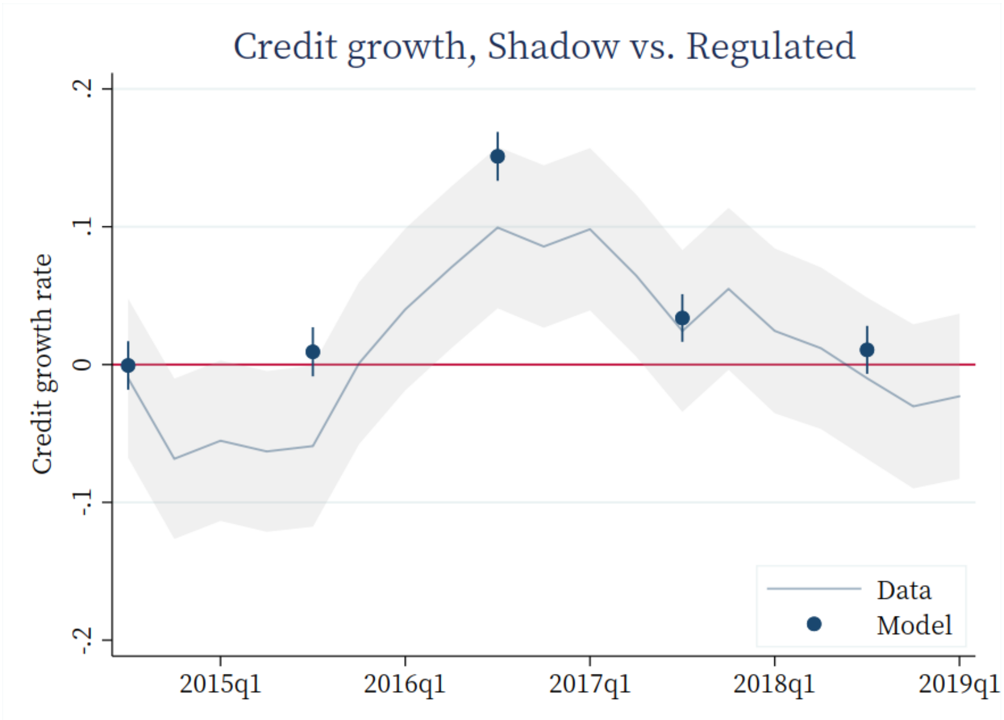
Note: Because our actual data ends at 2019Q1, we only use the years 2013-2018 in these model-based regressions. All standard errors (in parentheses) are clustered at the bank level. *** $p<0.01$

We next run regression (3), which estimates the spillover effect of the change in capital regulation on shadow credit growth, using a panel of simulated entrepreneurs generated by the model. Similarly as for the empirical data, we include time and lender fixed effects.[50] Figure 15 presents our results in the form of a graph that is a direct counterpart to Figure 4. Before the reform becomes binding in 2016, the growth of credit provided by shadow lenders does not significantly out-pace the one by regulated banks. This changes

[49] Because we do not have direct matching between banks and firms, controlling for ω, the shocks to banks' loan value, is the closest counterpart to firm fixed effects that we can include in our data regressions. We also ran all of the regressions without controlling for ω, and the estimated coefficient of interest is essentially the same.

[50] Naturally, in the simulated data we observe agents becoming shadow lenders and exiting in every period. Because the regression uses log differences, we only include agents in the sample if they have remained a shadow lender for at least two consecutive periods.

in 2016 when the capital requirement increases for the first time on our transition schedule, leading to a coefficient estimate of 0.15. This point estimate is somewhat larger than the 0.1 one we found in the data, but still within the 95% confidence interval. The spillover effect in the model then dissipates along with the data estimates in years 2017 and 2018.



Note: The navy line represents estimated coefficients from the data (Figure 4), and the gray area represents the 95% confidence interval of estimated coefficients. The navy dots and bars represent model estimates and their 95% confidence intervals, respectively. Annual estimation from the model is assigned to the third quarter of each data coefficient. All coefficients are estimated relative to the year 2013.

Figure 15: Estimated interaction effects of time and shadow dummies: model vs. data

6.3 The role of general equilibrium and shadow finance

We now investigate the role of the two main features of our model, a general equilibrium response and the resulting rise of the shadow credit, in shaping the impact of capital regulation on bank lending. Columns 3-4 of Table 6 present the results of running our headline regression (1) on the model-generated data in partial equilibrium, i.e. assuming the price vector stays constant. The coefficient of interest is –0.16, about 40% larger in absolute value than in the baseline but still well within the confidence interval of the empirical estimate (Table 2). This means that in the short run (and at the micro level), a partial equilibrium version of our banking model performs quite well. By contrast, Table

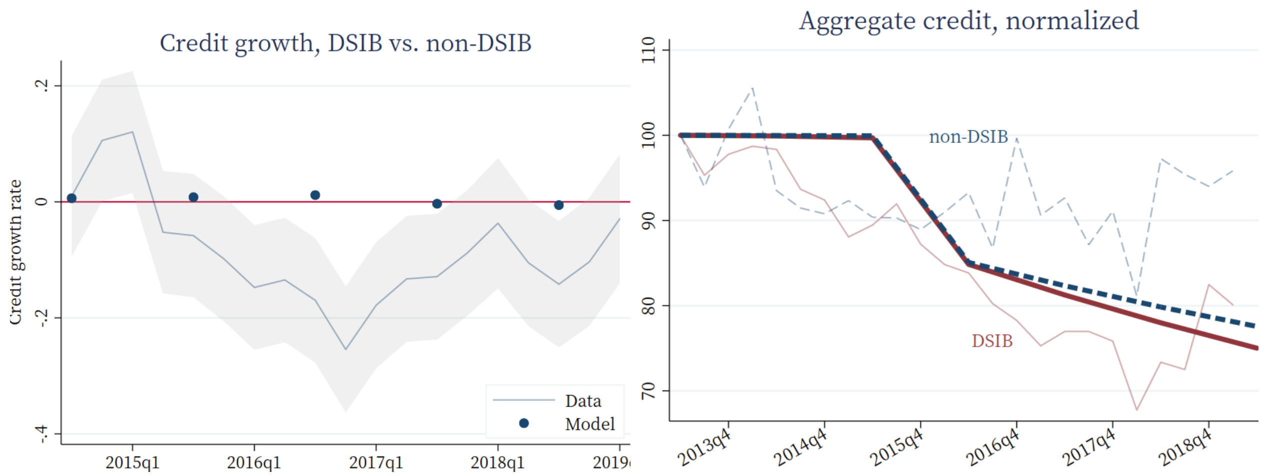
5 presents steady-state results, where regulated banking activity collapses in the long run without a general equilibrium adjustment. Columns 5-6 of Table 6 show analogous estimates in the counterfactual scenario where the rise of shadow lending is suppressed. The coefficient of interest is –0.03, about a quarter of the value obtained using our baseline model and far outside the confidence interval of the empirical estimate. This implies that, in general equilibrium, it is crucial to include a competitive non-bank lending sector to achieve realistic estimates of the reform's impact. The intuition is that, as Figure 11 shows, the general equilibrium price adjustment is too large when shadow credit is suppressed, inducing banks to accumulate equity faster and reduce lending by less (Figure 12(a)).

6.4 Effects on Domestic Systemically Important Banks (DSIBs)

In Section 3.2 we show that, in addition to the spillover effect on shadow lending, Basel III also differentially impacted those regulated banks with a designation as Systemically Important (DSIB). Because our model features two groups of heterogeneous banks, large and small, we can also analyze this margin theoretically. What aspect of the reform causes the divergence between DSIBs and non-DSIBs in 2016?

In line with the Korean implementation of Basel III, our baseline model features an additional one percentage point capital requirement imposed on the large banks. Hence, we now use the panel of simulated banks over the transition to estimate regression (2). Similar to Figure 3, panel 16(a) below plots the evolution of the estimated time effects interacted with the DSIB dummy. As can be noticed the result is null - on margin, small banks in the model get no advantage in terms of credit growth over the course of the reform implementation. Panel 16(b) illustrates why this is the case by plotting the (normalized) paths of aggregate lending by both bank groups. The reform affects both groups rather symmetrically, with DSIBs experiencing a smaller reduction in lending than in the data, and non-DSIBs a larger one. In other words, we find that the additional one percentage point capital requirement imposed on the largest banks has a small impact and cannot explain the rift between DSIBs and non-DSIBs caused by Basel III.

So what explains the differential impact of the reform on large and small banks? In addition to "higher loss absorbency" mandate (implemented in Korea with an additional capital requirement), the Basel Committee on Banking Supervision also proposed alternative policy tools for regulating systemically important banks, such as "more intensive



(a) Estimated marginal effects (b) Aggregate lending (normalized)

Note: (Left panel) The navy line represents estimated coefficients from the data (Figure 3), and the gray area represents the 95% confidence interval of estimated coefficients. The navy dots and bars represent model estimates and their 95% confidence intervals, respectively. Annual estimation from the model is assigned to the third quarter of each data coefficient. All model coefficients are estimated relative to the year 2013. (Right penal) Thin solid and dashed lines are data aggregate credit by DSIB and non-DSIB, respectively, normalized to 100 in 2013Q2 (Figure 27). Thick lines are model counterparts, where each year in the model is associated with the second quarter in the data.

Figure 16: DSIB vs. non-DSIB lending in the model - baseline

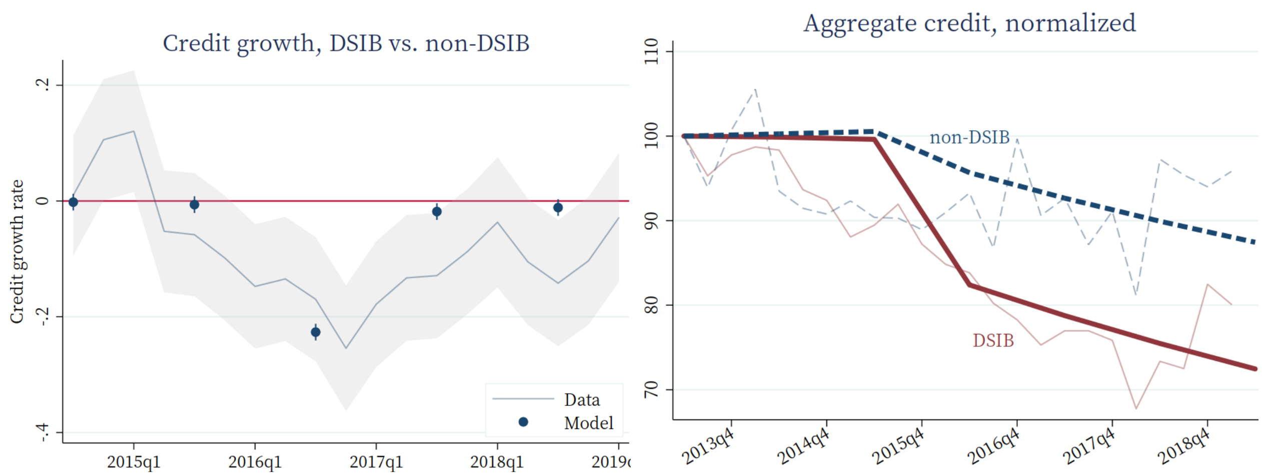
supervision".[51] While Korean regulators generally adopted the framework laid out by Basel III,[52] it is unclear to what extent they relied on such alternative tools because, unlike the minimum capital ratio requirement, they are not based on any quantitative indicators.

To shed more light on the source of the reform-induced decline of DSIBs, we now conduct an experiment where we introduce bank group-specific parameters ϕ_0 and ϕ_1 of the regulatory tax function τ. We engineer the differential values of these parameters to achieve a better fit of the model, both in terms of the estimated marginal effect (regression (2)) and aggregate trends.[53] Figure 17 presents the results of this exercise, which can be easily compared to the baseline results in Figure 16. As is evident, the more intensive super-

[51] *A framework for dealing with domestic systemically important banks*, Basel Committee on Banking Supervision, October 2012.

[52] Financial Supervisory Service (fisis.fss.or.kr), Policy Announcement on June 4th 2015.

[53] Ideally, we would select such parameters in a structured moment-targeting exercise, and match the observed divergence between DSIBs and non-DSIBs exactly. Unfortunately, this is challenging because finding a single post-reform general equilibrium along with the entire transition path is computationally burdensome (as detailed in Appendix D). Hence, for the sake of illustration, we present the results of a trial-and-error approach that matches the empirical findings approximately. The parameters of the tax function employed here are ($\phi_0 = 25$, $\phi_1 = 10$) for DSIBs, and ($\phi_0 = 3$, $\phi_1 = 2$) for non-DSIBs.



(a) Estimated marginal effects (b) Aggregate lending (normalized)

Note: (Left panel) The navy line represents estimated coefficients from the data (Figure 3), and the gray area represents the 95% confidence interval of estimated coefficients. The navy dots and bars represent model estimates and their 95% confidence intervals, respectively. Annual estimation from the model is assigned to the third quarter of each data coefficient. All model coefficients are estimated relative to the year 2013. (Right penal) Thin solid and dashed lines are data aggregate credit by DSIB and non-DSIB, respectively, normalized to 100 in 2013Q2 (Figure 27). Thick lines are model counterparts, where each year in the model is associated with the second quarter in the data.

Figure 17: DSIB vs. non-DSIB lending in the model - differential tax parameters

vision of DSIBs indeed has the power to explain the observed rift between the two bank groups, both in aggregate and on the margin. While the result of this exercise is engineered, as opposed to obtained as endogenous outcome of the model, it is nevertheless illuminating. It shows that the reform mostly impacted large banks through disproportional supervision intensity, while the additional capital requirement imposed on these banks by Basel III had a rather minor effect, at least in the short run.

What does this “more intensive supervision" translate to quantitatively? We answer this question by measuring the realized regulatory tax rates. In the baseline post-reform equilibrium, small and large banks face average tax rates of 4.65% and 1.42%, respectively, down from 7.85% and 1.94% before the reform. Under the disproportionate supervision, these averages revert to become 2.81% and 3.12%.

7 Macroeconomic effects of bank regulation

In this section, we briefly illustrate the broader macroeconomic effects of capital regulation on the transition path induced by Basel III, with further details in Appendix E. To highlight the role of shadow lenders in the economy, as well as the role of the reform design and implementation, we analyze several scenarios:[54]

1. **No rise of shadow:** As described in Section 5.4, along with introducing higher capital requirements, the government simultaneously increases the fixed cost of operating as a shadow lender, f_S, to prevent the share of shadow loans from increasing;

2. **No extra DSIB buffer:** Baseline reform without the additional capital requirement imposed on the large banks;

3. **No anticipation:** The reform is introduced without prior announcement, i.e the reform schedule unexpectedly kicks in in 2016.

Figure 18 plots the paths of total output under the three scenarios. We find that, first of all, the baseline increase in capital requirement has a modest impact on GDP in the economy. This effect is marginally worse under the alternative implementation schedule, where the increase takes the form of a one-time jump and is announced without anticipation. In both cases, the largest drop in output is below 0.1%. On the other hand, output drops by 0.25% in the world where the government simultaneously prevents the expansion of shadow lenders by imposing a higher fixed cost on them.

