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Capital Regulation and Shadow Finance: A Quantitative Analysis

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This article 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.

Key words: Bank regulation, Shadow banks, Heterogeneous agents, General equilibrium

JEL codes: E44, E50, G21

"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

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demand for risky loans may be channelled 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 article 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 micro-structure 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 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. At 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 1% increase in capital requirement

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.

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

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 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 was up to 20 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% decrease in regulated bank credit causes a 1.3% 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 labour 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.

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.

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 uncovered in the econometric part of our article. 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 the 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, modelled 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 article 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

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 article, we assume that capital requirements are put in place (and then changed) exogenously.

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 article 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 *et al.* (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 *et al.* (2020) and Faria-e-Castro (2020) further analyse 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) analyse bank balance-sheet-driven recessions through the lens of a model with heterogeneous banks that act as Bewley agents. De Nicolò *et al.* (2014), Mankart *et al.* (2020), and Goel (2019) further analyse 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 (2022) 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 (2022) 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 article 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 article 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) analyse the market for syndicated corporate loans in the U.S. and find a strong causal effect of Basel III on the increased shadow banking market share. Relative to their work, our article analyses 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, Buchack *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 article 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 *et al.* (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 (2008), or Morais *et al.* (2019).

The remainder of this article 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. Section 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 (Section 2.2) and discuss various underlying details (Sections 2.3–2.6). Then, we describe the Basel III reform (Sections 2.7 and 2.8), and the banks' behaviour upon its introduction (Sections 2.9 and 2.10). This establishes a correlation between the two at an aggregate level. In the rest of the article, 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 article is a panel of firm-lender matched credit accounts for all public companies in South Korea. The data are 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 article, 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 Supplementary 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 article, 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 Section 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

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.

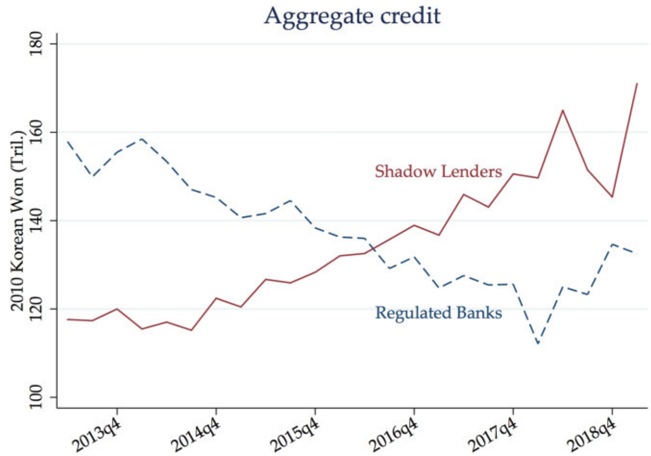

FIGURE 1

Total credit by regulated banks and shadow lenders

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.

2.2. *Aggregate credit in years 2013–19*

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 5 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

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 are 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 2013–19.

9. More specifically, six largest banks indicate Domestic Systemically Important Banks from 2016 to 2019. See Section B.5 for more details.

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 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 16 and 17 in Supplementary 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 Supplementary 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*

Supplementary 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 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

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.

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

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	$8.5 \ +H_{it}$	

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

around 100 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 Supplementary 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 2013–19 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 article. 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 Supplementary Appendix B.1 provides more details, here we flag the key takeaway. The new rules for minimum capital requirements, scheduled for implementation in years 2013–15, 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 1st December 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 1st January 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%. In addition to these baseline levels, a separate buffer was created for Domestic Systemically Important Banks, described by the variable H_{it}. The introduction of this buffer was also gradual and stretched over