More generally, although higher capital requirements lead to rather dramatic shifts in the financial intermediation markets, we find that their quantitative effects on the real economy are limited. While that is a result in itself, it may also be caused by some features of the model. The main issue potentially arises from the assumption of full commitment to repay loans by borrowers (apart from the non-strategic default). As a result, the most productive entrepreneurs may not borrow enough to invest an efficient amount of physical capital due to being liable for possible losses with their own wealth. In addition, entrepreneurs in our model are able to switch between physical and financial capital without any adjustment costs. Extending the model to overcome these limitations is plausible but would come at the expense of complicating the analysis and the computation.

[54]More detailed description of scenarios 2 and 3 are included in Appendix E.4.

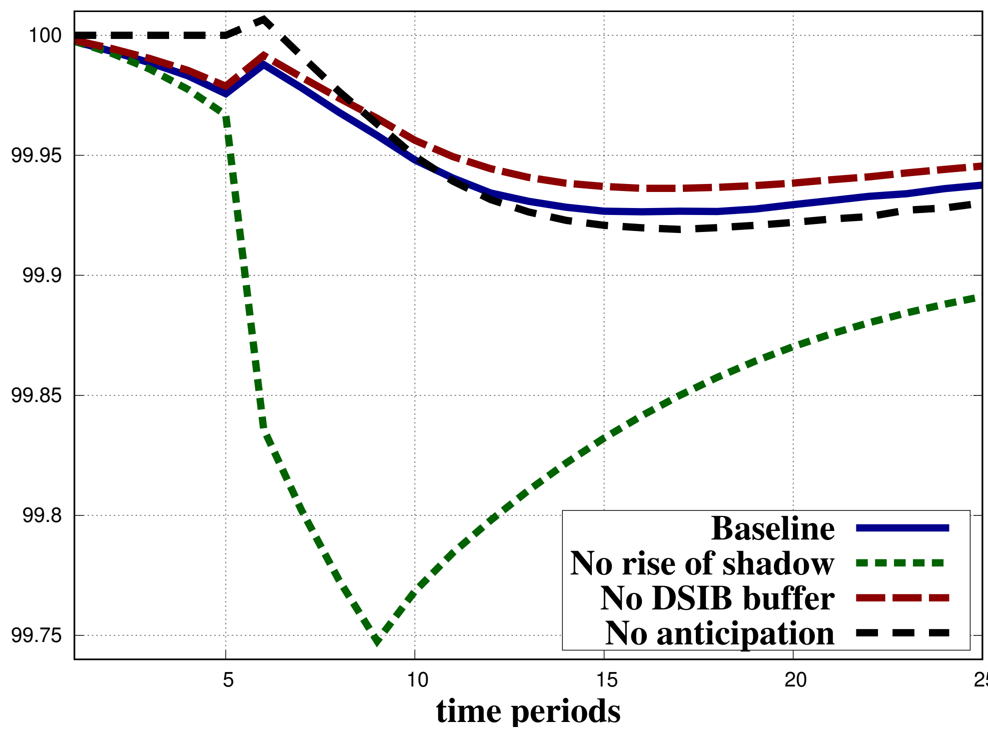


Figure 18: Output paths over transition under different scenarios

8 Conclusion

In this paper we document that the implementation of Basel III reforms in South Korea coincided with a 25% decline in lending to corporations by regulated banks, and a similar increase in lending from the shadow sector. We estimate the strongly negative effect of capital requirements on corporate credit growth at the bank-firm level, and a positive effect on non-bank (shadow) lending. We then corroborate these findings in a general equilibrium model with heterogeneous banks and firms. While our empirical work and the model are fully independent from each other, both produce consistent quantitative results. Our main finding is that Basel III can account for most of the observed decline in regulated bank lending, and about three quarters of the increase in shadow lending.

The significance of our work lies in helping us understand and quantify the unintended consequences of the new regulatory framework such as Basel III on credit markets. Any future changes in bank capital requirements, for example Basel IV, must take these effects into account. While we do not directly address the question of the optimal level of capital requirement, the current paper can be used to inform future research about the quantitative impact of such changes on financial intermediation markets.

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Appendices

A Further information on credit data

In this section, we provide various additional details regarding our main dataset.

A.1 Summary statistics

Table 7 presents summary statistics of the matched credit data from South Korea. Under **Credit level**, we describe the (firm $\times$ lender $\times$ time) observations of credit both in level (*total credit*) and log differences ($\Delta \ln$ *total credit*). Only observations with positive credit are recorded.[55] We hand-collected information on mergers between lenders and imputed them in the data. More specifically, if lender A is merged with lender B at time t, we add any credit from lender A to lender B starting from time $t + 1$. There was one notable merger between two large commercial banks in 2015Q3 (Hana Bank and Korea Exchange Bank merged to KEB Hana Bank), and we treat this case separately from other mergers. Since the merger has been approved by the regulators in 2012 and negotiations have been underway throughout our sample period, we treat the two banks as one for the entire sample period. By doing so, if a firm borrows from both Hana Bank and Korea Exchange Bank before 2015Q3, we sum up two credit observations and treat it as one observation associated with KEB Hana Bank. All growth measures and log differences are at annual frequency and all levels are deflated using GDP deflator with base year 2010.

In the next block of the summary statistics, **Lender level: regulated banks**, we describe regulated banks' aggregate credit level at each time period as well as their balance sheet information.[56] This part contains domestic commercial banks excluding special banks, and foreign bank branches.[57] These summary statistics are again based on an unbalanced panel, selecting only the banks with a positive amount of credit in the data. We report only aggregate credit level for non-banks (**Lender level: shadow lenders**), mainly because we could collect their balance sheets only for some parts of the observations.[58]

[55] The observations do not include any credit from special banks and 5 benefit societies (Gong-je-jo-hap), which entered only part of the sample period

[56] Bank balance sheet information was obtained from Financial Statistics Information System.

[57] Discrepancies in observation numbers of total credit and balance sheet info occur in foreign bank branches. After bank branches exit (e.g. BBVA branch), outstanding credit may still show up on the credit data. There is one takeover of foreign branch: the RBS PLC branch took over the existing operation of the RBS branch starting from 2013Q4. We treat observations of RBS before 2013Q4 with RBS PLC, and match with RBS balance sheet.

[58] Since non-banks are comprised of various institutions, the frequency and standard of balance sheet

Finally, we describe our credit data at **Firm level**, aggregating credit by (firm $\times$ time) observations and excluding any special bank credit. Our sample is restricted to listed firms in three of the trading boards: KOSDAQ, KOSPI, and KONEX, and any firms that were listed for at least one quarter during the sample period are included, even if they are delisted later.[59] In what follows, we provide descriptions of listed firms compared to the universe of firms using two main data sources: KisValue for listed firms and KOSIS for the census of corporations. Total number of employees working for listed companies in Korea is around 1.53 million based on the data from KisValue. This is approximately 15% of the total number of employees among for-profit corporations in Korea, which is 10.03 million. (KOSIS, Profit Corporation Statistics 2017). In terms of assets, listed companies constitute about 35% of all for-profit corporations, based on KisValue and KOSIS data in 2017.

Table 7: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Credit level					
total credit	21,083	91,017	0.88	6,771,667	309,292
Δ ln total credit	-0.09	1.08	-10.82	11.18	202,373
Lender level: regulated banks					
total credit	3,495,717	7,312,573	34	35,403,686	943
total assets	41,729,254	80,336,832	24,367	346,082,176	936
total liabilities	38,582,159	74,307,737	936	320,660,096	936
total equity	3,147,095	6,075,405	11,545	25,880,234	936
Lender level: shadow lenders					
total credit	457,158	1,740,774	0.88	21,718,998	7,053
Firm level					
total credit	130,478	699,635	0.88	22,533,432	49,976

Note: Total credit, assets, liabilities, and equity are in millions of 2010 Korean Won. Differences are between times t and $t-4$. Summary statistics exclude observations of special banks. Credit level is by (firm x lender x time) observations, lender level is by (lender x time), and firm level is by (firm x time) observations. All summary statistics include only observations with a positive amount of credit.

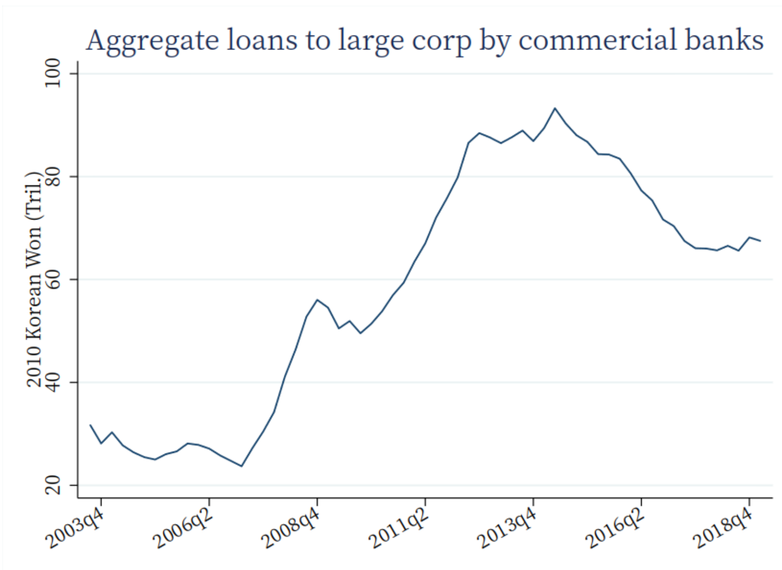
disclosure varies (most of cooperatives report semi-annually), if any, and matching of financial institutions from our credit data and publicly available financial information is not straightforward. We performed string matching by names and manual matching as well, but it is still patchy.

[59]We do not see the name of firms but only their detailed industry code and artificial identifier provided by the credit bureau.

A.2 Prior trends

In this section, we analyze the prior trends in corporate lending. To do so, we must rely on outside evidence due to the fact that our micro data only starts from 2013. We will examine the issue separately for credit from commercial banks, and from shadow lenders.

First, to investigate the prior trend in regulated bank lending, we acquire the balance sheets of all domestic banks from the Financial Supervisory Service (FISIS) dataset and aggregate them into a single time series. Figure 19 plots the balance sheet category "Korean Won loans to large corporations" going all the way back to 2003.[60] The figure paints a clear picture: regulated bank lending had been increasing almost monotonically (apart from the episode around 2008-2009) until around 2014 when it began to fall. The decline is even more pronounced since 2016, when Basel III became binding in Korea.



Note: Data source is Financial Supervisory Service (FISIS). The series includes all Korean Won loans provided to large corporations by all domestic banks.

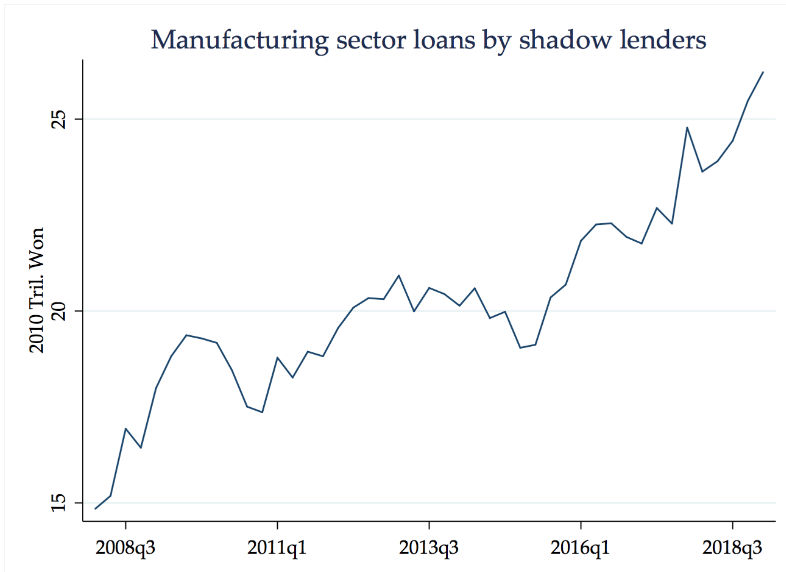
Figure 19: Aggregate bank lending over a longer sample

Second, to check the prior trend in shadow lending, Figure 20 plots the Bank of Korea aggregate loans data from shadow lenders to the manufacturing sector.[61] It can be noticed that while there is some increase in shadow loans in periods of time such as 2008-2010 or

[60] This data covers around 60% of our aggregate series presented in Figure 1. The discrepancy comes from two sources: only the domestic banks, and only Korean Won loans are included here.

[61] We choose manufacturing as a sector that is most representative of the sample of public firms which comprise our data.

2011-2013, the sharpest increase begins in 2015 and continues through 2019, precisely the period of implementation of Basel III in Korea.



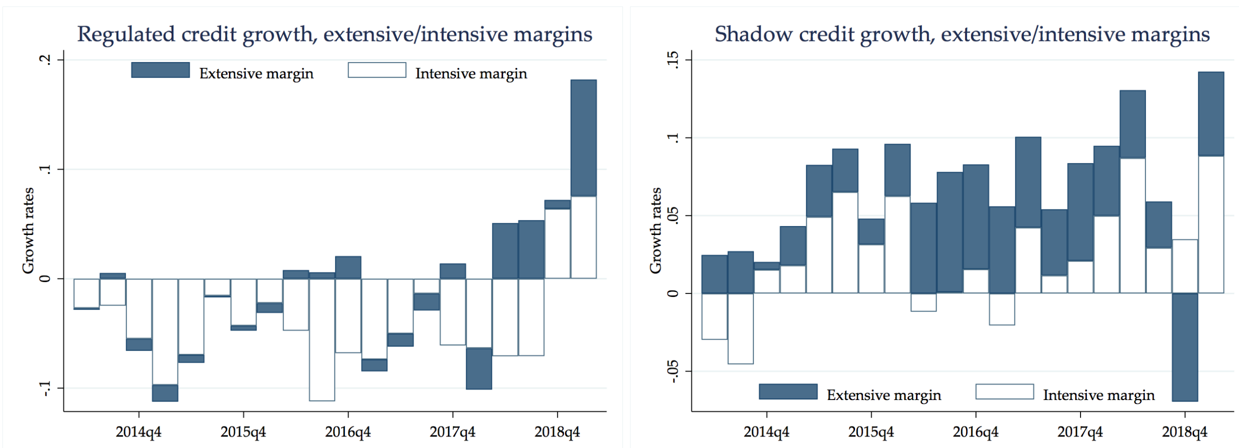
Note: Data source is Bank of Korea. Shadow lenders are restricted only to deposit-taking non-bank financial institutions, such as credit unions, cooperatives, and mutual savings.

Figure 20: Shadow lending over the longer sample

To summarize, due to the limited time coverage we are unable to examine the longer trends in corporate lending using our data. Nevertheless, we use alternative data sources and conclude that there is a clear reversal of the trends, both in regulated bank lending and shadow lending, starting from around 2015 which is the moment of time when Basel III is about to become binding in Korea.

A.3 Intensive and extensive margin decomposition

To shed more light on the trends documented in Figure 1, in this section we decompose credit growth into intensive and extensive margins for both bank credit and for shadow credit. The intensive margin includes year-on-year log differences in credit arising within existing firm-lender relationships. The extensive margin on the other hand consists of changes in credit due to entry or exit of firm-lender relationships. The sum of changes on the intensive and extensive margin is equal to aggregate credit growth in each time period. Figure 21 shows this decomposition separately for regulated (left) and shadow (right) credit markets. The dark and white bars depict changes on extensive and intensive margins, respectively. Two observations stand out immediately. First, most of the decline in regulated bank credit occurred on the intensive margin, i.e. within existing relationships. Second, most of the growth in shadow credit occurred on the extensive margin, especially starting from 2016Q1 which is when Basel III was enforced with penalties in Korea (see Section 2.8). This means that the formation of new firm-lender relationships mostly drove the observed increase in shadow lending. While some of these are literally new relationships between two entities that are already present in the data, the next section shows that many of them are actually due to new shadow lenders entering the business and adding to our sample.