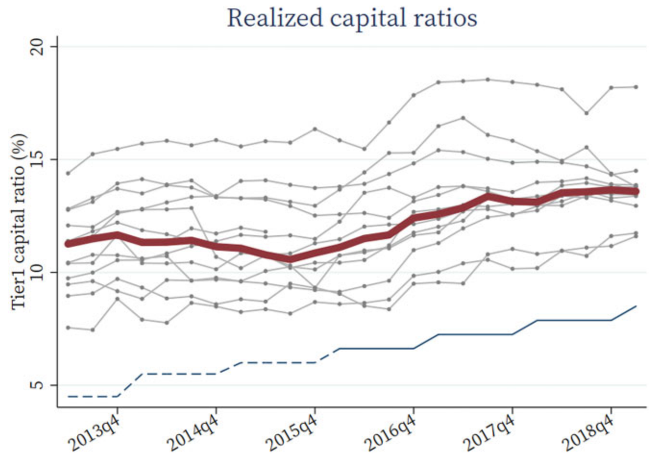

FIGURE 2
Realized bank capital ratios over time

Notes: Each dotted line represents the realized capital ratio of a domestic bank. The thick solid line is a median realized capital ratio in each quarter. The thin solid line at the bottom represents the minimum Tier 1 capital ratio requirement since 2016, while the thin dashed line is the "guideline" minimum capital ratio as in Table 1.

4 years. On the other hand, the counter-cyclical capital buffer has not been activated in Korea (remains at 0%).

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. Supplementary 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 Supplementary Appendix B.4.

2.9. *Bank capital ratios over time*

We now analyse 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 thick solid 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

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.

ratios is generally stable in years 2013–15 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 23 in Supplementary Appendix B.2 shows that the same trend is present for alternative measures of bank capital ratios.

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 Supplementary 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 article, 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 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

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

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***
	(0.043)	(0.047)	(0.043)	(0.046)
Constant	0.144*	0.143	0.356***	0.368***
	(0.078)	(0.084)	(0.082)	(0.089)
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
R^2	0.0699	0.0722	0.0919	0.0954

Notes: 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. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

arises from the core idea of Basel III, that a group of Domestic Systemically Important Banks 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 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%,

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. Section 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 Supplementary 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.

then they can expect it to cause a further 0.8% decline in corporate credit that would otherwise be constant.

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, 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 Supplementary Appendix Figure 24 that two bank groups display parallel trends in credit growth before the reform. The estimation results, available in Supplementary 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*).

To further analyse 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(a) 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 growth for DSIBs becomes significant only after the introduction of the Basel III regulation in 2016Q1 (vertical dashed line), consistent with the main estimation in Table 2. In Section 6.5, 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

20. As in Jiménez *et al.* (2012) or Blattner *et al.* (2020).

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.

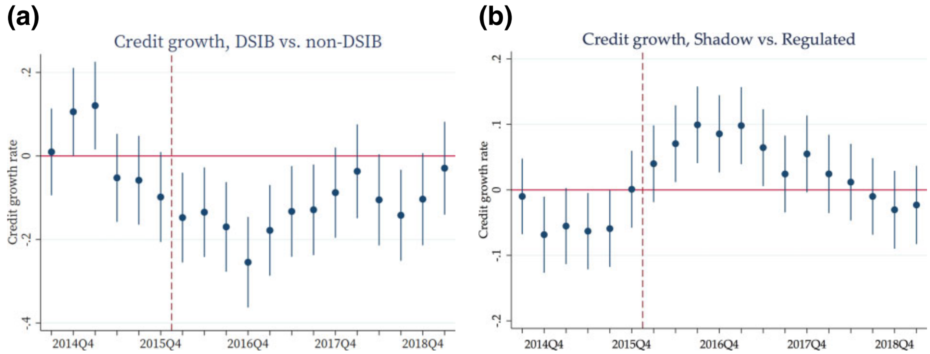

FIGURE 3

Differential credit growth at the time of the reform: (a) DSIBs versus non-DSIBs and (b) Shadow versus regulated

Notes: Each dot measures marginal credit growth of (i) DSIB compared to non-DSIB (left panel) (ii) shadow lenders compared to regulated banks (right panel) in each quarter, which is γ_t of equation (2) (left panel) and (3) (right panel). 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.

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 3(b) which shows the evolution of γ_t over time, along with 95% confidence intervals. Prior to 2016, *i.e.* before the penalties for non-compliance 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 Supplementary 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.