(a) Regulated banks

(b) Shadow lenders

Figure 21: Decomposition of credit growth into intensive and extensive margins

In Appendix A.4, we show that the extensive margin growth is not merely due to the same firms seeking new non-bank lenders. In fact, a majority of firms who *do not* borrow from shadow lenders at the beginning of our sample, end up doing so by the end of it.

A.4 Transition matrix of extensive margin

Figure 22 shows the transition matrix of firms by utilization of different credit sources. We consider firms at the beginning (2013Q2) and end (2019Q1) of our panel and divide them into four groups for each period: **none** (not borrowing from any of the lenders), **banks only** (borrowing from regulated banks only), **shadow only** (borrowing from shadow lenders only), and **both** (borrowing both from regulated banks and shadow lenders). An element in row i and column j means the fraction of firms from group i in 2013Q2 that moved to group j in 2019Q1. For example, among all firms that were borrowing from both regulated banks and shadow lenders (**both**) at the beginning of our sample, 18% are borrowing only from shadow lenders (**shadow only**) at the end of the sample. The figure shows that a majority of firms at the end of the sample period are borrowing from both regulated banks and shadow lenders, including those that were only borrowing from banks at the beginning of the sample period (59% from banks only to both). It is noteworthy that a significant fraction of firms moved to "shadow only" group towards the end, while "banks only" group did not experience such an inflow from other groups.

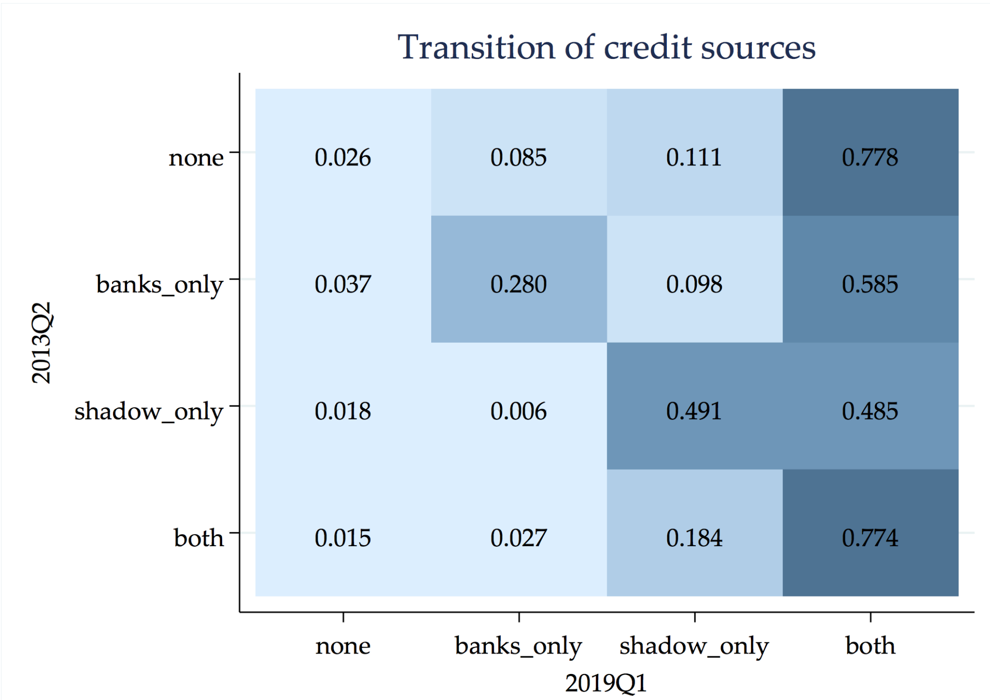


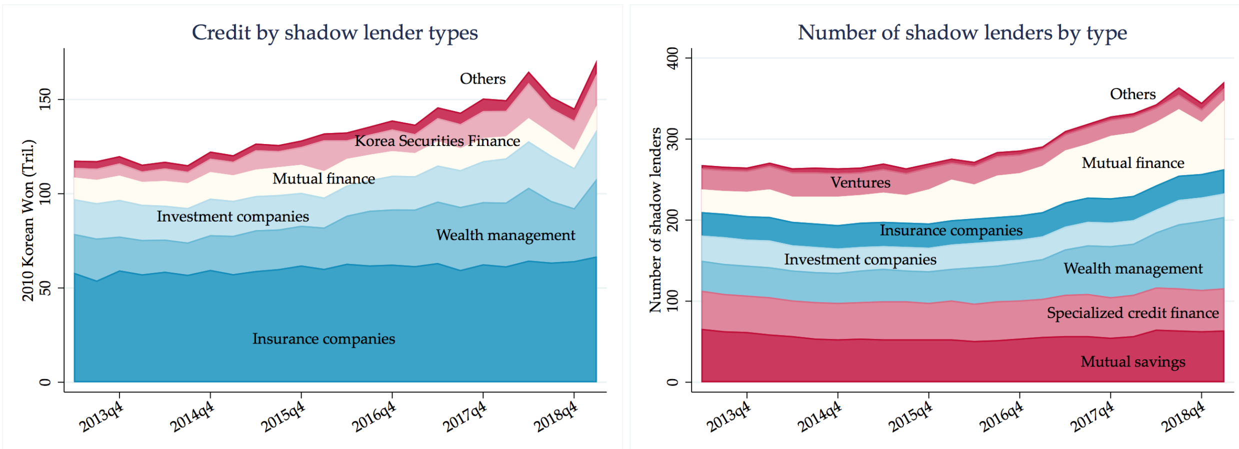
Figure 22: Transition of credit source at firm level, 2013Q2 to 2019Q1

A.5 Evolution of shadow lender types over time

Figure 23 provides a decomposition of these shadow lender types over time in terms of their number and total extended credit. We define a non-bank (shadow) lender as any institution that provides credit to corporations and is not a regulated bank. As such, the shadow lenders that we observe in our data span various financial institutions such as mutual finance firms, wealth management funds, insurance companies or even leasing departments of major car brands (collected under "specialized credit finance").[62] Panel 23(a) shows that roughly half of such loans come from insurance companies, although the largest growth in the amount of extended credit comes from wealth management funds and various investment firms. Panel 23(b) on the other hand presents the number of firms

[62]Note that Korea does not have any Global Systemically Important Insurers (G-SIIs) which, in principle, might also have been affected by Basel III.

who operate as shadow lenders in our data. This number is roughly constant, at just under 300 (compared with around 40 regulated banks), until 2016 and then starts to increase, which coincides with the introduction of penalties for non-compliance with Basel III (see Section 2.8). The number of shadow lenders eventually reaches almost 400 by 2019Q1, which means that there are around one hundred new shadow lenders appearing in our sample during the course of Basel III implementation in Korea.



(a) Total credit extended (b) Number of institutions

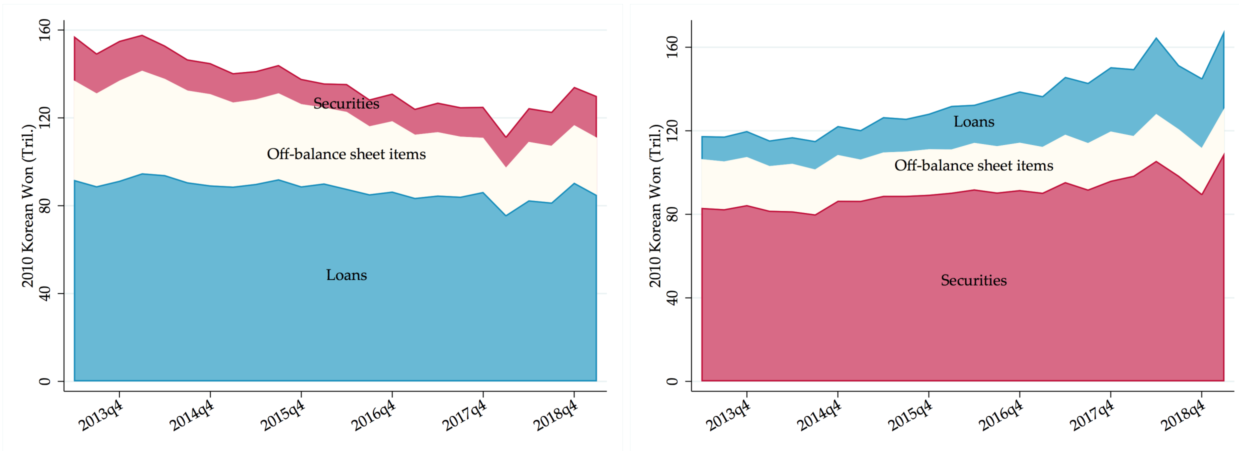
Note: The names of institution types are authors' own translation from Korean. Mutual finance includes various credit unions and cooperatives. Investment companies are also known as securities companies. Specialized credit finance includes credit card companies, leasing companies, and installment finance companies.

Figure 23: Decomposition of shadow bank types over time

A.6 Credit types

The Korean credit data used in this paper contains information about the types of credit. There are three broad types: *Loans, securities, and off-balance sheet items*. In Figure 24, we depict the break-down of total credit into these three types, for both regulated and shadow banks. Classification of credit types follows the regulatory guideline published by the Financial Services Commission (article 2014-9). Primary items included in *off-balance sheet items* are acceptances and guarantees. *Securities* comprise CP, bonds, and securities lent. *Loans* consist of a variety of financial products, from short-term and long-term loans to repurchase agreement, factoring, and financial/capital leasing.

Focusing on loans from regulated banks, working capital constitutes 54% of total loans



(a) Regulated banks (b) Shadow lenders

Figure 24: Decomposition of credit types

in KRW, followed by equipment loans (25%). While there are loans based on receivables or purchases (Accounts Receivable Loans and Purchase Price Loans), they account for a smaller fraction (6%) compared to the working capital or equipment loans.

Among the loans from shadow lenders, the largest category is those backed by securities such as bonds or equity (Loans on Securities Collateral), which comprises on average 70% of all shadow loans in KRW. Other types of secured loans, such as real-estate backed loans (10%), as well as unsecured credit (commercial paper discount, 13%, and credit line, 6%) comprise the rest of the loans extended by shadow lenders.

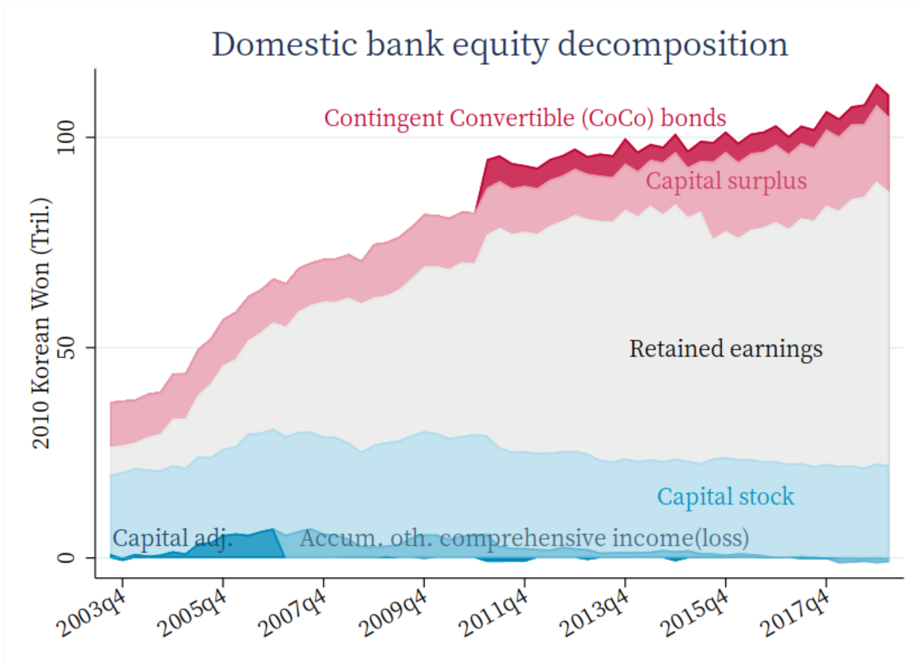
A.7 Bank equity decomposition

In this section, we investigate the time series of total bank equities and their decomposition in order to describe the major source of capital accumulation in response to the bank reform. Specifically, we analyze whether banks are increasing their equity, and if so, whether they raised their equity externally or internally. Figure 25 describes the five different types of equity accounts for the domestic commercial banks: Contingent Convertible (CoCo) bonds,[63] capital surplus,[64] retained earnings, capital stock, capital adjustment, and accumulated other comprehensive income (loss). Compared to the beginning

[63] Also known as hybrid bonds, they are introduced as a means to raise Tier 1 equity for banks in response to Basel III.

[64] Capital surplus includes Paid in capital in excess of par value, Gain on Capital Reduction, Gain on Business Combination, Assets Revaluation Reserve, and Others. There was a slight increase in capital surplus in 2015Q3, mostly from the two major banks that merged together.

of the sample period (2003Q3), when capital stock was the largest part of the bank equity, banks have mostly increased their equity via retained earnings. This implies that banks in Korea are closely held, since the increase in equity in the recent years was mostly through the internal equity such as retained earnings rather than external equity such as stock issuance or CoCo bonds. This observation justifies our model selection in Section 4 where the banks raise equity through retained earnings.



Source: FISIS. The series includes all domestic commercial banks and their equity accounts.

Figure 25: Aggregate bank equity accounts

B Further information on Basel III

In this section, we provide further information regarding the global Basel III accord, its implementation in Korea, and the banks' response to it.

B.1 Basel III

The Basel Committee on Banking Supervision reached an agreement in 2011 on the new global framework for capital requirements, the so-called Basel III. The new rules for minimum capital requirements, originally scheduled for implementation in years 2013-2015, consisted of the following:[65]

1. The minimum fraction of **Tier 1 capital to risk-weighted assets (RWA)** to increase from 4% to 6%.

2. A **conservation buffer** of 2.5% of Tier 1 capital to RWA to be maintained at all times, bringing the total requirement to 8.5%. Banks that fall below this threshold will be constrained in their ability to distribute earnings.

3. A **counter-cyclical buffer** of $0\% - 2.5\%$ (set by national authorities) of Tier 1 capital to RWA applicable in the times of high credit growth, to prevent the build-up of systemic risk.

4. A special buffer for **Systemically Important Banks** (SIB), mandated individually by national authorities of each country.

In summary, the statutory requirement for Tier 1 capital was increased from 4% to 8.5% of a bank's risk-weighted assets, with additional buffers left at the discretion of national authorities responsible for implementing the reform.

B.2 Capital requirements in terms of alternative measures

Table 8 extends the content of Table 1 by showing the implementation of Basel III in terms of two alternative measures of capital: the Common Equity Tier 1 Capital, and the Total Capital. It can be noticed that, while the requirements for different measures vary in terms of level, they all tend to be spread out over time.