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

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

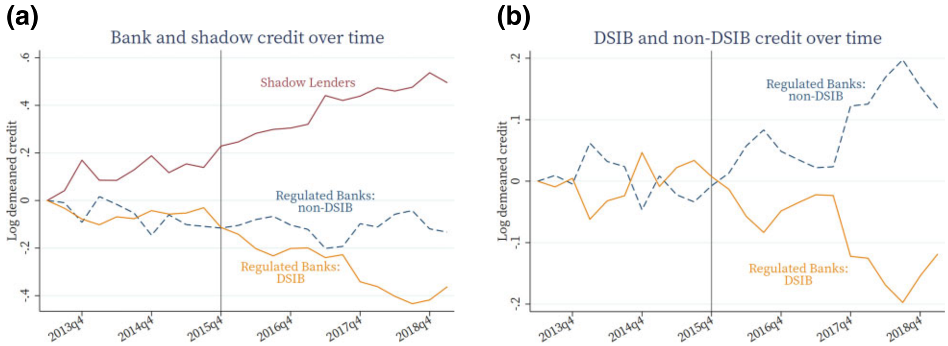

FIGURE 4

Substitution effect of shadow, DSIB, and non-DSIB credit: (a) Shadow versus regulated and (b) DSIB versus non-DSIB

Notes: Sample is restricted to firms that borrow from all three types of lenders (left) and both DSIB and non-DSIB, but not necessarily from shadow lenders (right). Observations are de-meaned at firm-quarter level, and normalized to the initial period of 2013Q2. By construction, the lines sum up to zero in each period.

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 4(a) 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 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

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.

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. In Figure 4(b), we visualize this observation by selecting only the firms that borrow both from DSIBs and non-DSIBs.[25] 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 Supplementary Appendix C.5, show that a 1% decrease in credit extended by regulated banks leads to a 1.3% increase in shadow credit.

3.5. *Robustness checks and further analysis*

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

In Supplementary 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 Supplementary 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.[26] 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

25. The sample firms included in Figure 4(b) not necessarily borrow from shadow lenders. Therefore, the sample firms in Figure 4(a) is a subset of those in Figure 4(b). Figure 4(b) is otherwise constructed in an analogous way to Figure 4(a).

26. We introduce permanent heterogeneity in bank discount factors to analyse the effects of size-specific regulation proposed in Basel III. None of the results in the article depend on this feature.

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.[27] 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 labour risk and accumulate precautionary savings. These savings are deposited in riskless bank accounts.

4.1. *Timeline and summary*

Figure 5 presents a graphic summary of the linkages between the different groups of agents in the model economy. Workers accumulate savings to insure against idiosyncratic labour 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.

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 6 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' value of risky assets, as well as the borrower default shocks. Following these realizations, the financial authorities measure banks' posted capital ratios and apply the taxes for non-compliance with capital requirements. Finally, day time is when production takes place.

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

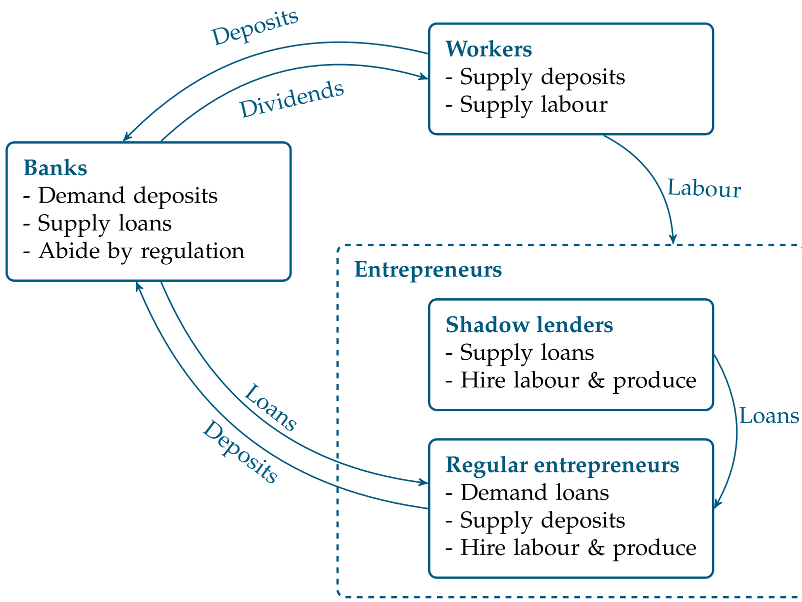

FIGURE 5
Structure of linkages in the model economy

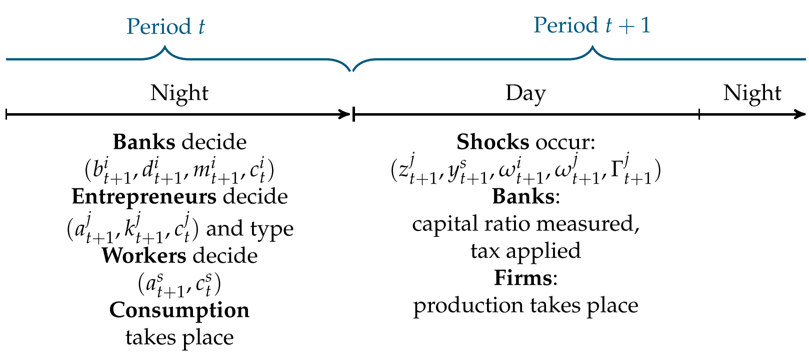

FIGURE 6
Timing of the model

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

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

$$\mathbb{E}_0 \sum_{t\geq 0} \tilde{\beta}^t_i u\left(\frac{c^i_t}{1+\tau(p^i_t)}\right), \tag{6}$$

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. $\tau(p_t^i)$ is a regulatory tax function on dividend payouts that depends on state variable p_t^i which measures compliance with capital requirements.

Budget constraint. Banks arrive in each period with a state variable of 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 the 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 realized equity of a bank in the next period 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. A typical minimum capital requirement states that $\frac{b_{t+1}^i\omega_{t+1}^i + m_{t+1}^i - d_{t+1}^i}{\chi b_{t+1}^i\omega_{t+1}^i} \geq \kappa$, where the numerator 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 be greater than an exogenously imposed parameter κ.

In our actual application, we impose this constraint in a soft form using a non-linear regulatory tax function τ introduced in equation (6). The tax rate depends on the distance of realized capital from the requirement and is measured by the following "penalty" variable

$$p_{t+1}^i = \kappa\chi b_{t+1}^i\omega_{t+1}^i - (b_{t+1}^i\omega_{t+1}^i + m_{t+1}^i - d_{t+1}^i). \tag{9}$$

This framework allows banks to violate the capital regulation at the expense of incurring a tax on dividend distribution. This in turn creates an incentive for banks to build a precautionary capital buffer, as is evident in the data (Figure 2). Supplementary Appendix D offers further discussion of the role of capital regulation by posing the model in recursive form, while in Section 5.1, we impose a specific functional form for the dividend tax function τ.

The second regulatory constraint is the minimum reserve requirement which states that banks must hold at least a fraction $\rho \in [0, 1]$ of 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 labour 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_t, each firm hires labour to maximize profit

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

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 to 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 behaviour.

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.[28]

An important assumption in our model is that the interest rates on regulated bank loans, and on shadow credit, are equal. While our data do not contain loan-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.

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 labour 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 labour. 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 $\mu \equiv \mathbb{E}(\omega_{t+1})$.[29] 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*

Supplementary Appendix D poses our model in a recursive form which is useful to directly compute the solution. It also provides a formal definition of a stationary equilibrium of this model.

28. 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.

29. 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 Supplementary Appendix E for details.

4.7. *Discussion of the model assumptions*

This section provides a discussion of some important modelling assumptions.

Household debt. Given the nature of our micro data, we focus on modelling 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 analyse the macroeconomic consequences of Basel III, our article 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.[30] 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.

We assume that both workers and entrepreneurs have the same CRRA preferences given by $u(c)=\frac{c^{1-\gamma}}{1-\gamma}$. The entrepreneurs' business productivity follows an autoregressive stochastic process of the form $\log(z_{t+1})=\rho_z\log(z_t)+\sigma_z\epsilon_{z,t+1}$. Similarly, the workers' labour efficiency follows the AR(1) 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. Supplementary Appendix E.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 article, 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 behaviour, 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 2010–13:[31] the ratios of average loans and average deposits to average equity,[32] 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.

30. 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).

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

32. As explained in Section 4.7, 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.

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	79.45	Joint calibration
b_B	Shape parameter b	0.78	Joint calibration
ϕ_0	Level parameter of penalty	15.90	Joint calibration
ϕ_1	Curvature parameter of penalty	6.35	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	Measure of large banks	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

This 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 behaviour of entrepreneurs and workers are fairly standard and consistent with existing literature.[33] The discount factor is set to 0.96, and risk aversion is 2. The persistence of both workers' labour 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.[34] Finally, we set the weight on capital α in the production technology by assuming a labour 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' labour efficiency shock σ_y, the

33. These parameter values are commonly used in macroeconomic studies modelling the Korean economy.

34. 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.