Figure 26 tracks the evolution of realized bank capital ratios over time for the two alternative measures of capital. The main observations from Figure 2 are equally applicable here. The capital ratios tend to be dispersed and exhibit a buffer over the posted requirement. Most importantly, the entire distribution tends to shift upwards starting from 2016 when the Basel III framework is implemented in Korea with penalties for non-compliance.

B.3 Basel III penalties

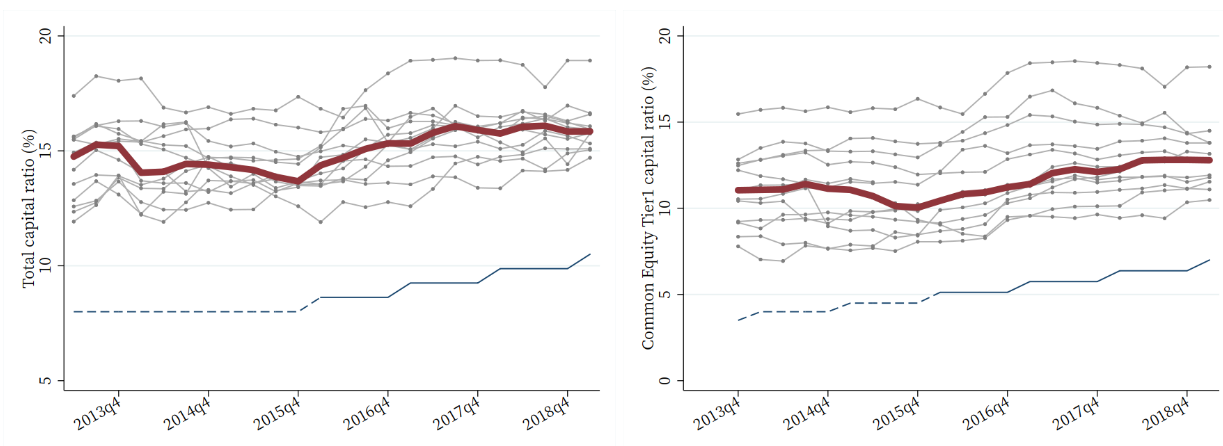
In this section, we discuss the penalties related to non-compliance with capital requirements in South Korea. Table 9 lists the thresholds for capital ratios below which any

[65] We present the reform in terms of the Tier 1 capital ratio requirement, which is a standardized and most commonly used measure of a bank's financial strength. In Appendix B.2 we discuss alternative measures of bank capital in the context of the Korean implementation of Basel III.

Table 8: Minimum capital ratio requirements - alternative measures

Capital Ratio (%)	CET1		Tier 1		Total		Note
Until 2012	None		4		8		Basel II
From 2013 Jan 1st	3.5		4.5		8		Basel III guideline (no penalties)
From 2014 Jan 1st	4.0		5.5		8		
From 2015 Jan 1st	4.5		6.0		8		
From 2016 Jan 1st	5.125	$+ H_{it} \times 1/4$	6.625	$+ H_{it} \times 1/4$	8.625	$+ H_{it} \times 1/4$	Basel III (with penalties)
From 2017 Jan 1st	5.75	$+ H_{it} \times 1/2$	7.25	$+ H_{it} \times 1/2$	9.25	$+ H_{it} \times 1/2$	
From 2018 Jan 1st	6.375	$+ H_{it} \times 3/4$	7.875	$+ H_{it} \times 3/4$	9.875	$+ H_{it} \times 3/4$	
From 2019 Jan 1st	7	$+ H_{it}$	8.5	$+ H_{it}$	10.5	$+ H_{it}$	

Note: CET1 denotes Common Equity Tier 1. CET1 $\subseteq$ Tier 1 $\subseteq$ Total. H_{it} is the sum of Countercyclical Capital Buffer and Domestic Systematically Important Banks (DSIB) capital.



(a) Total capital ratios

(b) Common Equity Tier 1 capital ratios

Note: Each connected gray line represents the realized capital ratio of a domestic bank. Solid red line is a median realized capital ratio of each quarter. Navy solid lines are minimum Total (left panel) and Common Equity Tier 1 (right panel) capital ratio requirements since 2016, respectively, and dashed navy lines are “guideline" minimum capital ratios as in Table 8.

Figure 26: Alternative measures of realized bank capital ratios over time

penalties are imposed. Additionally, the size of the restriction depends on how much the realized capital ratio fell below the required minimum. Specifically, in the event of violating the regulation, a minimum conservancy ratio is applied to the bank’s profit. This means that the bank is forced to buy back stocks or withhold dividend payments in proportion specified by the size of the capital ratio violation.

Table 9: Restrictions on profit distribution under Basel III (From 2019 Jan 1st)

Min. conserv. ratio	100%	80%	60%	40%	0%
CET1 capital ratio	$< 5.125 + H_{it}$	$< 5.75 + H_{it}$	$< 6.375 + H_{it}$	$< 7 + H_{it}$	$\geq 7{+}H_{it}$
or Tier 1 capital ratio	$< 6.625 + H_{it}$	$< 7.25 + H_{it}$	$< 7.875 + H_{it}$	$< 8.5 + H_{it}$	$\geq 8.5{+}H_{it}$
or Total capital ratio	$< 8.625 + H_{it}$	$< 9.25 + H_{it}$	$< 9.875 + H_{it}$	$< 10.5 + H_{it}$	$\geq 10.5{+}H_{it}$

Note: CET1 denotes Common Equity Tier 1. CET1 $\subseteq$ Tier 1 $\subseteq$ Total. H_{it} is the sum of Countercyclical Capital Buffer and Domestic Systematically Important Banks (DSIB) capital.

B.4 Other Basel III regulations

While the increase in capital requirements was its most important component, Basel III actually introduced many additional new regulations to the financial sector. In this section, we discuss the potential impact of these other reforms, namely the changes to Liquidity Coverage Ratio (LCR), Net Stable Funding Ratio (NSFR), and Leverage Ratio.

The minimum Liquidity Coverage Ratio (LCR) mandated by the Basel III accord was introduced in Korea starting from 2015 with the complete implementation by 2019. However, it should be pointed out that Korea already had an existing regulation of maximum Loan-to-Deposit (LTD) ratio, starting from 2012, which plays a similar role to minimum LCR in terms of reducing the procyclicality of banks' lending. Indeed, Kim (2018) shows that the LTD regulation has a stronger effect than the LCR in this dimension. Moreover, with the LTD regulation already in place, the authorities in Korea decided to introduce a minimum LCR of 80% in 2015, with increases of 5% over the next four years, rather than the Basel Committee's recommendation of 60% in 2015 and gradual increases of 10% until 2019. This allows us to conclude that the simultaneous introduction of minimum LCR regulation is unlikely to have biased the effects of higher minimum capital requirement on bank lending, at least in the case of Korea.

The other two pieces of new regulation, the Net Stable Funding Ratio (NSFR) and the Leverage Ratio (LR), were only introduced in Korea starting from 2018, two years after the implementation of higher minimum capital requirements with penalties for noncompliance. Moreover, Figure 1 shows that the declining trend in bank lending actually *reverted* in 2018, which is likely due to the simultaneous adjustment of risk weights, as discussed in Section 2.2. Hence, we conclude that the Korean implementation of minimum NSFR and LR is unlikely to have biased our estimates of the effect of higher capital requirements on the provision of bank credit.

B.5 Bank size distribution and DSIB selection

Under Basel III, Domestic Systemically Important Banks (DSIB) are subject to additional minimum capital requirements from 2016. Six banks are designated as DSIB sin year 2016, and until the end of our sample period (year 2019), the list of DSIB has not changed.[66] The fraction of DSIB equity out of all commercial banks' equity from 2010 to 2013 amounts to 69.4% on average, which is quite sizable.[67] Top 3 and 10 banks by equity size take 51% and 85% of the commercial banks' aggregate equity for the same time period, respectively.

C Further empirical analysis and robustness checks

In this Appendix, we conduct a battery of robustness checks for our econometric results in Section 3. We start by considering various alternative specifications for estimating the elasticity of regulated bank credit with respect to capital requirement. Then, we investigate the robustness of our estimates for the spillover effect on shadow financing.

C.1 Robustness of bank credit elasticity

Firm-Time fixed effects In order to control for the firms' demand for credit that is potentially time-varying, in this robustness check we include the time-firm fixed effects. Notice that the inclusion of time fixed effects recasts the estimation into a purely cross-sectional identification. More specifically, we are exploiting the differences between the Domestic-Systemically Important Banks (DSIB) and the rest, given that DSIBs are subject to an additional buffer of capital requirements. Also, note that the independent variable is now the growth of minimum capital requirements rather than the level, in the spirit of a diff-in-diff estimation. The estimation results in Table 10 show that, compared to non-DSIBs, DSIBs experience a 5% larger decline in credit growth in response to a 1% higher minimum capital requirement growth. For example, this implies that in 2016, when DSIBs are subject to 3.8% higher capital requirements than non-DSIBs, they responded with a 20% larger reduction in credit growth than non-DSIBs due to the extra capital requirement imposed on them.

[66] In principle, every year commercial banks are evaluated based on several criteria such as their connectedness and systemic importance, and authorities announce the selection in a timely manner. While the list can potentially change every year, in practice the same set of banks have been selected during our sample period.

[67] Total equity data for each bank is sourced from FISIS, at a quarterly frequency.

Table 10: Effects of capital requirements on credit growth with firm-time fixed effects

VARIABLES	(1) Δln total_credit	(2) Δln total_credit	(3) Δln total_credit	(4) Δln total_credit
Δ ln min_cap_req	-5.115***	-5.324**	-5.542***	-5.811**
	(1.417)	(1.932)	(1.456)	(1.950)
Constant	0.257**	0.268*	0.441***	0.465***
	(0.0980)	(0.135)	(0.101)	(0.139)
Observations	73,598	67,744	73,598	67,744
Sample	All	Domestic	All	Domestic
Relationship controls	No	No	Yes	Yes
R2	0.340	0.365	0.355	0.380
Fixed Effects	Firm×Time, Bank			

Note: All standard errors (in parentheses) are clustered at the bank level. *** p<0.01, ** p<0.05, * p<0.1

In this specification, one might be concerned that the estimation results are due to the DSIB specific trends compared to the non-DSIB ones. In order to address this concern, we show parallel trends between two bank groups up until the introduction of Basel III with legal penalties (2016Q1). Figure 27 depicts aggregate credit changes in our sample for the DSIBs and non-DSIBs. It shows that there is no discernible difference between aggregate credit extended by the two bank groups until 2015Q4. However, since 2016Q1, when an additional capital requirement is imposed on DSIBs under Basel III, we observe a divergence between the two groups. More specifically, DSIBs experience a significant decline in the total amount of credit compared to non-DSIBs, and the differences widen as the increment of extra capital requirement increases from 0.25% to 1%.

Pre-2016 guidelines only A natural concern regarding the estimates presented in Table 2 involves the anticipation period, following the announcement of the reform and prior to its actual coming into effect. Indeed, Figure 1 shows that some of the total decline in regulated bank credit occurred prior to 2016 when the reform became legally binding.[68] To understand the impact of this non-binding period of Basel III implementation on bank lending, we re-run regression (1) limited to years 2013-2015 and assuming that the "soft guidelines" presented in Table 1 were actually enforced with penalties. It should be emphasized that this exercise is *not* a placebo test; instead it is a test of the presence of any anticipation effects under the soft guidelines prior to 2016.

[68] As explained in Section 2.8, Basel III regulations were introduced in Korea since 2013 but legal penalties for violating capital requirements were applied only from 2016.

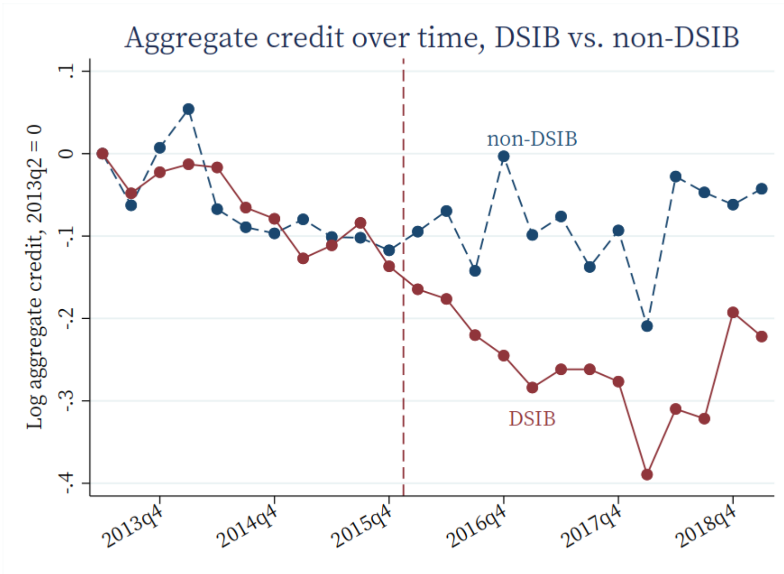


Figure 27: Normalized aggregate credit of DSIBs and non-DSIBs

Note: All credit amounts extended by two bank groups are aggregated and normalized in log values, by subtracting the log 2013Q2 values in each group.

Table 11: Effects of pre-2016 "guideline" capital requirements on credit growth

VARIABLES	(1) Δ ln total credit	(2) Δ ln total credit	(3) Δ ln total credit	(4) Δ ln total credit
ln min. Tier1 req.	-0.219	-0.162	-0.206	-0.143
	(0.153)	(0.158)	(0.150)	(0.156)
Constant	0.382	0.280	0.513*	0.416
	(0.268)	(0.278)	(0.264)	(0.274)
Observations	31,593	29,655	31,593	29,655
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Sample	All	Domestic	All	Domestic
Relationship control	No	No	Yes	Yes
R2	0.181	0.188	0.207	0.214

Note: Sample period: 2013Q2-2015Q4. All standard errors (in parentheses) are clustered at the bank level. *** p<0.01, ** p<0.05, * p<0.1

Table 11 shows that under the "soft guidelines" changes in capital requirement prior to 2016, we cannot find any statistically significant impact of such a reform on bank-firm credit growth. While the magnitude of this elasticity is even higher than for our benchmark results (in absolute value), the estimates are also very noisy and lack consistency across various specifications. This reflects the finding that, while there is an obvious negative correlation between capital requirements and credit growth on the aggregate level, the banks were not responding in any clear way to these non-binding guidelines. Instead, it is the regulator-enforced penalties that lead the banks to reduce lending in response to the change in capital requirements.

Full schedule, including guidelines Table 12 presents the results of running regression (1) under the full schedule of Basel III implementation in Korea (Table 1). That is, we treat the "guidelines" period of 2013-2015 as binding. As we can see, the results are similarly strong and consistent across different specifications. The estimated elasticity of bank credit growth amounts to about -0.22.