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	Labour 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		42.66%	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

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 labour 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 economy,[35] 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.

35. 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.

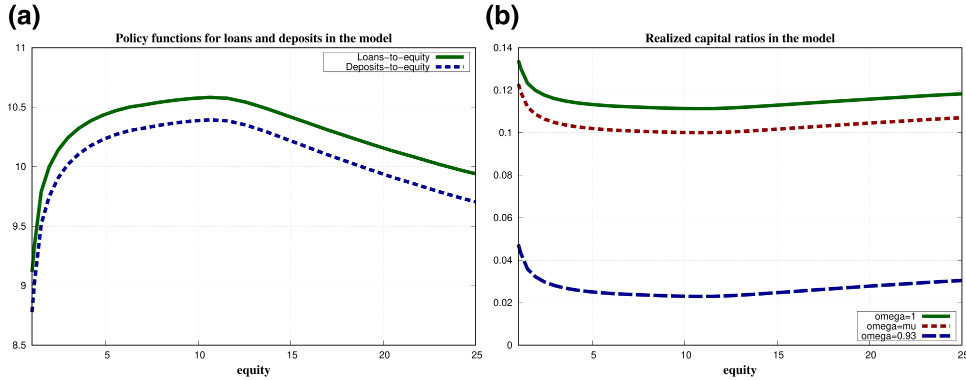

FIGURE 7

Bank policy functions in the model: (a) Loans and deposits and (b) Capital ratios

5.3. *Model mechanics*

Banks decisions. We first analyse the mechanics of a bank's decision making in the model, visualized in Figure 7. Figure 7(a) depicts the policy functions for loans and deposits (relative to equity) at different levels of bank equity. The main observation 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.[36] Small banks must build up equity to create a safe buffer above the requirement. On the other hand, large banks are exposed to a disproportionately higher penalty in the event of a bad shock to loan value and prefer to decumulate some of their equity.[37] We discipline this non-homotheticity of the penalty function by targeting the correlation of equity with realized capital ratios in the calibration.

Capital ratios. The effect of capital requirements on bank behaviour can be further appreciated by inspecting Figure 7(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.[38] 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.

36. 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.

37. Consistent with this logic, in Supplementary Appendix F.5.1, we also measure the average incurred taxes and show they are significantly lower (relative to equity) for the large banks who exhibit more precautionary behaviour.

38. 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 $\tau(\cdot)$.

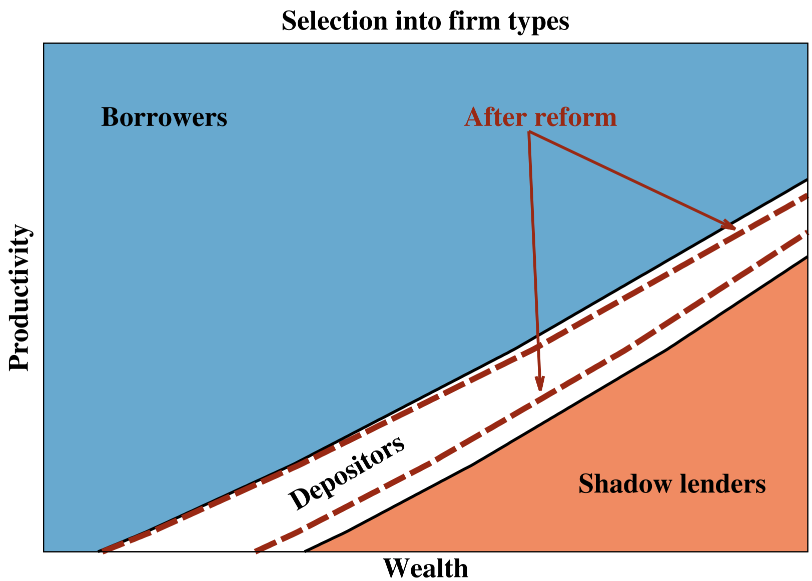

FIGURE 8

Endogenous selection into borrowers and shadow lenders in the model

Formation of shadow lenders. We next consider the behaviour of firms in our model, with a focus on the determinants of shadow lender formation in the economy. Figure 8 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 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 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.[39] 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 about 43% of all lending and just over 6% of all entrepreneurs choose to engage in this activity. The loan and deposit interest rates

39. 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.

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	8.20	104.79	129.76
Loans	910.54	55.36	723.22	882.49
Capital ratio (%)	10.97	20.82	15.10	15.20
Shadow lenders				
Loans	677.34	677.34	846.90	656.63
Share in all loans (%)	42.66	92.44	53.94	42.66
Share in all firms (%)	6.23	6.23	8.72	5.77
r_b (in %)	3.44	3.44	3.48	3.56
r_d (in %)	1.64	1.64	1.44	1.50
$w \times 100$	29.51	29.51	29.50	29.49

Notes: 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).

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 analyse 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).[40] As a first step, the second column of Table 5 presents the partial equilibrium results, *i.e.* the invariant distribution under fixed prices. A higher capital requirement leads the regulated banking sector to collapse in the long run which is caused by a significant increase in the dividend tax rates faced by the banks.[41] By contrast, 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.[42] 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

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

41. This large increase is due to the calibrated non-linearity in the tax function. In Supplementary Appendix F.5, we show this by measuring the incurred tax rates under different scenarios.

42. 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.

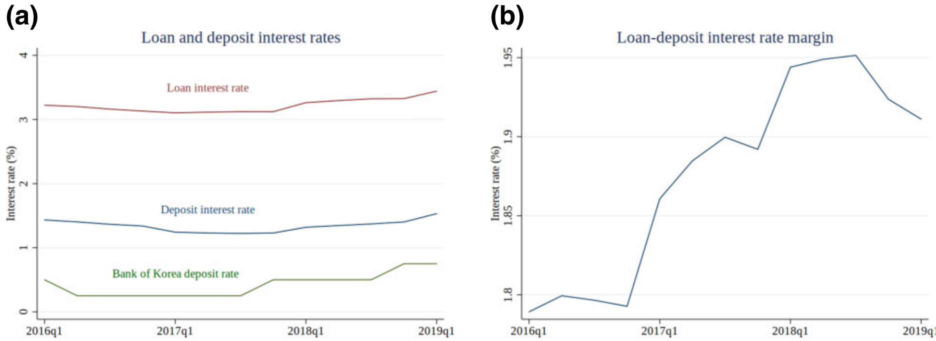

FIGURE 9

Interest rates for regulated banks in the data: (a) Interest rate levels and (b) Difference

Notes: 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.

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 government 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.[43] 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.

Supplementary Appendix F 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 9(a) plots the evolution of loan, deposit and a reference risk-free interest rate in years 2016–19, while Figure 9(b) calculates the corresponding loan-deposit interest spread. The rates are averages across regulated banks and weighted by their share in total credit.[44] As can be noticed, the rates do not vary significantly during this period,

43. See *e.g.* “Shadow Banks Need Regulation to Rein in Financial Risks”, *Bloomberg*, 1 November 2019; or “The clean-up of the non-bank sector needs to begin now”, *Financial Times*, 19 April 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.

44. 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.

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%.

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 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.[45] 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 10 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 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.[46]

Figure 11 presents the normalized paths of regulated bank lending. Figure 11(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, Figure 11(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, the share of shadow credit is kept constant in the counterfactual scenario (Figure 28(a) in Supplementary Appendix E.2 shows the sequence of fixed costs needed to generate it).

Figure 12(a) 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 2013–19. 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]

Figure 12(b) constructs the model counterpart to our empirical observation on the behaviour of bank capital ratios in Figure 2. It plots the distribution of realized capital ratios in the model

45. Supplementary Appendix E.2 describes the details of the algorithm we use to compute the transition.

46. Because our model does not allow for external equity financing (motivated by the evidence in Supplementary Appendix A.7), the overall cost of bank funding essentially boils down to the cost of deposits and the utility cost of building retained earnings.

47. The mismatch in years 2014–15 indicates that the change in credit provision in anticipation of the reform was potentially stronger in reality than what our model predicts.