Table 12: Effects of Tier 1 capital requirements on credit growth, including guidelines before 2016

VARIABLES	(1) Δ ln total_credit	(2) Δ ln total_credit	(3) Δ ln total_credit	(4) Δ ln total_credit
ln min. Tier1 req.	-0.216***	-0.215***	-0.237***	-0.238***
	(0.0249)	(0.0256)	(0.0246)	(0.0253)
Constant	0.378***	0.379***	0.561***	0.575***
	(0.0497)	(0.0511)	(0.0496)	(0.0510)
Observations	83,599	77,774	83,599	77,774
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Relationship control	No	No	Yes	Yes
Sample	All	Domestic	All	Domestic
R2	0.0704	0.0728	0.0929	0.0964

Note: Guidelines are set to be 4.5% in 2013, 5.5% in 2014, and 6% in 2015 according to Table 1. All standard errors (in parentheses) are clustered at the bank level. *** p<0.01, ** p<0.05, * p<0.1

Foreign banks only Foreign bank branches are included in our regulated bank sample but they are not subject to the domestic Basel III regulations. While Basel III is a set of global banking regulations that was implemented in most developed countries, the time schedule and regulation details differ across countries. Therefore, we view foreign bank branches as being under "soft" domestic regulation, and we expect the elasticity of minimum capital requirements to be lower than those from domestic banks. Table 13 shows that estimated coefficients are not significant and point estimates are lower than the main results (around -0.14) across different sets of controls. While lower number of observations compared to the main regression in Table 2 may have contributed to the higher standard errors, the result suggests that foreign banks were less affected by the capital regulation reform compared to the domestic banks.

Table 13: Effects of Tier 1 capital requirements on credit growth, foreign banks only

VARIABLES	(1) Δ ln total_credit	(2) Δ ln total_credit	(3) Δ ln total_credit
ln min. Tier1 req.	-0.123	-0.125	-0.127
	(0.0815)	(0.0855)	(0.107)
Constant	0.211	0.363**	0.226
	(0.146)	(0.157)	(0.188)
Observations	5,812	5,812	5,812
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank
Sample	Foreign	Foreign	Foreign
Relationship control	No	Yes	Yes
GDP	No	No	Yes
Stock mkt	No	No	Yes
Exports	No	No	Yes
R2	0.0542	0.0706	0.0567

Note: All standard errors (in parentheses) are clustered at the bank level. *** p<0.01, ** p<0.05, * p<0.1

Additional controls In Table 15, we check the omitted variable bias by adding different control variables to the main regression in Table 2. Additional variables are: detrended real GDP, two stock market indices (KOSPI and KOSDAQ), and volume index of manufacturing sector exports. All variables are at quarterly frequency, and all data series are from the Bank of Korea. Each variable is in log and detrended using HP-filter, and stock market indices are averaged at a quarterly level (original series is at daily frequency). The estimated elasticity after adding various control variables remains significantly negative, ranging from -0.15 to -0.163. These are slightly bigger in magnitude compared to the baseline estimation (around -0.14), which suggests that our baseline estimation is on the conservative side compared to the figures in robustness checks.

Weighted regression In Table 14 we show the results of a weighted regression with lagged total credit, in order to verify that firm-bank pairs with large amounts of loans are also affected by the tighter capital regulation. Compared to the main results in Table 2, coefficients are larger in scale which indicates that bank-firm pairs with larger amounts of credit in fact declined more than those with smaller outstanding credit. After controlling for other aggregate variables as in Table 15, the elasticity becomes even larger as column (5) of the table shows. It is partly because a significant number of firms with large outstanding credit in our sample are exporters and their credit comoves with some of the control variables such as exports and GDP. In our main estimation, we take non-weighted regression as our benchmark in order to bring the empirical result as close as possible to the model, which does not have direct matching between firms and banks.

Table 14: Effects of Tier 1 capital req. on credit growth, weighted by lagged credit

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Δ ln total_credit	Δ ln total_credit	Δ ln total_credit	Δ ln total_credit	Δ ln total_credit
ln min. Tier1 req.	-0.219**	-0.251**	-0.231**	-0.264**	-0.357**
	(0.0945)	(0.109)	(0.0998)	(0.115)	(0.143)
Constant	0.133	0.183	0.254	0.323	0.486*
	(0.169)	(0.194)	(0.192)	(0.221)	(0.270)
Observations	83,559	77,733	83,559	77,733	77,733
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Sample	All	Domestic	All	Domestic	Domestic
Relationship control	No	No	Yes	Yes	Yes
GDP	No	No	No	No	Yes
Stock mkt	No	No	No	No	Yes
Exports	No	No	No	No	Yes
R2	0.115	0.131	0.120	0.137	0.140

Note: All standard errors (in parentheses) are clustered at the bank level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 15: Effects of minimum capital requirements on credit growth, additional controls

VARIABLES	(1) Δ ln total_credit	(2) Δ ln total_credit	(3) Δ ln total_credit	(4) Δ ln total_credit	(5) Δ ln total_credit	(6) Δ ln total_credit
ln min. Tier1 req.	-0.154***	-0.161***	-0.151***	-0.158**	-0.158***	-0.163***
	(0.0440)	(0.0473)	(0.0478)	(0.0517)	(0.0430)	(0.0464)
Constant	0.175**	0.181*	0.375***	0.393***	0.182**	0.184**
	(0.0779)	(0.0838)	(0.0860)	(0.0934)	(0.0769)	(0.0831)
Observations	83,559	77,733	83,559	77,733	83,559	77,733
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Sample	All	Domestic	All	Domestic	All	Domestic
Relationship control	No	No	Yes	Yes	No	No
GDP	Yes	Yes	Yes	Yes	Yes	Yes
Stock mkt	No	No	No	No	Yes	Yes
Exports	No	No	No	No	No	No
R2	0.0700	0.0723	0.0919	0.0954	0.0700	0.0723

VARIABLES	(7) Δ ln total_credit	(8) Δ ln total_credit	(9) Δ ln total_credit	(10) Δ ln total_credit	(11) Δ ln total_credit	(12) Δ ln total_credit
ln min. Tier1 req.	-0.155***	-0.160**	-0.154***	-0.158**	-0.150***	-0.154**
	(0.0480)	(0.0521)	(0.0473)	(0.0510)	(0.0548)	(0.0596)
Constant	0.381***	0.395***	0.176**	0.176*	0.373***	0.385***
	(0.0862)	(0.0942)	(0.0840)	(0.0907)	(0.0957)	(0.105)
Observations	83,559	77,733	83,559	77,733	83,559	77,733
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Sample	All	Domestic	All	Domestic	All	Domestic
Relationship control	Yes	Yes	No	No	Yes	Yes
GDP	Yes	Yes	Yes	Yes	Yes	Yes
Stock mkt	Yes	Yes	Yes	Yes	Yes	Yes
Exports	No	No	Yes	Yes	Yes	Yes
R2	0.0920	0.0955	0.0700	0.0723	0.0920	0.0955

Note: All standard errors (in parentheses) are clustered at the bank level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Correlated credit demand and supply shocks Another concern is that including firm fixed effects might not be sufficient for identification of the effects of the changes in capital regulation if firms' credit demand is credit-type specific and shocks to credit demand are correlated with shocks to banks' funding cost. To address this issue, here we redo our main regression by using firm fixed effects interacted with credit type. We also run the regression on a subsample of our data restricted to loans only, by far the largest category of regulated bank lending (Appendix A.6). We find that our baseline elasticity estimates are mostly robust in both cases.

In order to rule out potential concerns regarding the correlation between shocks to credit type-specific demand and bank funding cost, we first include Firm×Credit_Type fixed effects in the Table 16 below, following the referee's suggestion.

Table 16: Effects of minimum capital requirements on credit growth: Finer credit groups

VARIABLES	(1) Δ ln credit	(2) Δ ln credit	(3) Δ ln credit	(4) Δ ln credit
ln min. capital req.	-0.113***	-0.117**	-0.122***	-0.126***
	(0.0388)	(0.0421)	(0.0369)	(0.0398)
Constant	0.114	0.117	0.304***	0.316***
	(0.0695)	(0.0754)	(0.0772)	(0.0838)
Observations	106,197	99,758	106,152	99,726
Relationship controls	No	No	Yes	Yes
Sample	All	Domestic	All	Domestic
R2	0.0685	0.0710	0.0802	0.0831
Fixed Effects	Firm*Credit_Type, Bank			

Note: Sample period: 2013Q2-2019Q1. For the results in this table, the capital requirement prior to 2016 is assumed to be 4% (the "guideline" requirements prior to 2016 were not legally binding). All standard errors (in parentheses) are clustered at the bank level. *** p<0.01, ** p<0.05, * p<0.1

We find that the elasticity of bank lending with respect to capital requirement after including Firm×Credit_Type fixed effects ranges from -0.113 to -0.126, while the analogous estimation in the main text (Table 2) with firm fixed effects only ranges from -0.135 to -0.143. In order to better understand this change in the results after including the interaction of firm fixed effects with credit types, we also restrict the sample to *Loans* only and run the same regression as in the main text. In Table 17, the elasticity estimates are slightly higher in absolute value compared to the baseline specification based on total credit.

Table 17: Effects of minimum capital requirements on credit growth: Bank loans only

VARIABLES	(1) Δ ln loans	(2) Δ ln loans	(3) Δ ln loans	(4) Δ ln loans
ln min. capital req.	-0.145***	-0.148**	-0.148***	-0.151***
	(0.0490)	(0.0522)	(0.0433)	(0.0459)
Constant	0.170*	0.170*	0.357***	0.367***
	(0.0874)	(0.0931)	(0.0914)	(0.0973)
Observations	69,765	66,056	69,763	66,055
Relationship controls	No	No	Yes	Yes
Sample	All	Domestic	All	Domestic
R2	0.0790	0.0814	0.0950	0.0982
Fixed Effects	Firm, Bank			

Note: Sample period: 2013Q2-2019Q1. For the results in this table, the capital requirement prior to 2016 is assumed to be 4% (the "guideline" requirements prior to 2016 were not legally binding). All standard errors (in parentheses) are clustered at the bank level. *** p<0.01, ** p<0.05, * p<0.1

C.2 Bank credit elasticity under alternative measures

In this part, we redo our main estimations of bank credit elasticities for the alternative two measures of bank capital ratio, Total and CET1, previously introduced in Appendix B.2. As expected, we obtain equally significant and consistent results across different variants of the regression. While the estimated coefficients are around similar magnitude using CET1 capital ratio (Table 20), note that those for Total Capital Ratios (Table 19) are generally higher (in absolute value) than with Tier 1 capital ratio in Table 2. This is because the Total capital ratios (which include a bank's total capital) changed by smaller magnitude over time, and hence the elasticities are correspondingly higher. In the following regressions, we control for bank-firm relationships only, so that the estimated coefficients are directly comparable to the main results.

To make our results more useful for future research, Table 18 summarizes our estimated elasticities for the three measures of capital ratio and two possible specifications.

Table 18: Summary of bank credit elasticities for alternative measures of capital ratio

Measure	Elasticities
Tier 1	−0.14
Common Equity Tier 1	−0.15
Total capital (BIS)	−0.30

Note: The reported numbers are the median of the estimates obtained in each Table.

Table 19: Effects of total (BIS) capital requirements on credit growth

VARIABLES	(1) Δ ln total_credit	(2) Δ ln total_credit	(3) Δ ln total_credit	(4) Δ ln total_credit
ln min. Total req.	-0.287**	-0.287*	-0.322***	-0.323**
	(0.125)	(0.134)	(0.114)	(0.123)
Constant	0.534*	0.528	0.813***	0.822**
	(0.274)	(0.296)	(0.259)	(0.279)
Observations	83,559	77,733	83,559	77,733
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Sample	All	Domestic	All	Domestic
R2	0.0693	0.0715	0.0914	0.0948

Note: All standard errors (in parentheses) are clustered at the bank level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

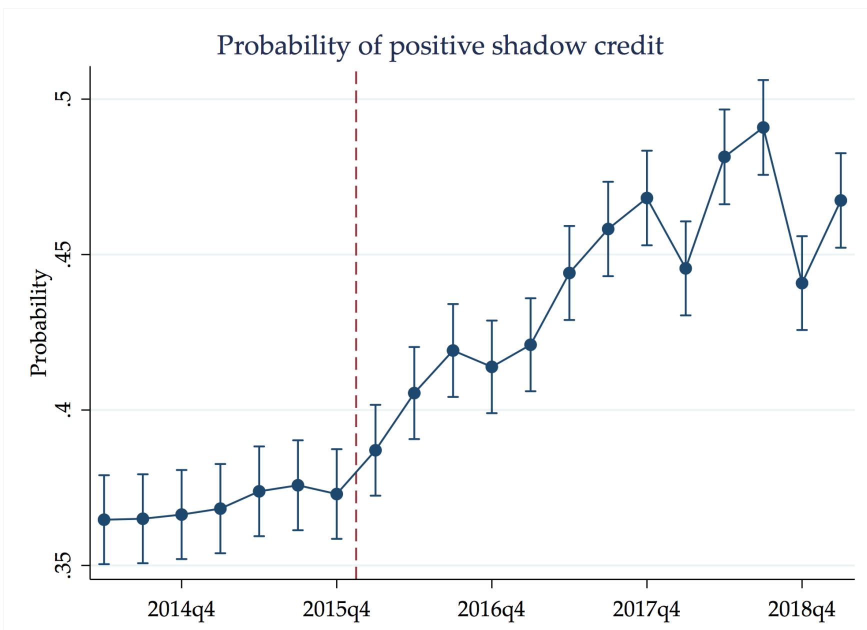
Table 20: Effects of Common Equity Tier 1 capital requirements on credit growth

VARIABLES	(1) Δ ln total_credit	(2) Δ ln total_credit	(3) Δ ln total_credit	(4) Δ ln total_credit
ln min. CET1 req.	-0.142***	-0.144**	-0.149***	-0.152**
	(0.0483)	(0.0523)	(0.0465)	(0.0503)
Constant	0.130	0.127	0.346***	0.356***
	(0.0775)	(0.0840)	(0.0812)	(0.0880)
Observations	83,559	77,733	83,559	77,733
Fixed Effects	Firm, Bank	Firm, Bank	Firm, Bank	Firm, Bank
Sample	All	Domestic	All	Domestic
R2	0.0698	0.0720	0.0918	0.0953

Note: All standard errors (in parentheses) are clustered at the bank level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

C.3 Spillover effect on the extensive margin of shadow lending

One thing to note about the analysis in Section 3.3 is that it only accounts for the changes in credit provision on the intensive margin.[69] Yet, as it is emphasized in subsection 2.4, a significant portion of the growth in shadow credit occurs on the extensive margin. To estimate the effect of changes in capital regulation on the formation of shadow lending relationships, we now focus our analysis exclusively on the extensive margin. To this end, we restrict our sample to shadow lenders only and run a logistic regression of $\mathbb{1}\{total\_credit_{ijt} > 0\}$, a binary indicator for whether firm i had any outstanding credit from shadow lender j in time period t, on the usual set of regressors, that is $f_i + f_j + f_t + \Psi X_{ijt} + \varepsilon_{ijt}$. Figure 28 summarizes the results of this exercise by plotting the predicted marginal effects of time fixed effects along with their respective confidence intervals. As can be noticed, the probability that a firm-lender relationship exists is roughly constant at 35% over time until 2016, when the penalties for non-compliance with Basel III come into effect. Starting from then, the probability increases by up to 10 percentage points before stabilizing at around 45% in 2018. This indicates that the change in bank regulation had a sizable effect on the formation of shadow lending relationships.