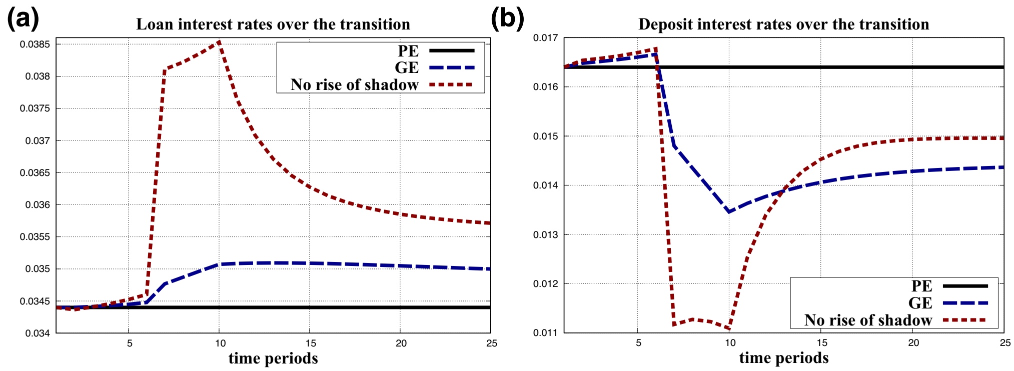

FIGURE 10

General equilibrium interest rates over the transition: (a) Interest rate on loans and (b) Interest rate on deposits

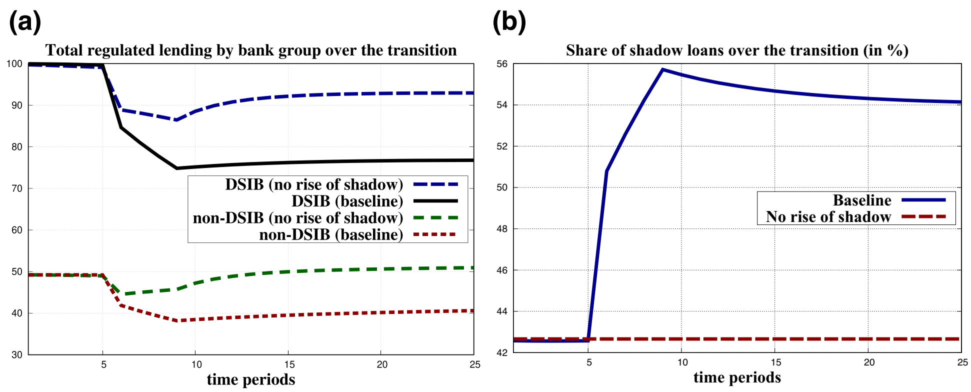

FIGURE 11

Equilibrium lending over the transition: (a) Total bank lending by bank group and (b) Share of shadow loans

for the periods of the transition that correspond to years 2013–19. Recall from 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]

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 large numbers of banks and entrepreneurs and track them over the transition. Then, we run the model-analogues

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 2010–13, 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.

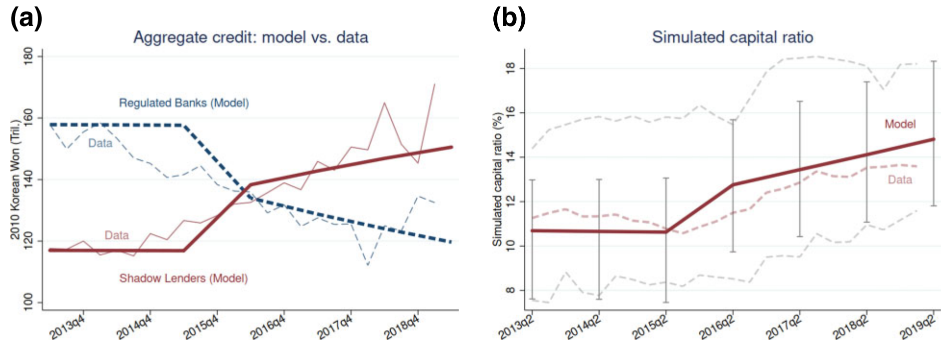

FIGURE 12
Total credit and distribution of capital ratios: model simulation vs data: (a) Total credit supply by lender type and (b) Realized bank capital ratios

Notes: (left panel): 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. (right panel): The thick solid line represents the capital ratio of a median bank. The vertical bars stretch from the 5th to the 95th percentile of realized capital ratios in the simulated sample. Dashed lines represent the maximum, median, and minimum capital ratios in the data.