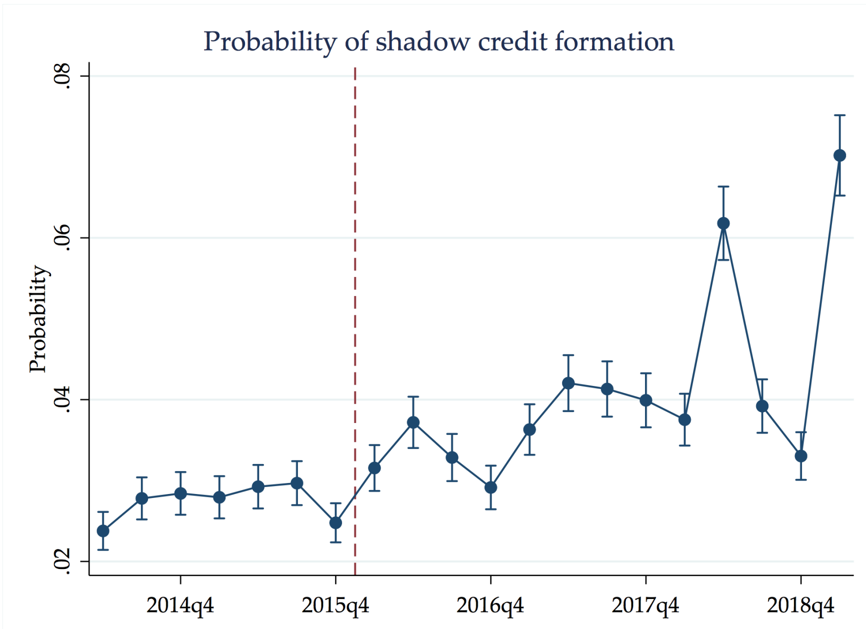


Note: Each dot is an estimate of the probability of positive shadow credit based on the predicted marginal effects of time fixed effects (f_t) in the logistic regression. Each line is a confidence interval. Dashed vertical line is 2016Q1, indicating the beginning of the reform.

Figure 28: Predicted probability of credit from shadow lenders

[69]This is because growth rates are undefined when credit level was equal to zero in the previous period.

To further strengthen this point, we also conduct this exercise for *changes* in the extensive margin (as opposed to existence of lending relationships). Figure 29 plots the predicted marginal effects of the time fixed effects estimated in a logistic regression of $\mathbb{1}\{total\_credit_{ijt-1} = 0, total\_credit_{ijt} > 0\}$, a binary indicator for whether firm i started borrowing from shadow lender j in time period t, on the usual set of regressors, that is $f_i + f_j + f_t + \Psi X_{ijt} + \varepsilon_{ijt}$. We find a similar pattern of the reform effects where the probability a firm-lender credit account becomes active rises from around 3% before the reform to 7% after.



Note: Each dot is an estimate of the probability of shadow credit formation based on the predicted marginal effects of time fixed effects (f_t) in the logistic regression. Each line is a confidence interval. Dashed vertical line is 2016Q1, indicating the beginning of the reform.

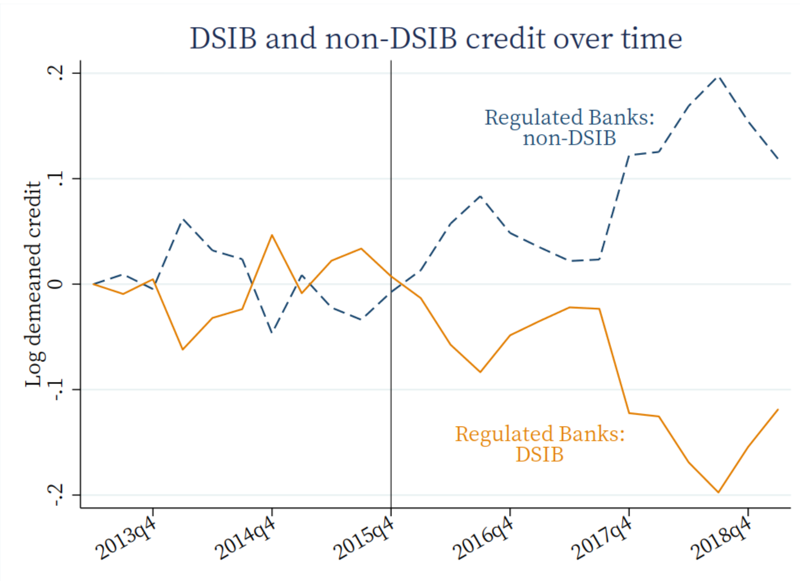
Figure 29: Predicted probability of new shadow lending relationships

C.4 Substitution between bank and shadow lending

In order to quantify the substitution effect between bank and shadow credit, we restrict our samples to those firms that borrow both from at least one regulated bank and one shadow lender. A natural candidate to estimate the substitution effect would be a simple fixed effects specification, where we regress the growth of total shadow credit for each firm i at time t on the corresponding growth of total regulated bank credit:

$$\Delta ln\ shadow\_credit_{it} = f_i + \beta \cdot \Delta ln\ regulated\_credit_{it} + \Psi X_{it} + \varepsilon_{it} \quad (37)$$

where f_i is the firm fixed effect, X_{it} contains other control variables, and β is the main coefficient of interest. If there is a strong substitution effect between the shadow and regulated credit, then we expect a significantly negative coefficient β. However, using the above fixed effects regression, the coefficient estimate is potentially biased. It is because if a firm is hit by a positive productivity shock, it may increase both regulated and shadow credit, and vice versa under a negative shock. Then, in order to control for the firm demand side, we introduce a Bartik instrument that uses the initial share of DSIB versus non-DSIB credit within a firm.



Note: Sample is restricted to firms that borrow from both DSIB and non-DSIB. Observations are demeaned at firm-quarter level, and normalized to the initial period 2013Q2. By construction, in each period the lines sum up to zero.

Figure 30: Substitution effect of DSIB and non-DSIB credit

More specifically, in order to design a Bartik instrument, we exploit the fact that the DSIB and non-DSIB credit growth diverge only after the implementation of Basel III with legal penalty in 2016Q1, as Figure 30 visualizes. In constructing this figure, we select only those firms that borrow both from DSIB and non-DSIB banks, and investigate a within-firm changes in credit compared to the initial period analogous to Section 3.4.[70] Notice that the relative amount of DSIB and non-DSIB credit before 2016Q1 hovers around zero, and the pattern of divergence emerges only after the implementation of Basel III with

[70] In this case, the firm may or may not borrow from shadow lenders. The total amount of credit from this subset is about 87% of the regulated bank credit in the entire sample. We also subtract the log average of bank credit across DSIBs and non-DSIBs within each firm-quarter observation.

legal penalty.[71] Therefore, based on the fact that such divergence between DSIB and non-DSIB is triggered by a policy change that imposes extra minimum capital requirement on DSIBs, we exploit differential "exposure" to DSIBs across firms as an instrument to correct the bias of credit demand shocks:

$$\Delta ln\ regulated\_credit_{it} = q_i + \gamma \cdot S_i \cdot G_t + \Phi X_{it} + \xi_{it} \tag{38}$$

where $S_i \cdot G_t = \sum_j s_{i,j} g_{j,t}$ is a dot product of initial period credit share by bank j within firm i ($s_{i,j}$) and bank j credit growth rate in time t ($g_{j,t}$). In other words, in place of the observed regulated credit growth, we use predicted values based on the shift-share instrument. Estimation results, both ordinary least squares (OLS) and 2-stage least squares (2SLS) using the Bartik instrumental variable, are reported in Table 21.

Table 21: Spillover estimation: OLS and IV regressions

VARIABLES	(1) OLS $\Delta ln\ shadow\_cr$	(2) 2SLS $\Delta ln\ shadow\_cr$	(3) First Stage $\Delta ln\ regulated\_cr$
Post.2016Q1	0.165***	0.0544	-0.0838***
	(0.0158)	(0.0478)	(0.0125)
$\Delta ln\ regulated\_cr$	-0.0153**	-1.358***	
	(0.00755)	(0.508)	
Bartik Instrument			0.2224***
			(0.0613)
Observations	29,849	29,849	29,849
Fixed Effects	Firm	Firm	Firm
Sample	All	All	All

Note: Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

There are two sets of regressions in Table 21. First, columns 1 and 2 compare the estimation results of OLS and IV regressions, respectively, and include a dummy variable (Post.2016Q1) which is equal to 1 after 2016Q1 (post-reform), and 0 otherwise. They show that while the substitution effect between regulated and shadow credit is statistically significant under the OLS, the estimation is orders of magnitude larger using the Bartik instrument. The result shows that a 1 percent decrease in credit extended by regulated

[71] Since large banks are selected as DSIBs and that selection did not change over time, it is hardly the case that the share of DSIB credit is random across firms. However, given the observation that the DSIB credit shares within a firm react only after 2016Q1, we argue that the initial DSIB shares can be used as a valid instrument for substitution effects.

banks leads to a 1.3 percent increase in shadow credit. Moreover, only with the instrument, the substitution effect is large and significant compared to the time effect (column 2). This emphasizes the importance of controlling the firms' demand in order to estimate the substitution effect. Finally, the first stage results (column 3) show that the instrument is significantly correlated with the growth of regulated credit, which is the independent variable of interest.

D Numerical Algorithms

In this Appendix we describe the numerical algorithms used to analyze the model. We start by describing the approach to find a general equilibrium with stationary distributions of agents. Then, we present the algorithm used to calculate a deterministic transition path induced by the change in bank capital requirements.

D.1 Stationary equilibrium

To compute a stationary equilibrium of the model, we use the following algorithm.

0. Create separate grids for banks' equity e, workers' wealth x_w and labor income y, and entrepreneurs' wealth x and business productivity z. Use the Tauchen method to discretize the stochastic processes for entrepreneurial productivity and workers' labor income.

1. Assume an initial vector of general equilibrium prices $\{r_b, r_d, w, \mu\}$.[72]

2. Taking the prices as given, solve the bank's problem as follows:

   i. Guess the dividend function $c^0(e)$.

   ii. For each equity grid point, find the optimal policies $\{b'(e), m'(e), d'(e)\}$ by solving the system of first-order conditions implied by the bank's problem, and back out the resulting dividend function $c^1(e)$. Use linear interpolation to evaluate the off-grid values of next-period dividend.

   iii. Evaluate the maximum deviation between the functions $c^0(e)$ and $c^1(e)$. If it is below a pre-specified tolerance level ε then stop; otherwise update the dividend function $c^0(e) = \lambda c^1(e) + (1 - \lambda)c^0(e)$ and go back to step ii.

[72]The mean repayment rate for loans, μ, is technically not a price, but we still need to adjust it in order to balance out the quantities of defaulted loans. With a slight abuse of terminology, we include it here in the vector of general equilibrium prices for conciseness. The required adjustments of μ across different equilibria are of the order of magnitude of 10^{-4} at most.

iv. After the dividend function has converged, calculate the stationary distribution of bank equity by iterating on the banks' CDF.

v. Calculate the aggregate bank loans and deposits, as well as the average dividend payout to workers in the stationary equilibrium.

3. Taking as given the equilibrium price vector and average dividend payout from the banks, use value function iteration to solve for the workers' optimal policies and a stationary distribution of wealth and savings (Aiyagari, 1994).

4. Taking the equilibrium price vector as given, solve the entrepreneurs' problem as follows:

   i. Guess the initial value functions $v_i^0(x,z)$, for each entrepreneur type $i \in \{borrower, depositor, shadow\,lender\}$.

   ii. For each entrepreneur type i and for each grid point (x,z), find the optimal portfolio allocations $\{a_i'(x,z), k_i'(x,z)\}$ by maximizing the return function. Use linear interpolation to evaluate the off-grid values of next-period wealth. Use the Gauss-Legendre quadrature to approximate the expectations with respect to ω', the idiosyncratic shock to loan value. Back out the implied consumption policy $c_i(x,z)$.

   iii. Using the policy functions (c_i^1, a_i', k_i') found in the previous step, update the value functions for each entrepreneur type:

$$v_i^1(x,z) = u\Big(c_i(x,z)\Big) + \beta \mathbb{E} \max\Big\{v_b^0(x,z), v_d^0(x,z), v_s^0(x,z)\Big\}$$

   iv. Using the value functions calculated in the previous step, find the cash-on-hand thresholds for each productivity grid point, $\bar{x}_1(z)$ and $\bar{x}_2(z)$, at which an entrepreneur is indifferent between borrowing and saving, and between saving and becoming a shadow lender, respectively.

   v. Evaluate the maximum distance between the value functions $v_i^0(x,z)$ and $v_i^1(x,z)$ for each entrepreneur type i. If it is below a pre-specified tolerance level ε then stop; otherwise update the functions as follows

$$v_i^0(x,z) = \lambda v_i^1(x,z) + (1-\lambda) v_i^0(x,z)$$

   and go back to step ii. λ is a parameter that determines the speed of updating.

vi. After the value functions have converged, iterate on the CDF to calculate the stationary distribution of entrepreneurs in terms of wealth and productivity.

vii. Calculate the entrepreneurs' aggregate saving, borrowing and labor hiring.

5. Evaluate the aggregate excess demand for loans, deposits, labor, and defaulted loans. If the maximum excess demand is below a pre-specified tolerance criterion ε then stop. Otherwise, update the vector of prices $\{r_b, r_d, w, \mu\}$ in the direction that reduces the excess demand and go back to step 2.[73]

D.2 Transition induced by the reform

To compute the transitional dynamics induced by the change in capital requirement, we use the following numerical algorithm.

0. Calculate the stationary equilibrium before and after the reform; record the associated equilibrium price vectors as $\{r_b^*, r_d^*, w^*, \mu^*\}$ and $\{r_b^{**}, r_d^{**}, w^{**}, \mu^{**}\}$, respectively.[74] Save the associated post-reform policy functions for all agents, and the associated pre-reform stationary distributions for all agents.

1. Assume the transition occurs over $T = 500$ number of periods. Construct a vector of capital requirements $\{\kappa_t\}_{t=1}^T$ that resembles the Basel III implementation in Korea (summarized in Table 1). Assume this reform schedule is announced to all agents unexpectedly at the beginning of period $t = 1$.

2. Guess the initial path for general equilibrium prices over the transition $\{r_{t,b}^0, r_{t,d}^0, w_t^0, \mu_t^0\}_{t=1}^T$. In particular, assume that $\{r_{1,b}^0, r_{1,d}^0, w_1^0, \mu_1^0\} = \{r_b^*, r_d^*, w^*, \mu^*\}$ and $\{r_{T,b}^0, r_{T,d}^0, w_T^0, \mu_T^0\} = \{r_b^{**}, r_d^{**}, w^{**}, \mu^{**}\}$.[75]

3. Taking the paths of prices and capital requirements as given, calculate the full transition in two steps:

[73]We define the "excess demand" for defaulted loans as the difference between loans defaulted on by the borrowers and loans written-off by the lenders.

[74]Similarly as in Section D.1, while μ is technically not a price, we include it in the price vector with a slight abuse of terminology. We then define the excess demand for defaulted loans as the difference between loans defaulted on by the borrowers, and loans written-off by the lenders. Figure 31(b) shows that the required adjustments of μ across transition periods are smaller than 10^{-4} for the baseline reform, and smaller than 5×10^{-4} for the counterfactual "no rise of shadow lending" scenario.

[75]When calculating the transitional dynamics in the counterfactual scenario ("No rise of shadow lending"), we augment the price array with a time series for fixed cost of shadow lending, $\{f_{t,S}\}_{t=1}^T$. In every iteration, we vary the elements of this series period-by-period, as described in step 5, to guarantee that the share of shadow loans in total lending stays constant over the transition. Figure 31(a) plots the resulting sequence of fixed costs.

i. Solve for optimal policy and value functions over the transition for $t = T - 1, T-2, ..., 1$ (i.e. iterate backwards). For each period t, use policy and value functions just derived from period $t+1$ to solve the problem. The functions in period $t = T$ are the ones derived from the post-reform stationary equilibrium. Save the value and policy functions for all agents over the entire transition.

ii. Compute the evolution of all three distribution functions over the transition for $t = 2, 3, ..., T$ (i.e. iterate forward). For each period t, use the distribution functions just derived from period $t-1$, as well as the corresponding policy functions obtained in step i, to update the CDFs. The distributions in period $t = 1$ are the ones derived from the pre-reform stationary equilibrium. Calculate aggregate borrowing, saving, labor, and defaulted loans for all agents over the entire transition. Calculate the paths of excess demands in all markets.

4. If the largest excess demand from step $3i$ is smaller than a pre-specified tolerance criterion ε then stop. Otherwise, proceed to the next step.

5. For each period $t = 2, 3, ..., T$,[76] find the vector of prices $\{r^1_{t,b}, r^1_{t,d}, w^1_t, \mu^1_t\}$ that reduces the absolute value of excess demands in period $t-1$ below ε. In doing so, take as given the value and policy functions saved in step $3i$, as well as just-derived distribution functions from period $t = 1$. Once the market-clearing price vectors have been found, update the CDFs for all agents.

6. After the new paths of general equilibrium prices $\{r^1_{t,b}, r^1_{t,d}, w^1_t, \mu^1_t\}^T_{t=1}$ are found, update the initial paths using some dampening parameter λ as follows

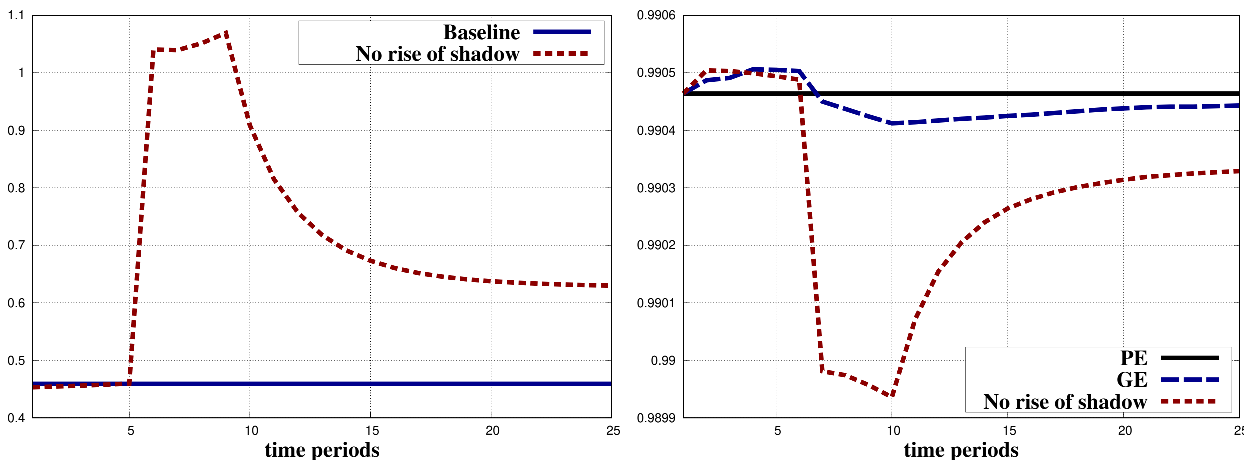
$$\left\{r^0_{t,b}, r^0_{t,d}, w^0_t, \mu^0_t\right\}^T_{t=1} = \lambda \left\{r^1_{t,b}, r^1_{t,d}, w^1_t, \mu^1_t\right\}^T_{t=1} + (1-\lambda)\left\{r^0_{t,b}, r^0_{t,d}, w^0_t, \mu^0_t\right\}^T_{t=1}$$

and go back to step 3.

E Further macroeconomic analysis using the model

In this appendix, we provide various additional results from the model that were omitted in the main text of the paper.

[76]Optionally, we can also go backwards, i.e. $t = T, T-1, ..., 2$. Depending on the calibration, either forward iterations, or backward iterations, or alternating between the two yields best convergence properties.



(a) Fixed cost parameter f_S (b) Mean asset repayment μ

Figure 31: Fixed cost f_S and mean asset repayment μ over the transition

E.1 Key untargeted pre-reform moments

To evaluate the model's fit, Table 22 lists a collection of important moments that were untargeted in our calibration procedure. The main aggregate moment to consider is the average loans-to-deposits ratio among banks of 1.04. By separately targeting the aggregate loans-to-equity and deposits-to-equity ratios, this moment is indirectly tied to the data. However, it is reassuring that our model also replicates it by averaging across individual banks (i.e. an unweighted average). Table 22 also shows that our wider model comes close to reproducing the average amount of corporate debt in the economy of 63%, as inferred from Korean data in 2008-2021.

Table 22: Key untargeted pre-reform moments

Moment	Model	Data
Corp. debt/output ratio	0.70	0.63
E(loans/deposits)	1.04	1.04
E(realized cap. ratio of small)	10.78	10.64
E(realized cap. ratio of large)	11.34	11.35
St. dev. (realized cap. ratio of small)	1.52	1.93
St. dev. (realized cap. ratio of large)	1.71	0.99

Table 22 also considers the moments of realized capital ratios separately for the two bank groups, which are non-targeted (only the aggregate ones for all banks are targeted). The table shows that the model gets the levels correct, i.e. smaller banks tend to have lower pre-reform capital ratios, while larger banks tend to have higher. On the other hand, the model cannot match the difference in dispersions - in the data, capital ratios for non-DSIBs have double the standard deviation as the capital ratios of DSIBs, while in the model both dispersions are approximately similar.

E.2 Comparison of stationary equilibria

Table 23 presents further a more detailed comparison of the stationary equilibria of our model (relative to Table 5). In particular, it also presents the statistics for the counterfactual exercise discussed in Section 7, where together with an increase in capital requirements we also raise the fixed cost of operating as a shadow lender. It is in particular worth pointing out that the model predicts both mean and standard deviation of capital ratios to go up as a result of the reform, while the correlation of equity with capital ratio to drop. All these movements indeed occur in the data, although to a smaller extent.

Table 23: Stationary equilibria before the reform, after and in the counterfactual

	Before reform	After (PE)	After (GE)	Counter (GE)
Capital requirement	4%	8.5%	8.5%	8.5%
Banks				
Equity	100.00	9.52	104.76	129.94
Deposits	880.04	59.93	673.14	820.27
Loans	910.56	64.64	722.45	882.49
Reserves	61.60	4.20	47.12	57.42
Dividend	7.85	0.58	8.29	10.28
Capital ratios (in %)				
Mean	10.97	20.42	15.15	15.25
St.dev.	1.61	5.13	1.74	1.78
Corr w/ equity	38.59	-61.51	50.05	52.85
Prices				
r_b (in %)	3.44	3.44	3.48	3.56
r_d (in %)	1.64	1.64	1.44	1.49
$w \times 100$	29.51	29.51	29.50	29.49

E.3 Firm behavior in stationary equilibria

Table 24 presents further information about the behavior of firms in the model equilibria before and after the reform. All variables except for labor and productivity are expressed in terms of aggregate output which is normalized to 100. With the capital requirement of 4%, about 75% of firms choose to borrow, while around 18% are depositors. In line with basic intuition, borrowers tend to have lower wealth and physical capital, but they hire more labor and are more profitable. They are also the most productive, on average, but

Table 24: Stationary distribution of firms before the reform, after, and in the counterfactual

Before reform (capital requirement 4%)			
Aggregates:	Borrowers	Depositors	Shadow lenders
Share	75.21	18.56	6.23
Output	107.84	75.06	79.69
Assets	-93.63	97.37	482.28
Capital	278.93	231.35	226.99
Profit	52.52	36.55	38.81
Consumption	26.59	33.22	49.20
Wealth	211.90	361.93	760.60
Labor	40.20	27.98	29.71
Productivity	1.62	0.72	0.86

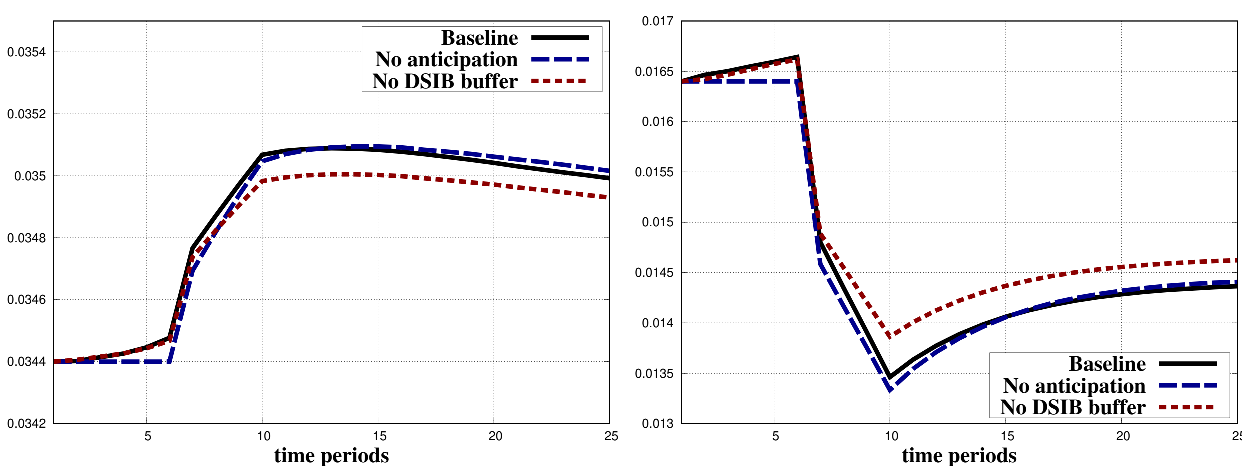
After reform (capital requirement 8.5%)			
Aggregates:	Borrowers	Depositors	Shadow lenders
Share	75.89	15.38	8.74
Output	107.51	75.17	78.14
Assets	-91.75	71.70	430.47
Capital	278.11	236.66	221.48
Profit	52.36	36.61	38.05
Consumption	26.60	32.21	46.80
Wealth	212.96	340.57	700.89
Labor	40.09	28.03	29.14
Productivity	1.62	0.69	0.86

Counterfactual (capital requirement 8.5%, f_S 36% higher)			
Aggregates:	Borrowers	Depositors	Shadow lenders
Share	75.44	18.78	5.77
Output	107.32	76.58	78.96
Assets	-90.45	90.89	504.64
Capital	276.27	239.71	222.54
Profit	52.27	37.29	38.45
Consumption	26.54	33.30	49.67
Wealth	212.36	363.90	779.74
Labor	40.04	28.57	29.46
Productivity	1.62	0.71	0.86

at the same time they consume the least. On the other hand, shadow lenders have the highest wealth and because they can achieve a higher return on their financial assets than regular depositors, they install less physical capital.

E.4 Other reform scenarios

In this section, we provide more details behind the two additional reform counterfactuals that are introduced in Section 7, namely the "No anticipation" and the "No extra DSIB buffer" scenarios. In the former, the reform schedule is enacted in the same format as in the baseline (modeled after the actual Korean implementation of Basel III as outlined in Table 1) except for the pre-announcement period, i.e. the reform is announced and immediately enforced in 2016. In the latter, there is no additional 1 percentage point capital requirement imposed on DSIBs (large banks in our model), as well as the partial requirements in years 2016-2019. Figure 32 plots the series of general equilibrium interest rates on loans and deposits for these two scenarios, along with the baseline (actual) reform. It can be observed that all paths are quite close to each other, implying that the two counterfactuals in general do not change the main results by much. The additional requirement on DSIB produces a clear, albeit minor (which is related to our negative result in Figure 16), difference in the interest rates in the long run, while the no anticipation scenario by construction eliminates any movement in prices ahead of the actual reform enactment. In terms of aggregate quantities, Figure 18 in Section 7 also shows that the paths of output over the transition are very similar for these two scenarios to the baseline one.



(a) Interest rate on loans

(b) Interest rate on deposits

Figure 32: Interest rates over the transition under alternative reform scenarios

Table 25 summarizes the results of running our headline regression (1) on the model-simulated banks under the two counterfactual scenarios along with the actual one. While the results are broadly in line with our main results, it is worth pointing out that the coefficient estimate on capital requirement in the "No anticipation" case is -0.1, noticeably smaller than -0.11 in the baseline. This difference is caused by the general equilibrium channel. Without anticipation, lending rate increases by more on impact of the reform (which reduces the banks' pressure on reducing credit supply), while the deposit rate declines by more (which makes financing of loans more attractive). As a result, the estimated impact of Basel III on bank lending is smaller with no anticipation of the reform. On the other hand, Table 25 also shows that the coefficient estimate under the "No extra DSIB buffer" scenario is essentially the same as in the baseline.

Table 25: Effects of capital requirements on credit growth under alternative scenarios

	Baseline reform		**No anticipation**		**No extra DSIB buffer**	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Δ ln loans	Δ ln loans	Δ ln loans	Δ ln loans	Δ ln loans	Δ ln loans
ln cap. req.	-0.114***	-0.114***	-0.101***	-0.101***	-0.116***	-0.116***
	(0.0020)	(0.0016)	(0.0020)	(0.0017)	(0.0020)	(0.0017)
ω	-1.965***	-0.076	-1.904***	-0.060	-1.851***	0.033
	(0.0594)	(0.0519)	(0.0578)	(0.0502)	(0.0600)	(0.0517)
Constant	2.098***	0.227***	2.019***	0.193***	1.988***	0.122**
	(0.0584)	(0.0513)	(0.0570)	(0.0496)	(0.0591)	(0.0511)
Observations	60,048	60,048	60,048	60,048	60,048	60,048
Fixed Effects	Bank	None	Bank	None	Bank	None
R2	0.212	0.0601	0.207	0.0504	0.210	0.0578

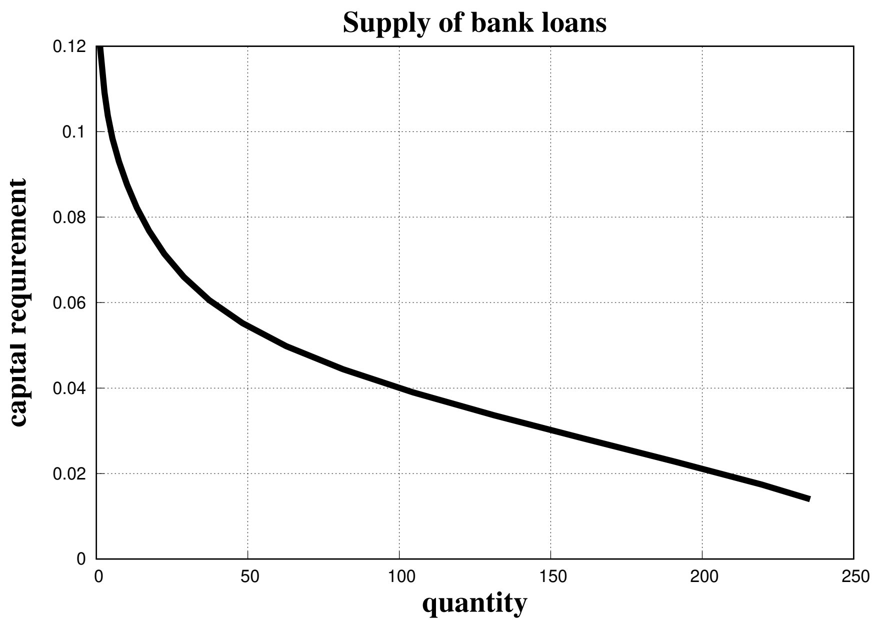
Note: Because our actual data ends at 2019Q1, we only use the years 2013-2018 in these model-based regressions. All standard errors (in parentheses) are clustered at the bank level. *** p<0.01

E.5 Supply and demand analysis

E.5.1 Steady states

In this section, we use our model to shed more light on the determinants of the change in equilibrium quantity of credit in response to the change in capital requirement. The observed change is driven by three main forces – the size of the shift in supply (under partial equilibrium) induced by the reform, and the price elasticities of supply and demand.

Shift in supply As a first step, we seek to understand the direction and size of the shift in the supply curve without any equilibrium adjustment. Figure 33 plots the regulated bank loans supply curve with respect to the capital requirement parameter under the pre-reform price vector. The elasticity of loan supply with respect to the capital requirement ranges from around -0.3 at lowest levels of the capital requirement, to around -10 at the highest levels, and it is equal to -1.7 at the pre-reform stationary equilibrium.



Note: Quantities are normalized such that the bank loan supply in the pre-reform stationary equilibrium is equal to 100.

Figure 33: Supply of bank loans with respect to capital requirement

While these elasticities may appear modest, we do not have a relevant benchmark to evaluate their magnitude. Nevertheless, it is intriguing that the quantity of credit supplied drops by over 90% in response to the Basel III regulation in partial equilibrium (Table 5). To better understand the drivers of this behavior, in Table 26 we calculate the distributions of realized tax rates under several scenarios, along with the normalized aggregate bank credit supply. The first row shows that the dividend tax faced by banks is around 6% on average, and the distribution is extremely concentrated such that only about a quarter of all banks face a positive tax rate in any given period. This result is a consequence of our assumption that the loan value shock ω follows the beta distribution. The second row of the table shows what happens when we calculate the post-reform ($\kappa = 8.5\%$) partial equilibrium stationary distribution using the pre-reform banks' policy functions $\{b', m', d'\}$.

Because policy functions are the same, the credit supply is unchanged, but the realized tax rates are very different via equation (20). Specifically, the average tax rate amounts to almost 80% and banks in the upper quartile of the distribution face rates in excess of 114%. Exposure to such high tax rates is suboptimal and to reduce them, banks must downsize. The third row shows this by presenting the post-reform partial equilibrium using the optimal policy functions. Even though the bank supply shrinks by over 90%, the average tax rate is still 24% and the distribution is much more dispersed. Finally, the last row shows that in the post-reform general equilibrium, a wider interest rate margin allows banks to reduce realized tax rates by about a half compared to the pre-reform economy. This is possible because banks have incentive to accumulate more equity, and they lend about 20% less.

Table 26: Distributions of tax rates (in %) and credit supply under different scenarios

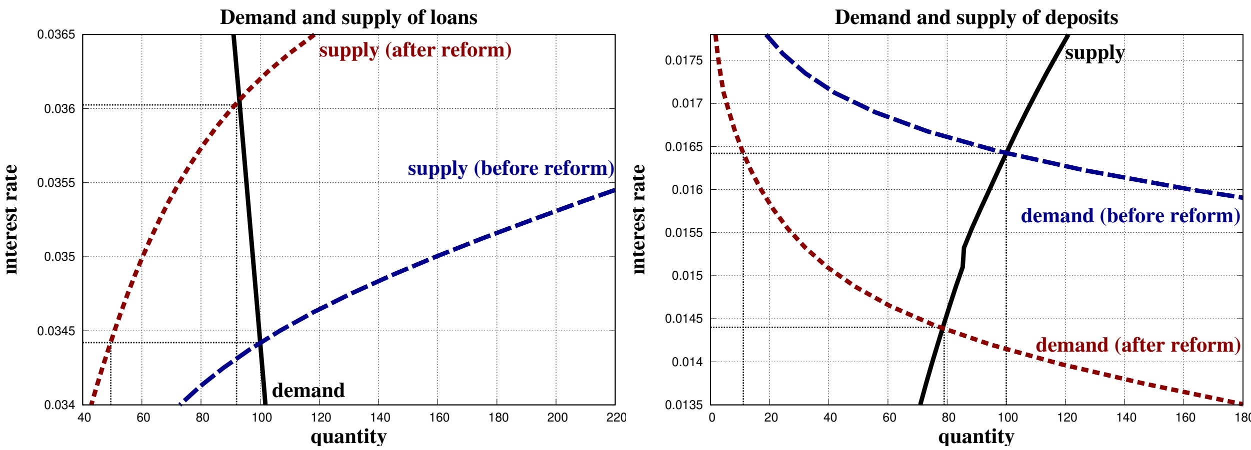
	Average	75% perc.	Median	25% perc.	Supply
Pre-reform GE	5.9	0.005	0	0	100
Post-reform PE with pre-reform policies	79.5	114.0	1.1	0	100
Post-reform PE	24.1	28.9	8.2	1.0	7.1
Post-reform GE	3.6	0	0	0	79

Note: Supply refers to bank credit supply and is normalized to the pre-reform GE level.

To summarize, our analysis indicates that the partial equilibrium elasticity of bank credit supply with respect to the capital requirement is driven by a non-linearity of the dividend tax function. This non-linearity arises in calibration as a result of matching the moments of realized bank capital ratios.

Price elasticities of supply and demand Figure 34 plots the stationary equilibrium demand and supply curves (before and after the reform) for loans and deposits in the model.

The main observation from analyzing different steady states of the model (Table 5) is that aggregate bank lending collapses in the partial equilibrium reform scenario, but declines very little in the general equilibrium. Panel 34(a) explains the forces underlying this result. While both the demand and the supply curves are elastic in the model, the latter is much more so (specifically, at the pre-reform stationary equilibrium, the price elasticity of demand is $\epsilon_d^b = -1.46$, while the elasticity of supply is $\epsilon_s^b = 34.82$). It is also notable that the supply curve of regulated banks is more elastic than the one of shadow lenders (55.1



(a) Loans (b) Deposits

Note: The figure is constructed by computing multiple stationary equilibria as function of the interest rate on loans (panel 34(a)) and deposits (panel 34(b)). All other prices (including r_d and r_b, respectively) are held constant at their pre-reform levels. Quantities are normalized to equal 100 at the respective pre-reform equilibrium quantities. The after-reform capital requirement is $\kappa = 8.5\%$ (for simplicity, we assume away the additional requirement for large banks).

Figure 34: Demand and supply curves in the model: loans and deposits

and 7.6, respectively), and hence, the post-reform aggregate supply curve becomes overall less elastic than before. As a result of this high elasticity of the supply of credit, relative to the demand, the new general equilibrium quantity is close to that of the pre-reform one.

Panel 34(b) presents a similar analysis for the deposits market. As Table 5 shows, the higher capital requirement induces banks to severely reduce their demand for deposits in the partial equilibrium. Analogously, because their demand for deposits is much more elastic than the supply (specifically, at the pre-reform stationary equilibrium, the price elasticity of demand is $\epsilon_d^b = -25.64$, while the elasticity of supply is $\epsilon_s^b = 2.17$, which aggregates the price elasticities of workers' and entrepreneurs' deposits of 1.16 and 3.34, respectively), the post-reform general equilibrium quantity of deposits is much closer to the pre-reform one than the partial equilibrium quantity. However, because shadow lenders are not deposit-taking institutions, it is ultimately still around 20% lower.

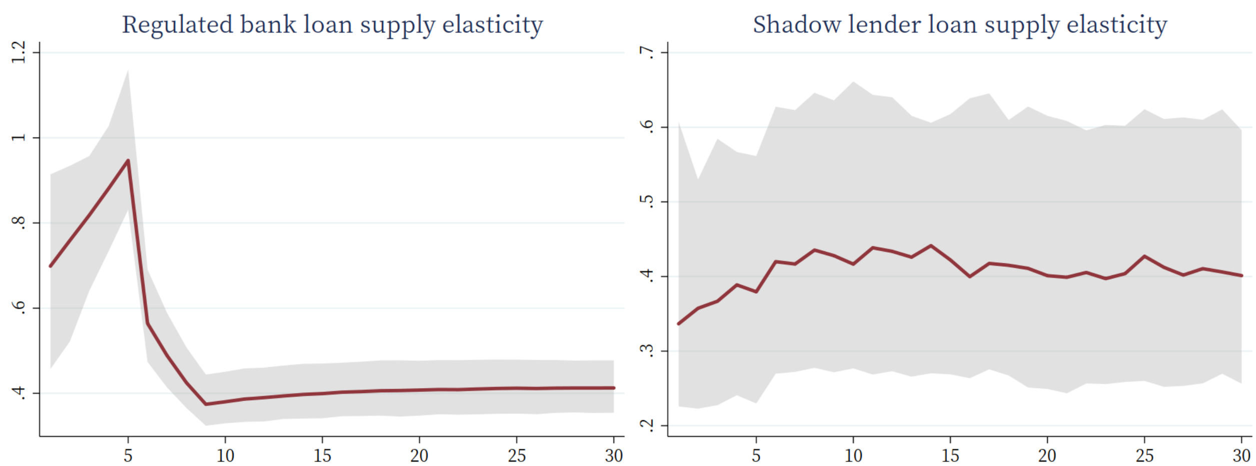
It should be remarked that all of these elasticities, which combine to deliver the general equilibrium effect of the capital requirement reform, arise endogenously from the model's microfoundations (rather than being assumed or imposed exogenously). They are also broadly consistent with the available evidence from the empirical literature. For example, in an analysis for the United Kingdom, Chiu and Hill (2018) estimate the elasticity of household deposit supply with respect to interest rate in the range from 0.1 to 0.5, while Karlan and Zinman (2019) conduct a field experiment in Mexico and find the elasticity of firms' demand for credit between -1.1 in the short run and -2.9 in the long run.

What stands out from the results reported above are the large (in absolute value) elasticities of banks' credit supply and deposit demand with respect to the corresponding interest rates. We are not aware of relevant empirical or theoretical literature that these numbers could be compared with. However, it should be emphasized that banks are highly responsive to the interest rate *margin*, on top of the individual interest rate *level*. Hence, by perturbing one price at a time, we also perturb the margin. To illustrate this point, we calculate the analogous "elasticities" where both interest rates (on loans and deposits, r_b and r_d) are perturbed simultaneously. The resulting bank elasticities are mostly muted: the elasticity of banks' credit supply is 0.84, while the elasticity of banks' deposit demand is 0.39 (notice the positive sign). By contrast, while other types of agents in the economy also respond to both interest rates, their elasticities are much less affected by conducting such an exercise. For example, the elasticity of entrepreneurs' credit demand becomes -1.58, while the elasticity of shadow lenders' credit supply is 4.20.

E.5.2 Elasticities over transition

The previous subsection is helpful in understanding the role of general equilibrium forces in the aggregate long-run impact of the reform. However, our headline estimate concerns the elasticity of credit growth with respect to capital requirement at micro level and over the course of Basel III implementation, a relatively short period of time. Not surprisingly, the two sets of results are quite different. In the long run, and on aggregate, the general equilibrium effect mostly offsets the partial equilibrium decline in quantity (Table 5). By contrast, on transition and at the micro level the gap between the two sets of estimates is notably smaller (Table 6). What explains this difference?

Breaking down the forces behind the estimates in Table 6 is a complex task. Here, we use the logic from the previous subsection to shed some light on why the micro estimates of the effects of higher capital requirements on credit provision are not as far apart in the partial and in the general equilibrium. Figure 35 plots the distributions of agents' individual elasticities of credit supply with respect to the interest rate on loans over the transition. As can be immediately noticed, these elasticities are much smaller than the ones obtained in the steady state. This is natural, given that the latter aggregate agents' responses over many periods, until convergence to a new stationary equilibrium, while the former represent a one-period response only. Also, in the aftermath of the reform, the regulated bank credit supply becomes less elastic which is consistent with Figure 34(a).

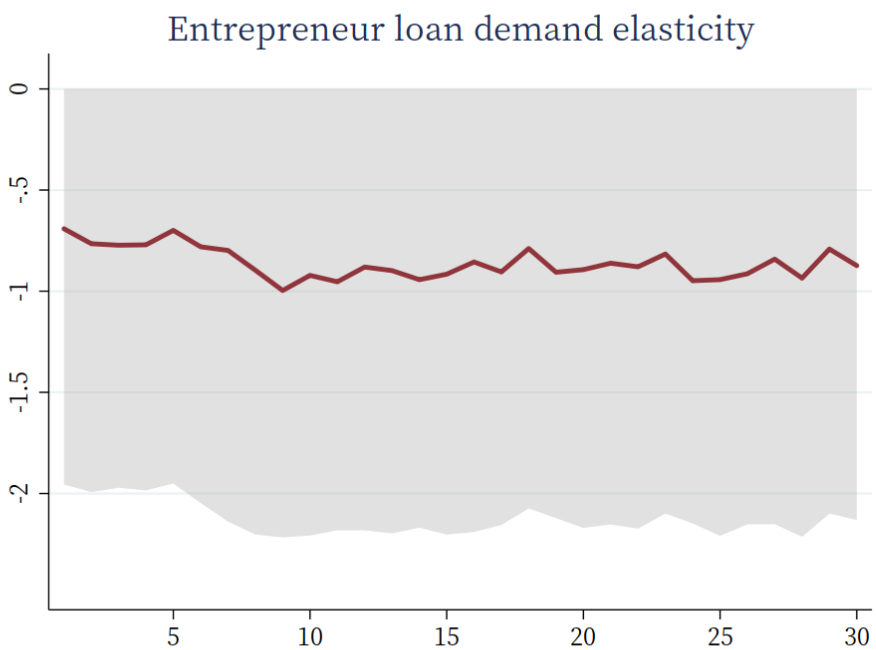


(a) Banks (b) Shadow lenders

Note: Red line plots the median elasticity among simulated agents over the transition, while the gray area spans the first and the third quartile. The elasticities are constructed by perturbing the loan interest rates, one period at a time, over the transition and solving for the optimal perturbed policy functions.

Figure 35: Individual price elasticities of credit supply over the transition

Similarly, Figure 36 plots the distribution of borrowers' individual elasticities of credit demand. The striking observation here is that these elasticities are highly dispersed, not much different from the demand elasticity in the steady state. They are also of the same order of magnitude as the elasticities of credit supply. As Figure 34 illustrates, the general equilibrium change in the quantity of credit is determined by the relative elasticities of supply and demand. Because over the transition, and at the micro level, elasticities are of similar size, it is not surprising that the gap between the partial and the general equilibrium effects of the reform is much smaller than in the long run, and in the aggregate.



Note: Red line plots the median elasticity among simulated agents over the transition, while gray area spans the first and the third quartile.The elasticities are constructed by perturbing the loan interest rates, one period at a time, over the transition and solving for the optimal perturbed policy functions. The elasticities at 75th percentile are all zero due to the fact that these entrepreneurs are at the borrowing constraint and do not respond to a change in interest rate on loans.

Figure 36: Individual price elasticities of credit demand over the transition