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

	General equilibrium		Partial equilibrium		No rise of shadow	
Variables	(1) Δ ln loans	(2) Δ ln loans	(3) Δ ln loans	(4) Δ ln loans	(5) Δ ln loans	(6) Δ ln loans
ln cap. req.	−0.12***	−0.12***	−0.16***	−0.16***	−0.03***	−0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
omega	−1.85***	0.02	−1.92***	0.02	−1.79***	−0.03
	(0.06)	(0.05)	(0.07)	(0.06)	(0.06)	(0.05)
Constant	1.98***	0.14***	2.12***	0.19***	1.81***	0.06
	(0.06)	(0.05)	(0.07)	(0.05)	(0.06)	(0.05)
Observations	60,048	60,048	60,048	60,048	60,048	60,048
Fixed effects	Bank	None	Bank	None	Bank	None
R^2	0.210	0.0624	0.247	0.106	0.159	0.0045

Notes: Because our actual data ends at 2019Q1, we only use the years 2013–18 in these model-based regressions. All standard errors (in parentheses) are clustered at the bank level. *** $p < 0.01$.

of regressions (1) and (3), which we used in our econometric analysis, for the corresponding time period, and we compare the results.

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 −0.12, 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.

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.

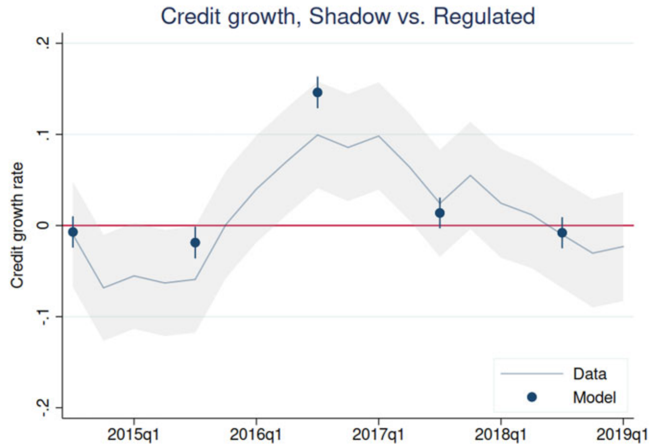

FIGURE 13

Estimated interaction effects of time and shadow dummies: model versus data

Notes: The solid line represents estimated coefficients from the data (Figure 3(b)), and the shaded area represents the 95% confidence interval of estimated coefficients. The 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.

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 in the empirical analysis, we include time and lender fixed effects.[50] Figure 13 presents our results in the form of a graph that is a direct counterpart to Figure 3(b). Before the reform becomes binding in 2016, the growth of credit provided by shadow lenders does not significantly outpace the one by regulated banks. This changes 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.

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 a third 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 contracts by around 90% in the long run without a general equilibrium adjustment. The reason behind this contrast is that Table 5 shows a long-run adjustment, while the regression results only include the banks' short-run response over the period of gradual implementation

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.

of the reform. Columns 5 and 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 10 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 11(a)).

6.4. *Understanding the difference between long- and short-run effects*

In Supplementary Appendix F.5, we further explore the difference between the long- and short-run effects of the reform on bank lending by measuring price elasticities of supply and demand for credit. We show that in the long run, the demand for loans (coming from firms) and the supply of deposits (coming from firms and workers), are characterized by relatively low price elasticities compared to the banks' supply of loans and demand for deposits. As a result of these low elasticities, the post-reform quantities in both markets do not deviate much from the pre-reform ones and most of the general equilibrium adjustment is reflected in the change in interest rates. On the other hand, the post-reform partial equilibrium quantities react much more due to the absence of price adjustment.

Supplementary Appendix F.5 also shows that, by contrast, in each period of the transition lenders are much less responsive to a change in loans interest rate than across stationary equilibria. This makes sense given that what we consider here is a single response on the transition, rather than multi-period convergence to a new stationary distribution. Consequently, with the elasticities of demand and supply being of similar order of magnitude, the estimated impact of the reform on quantity of credit in the partial equilibrium is not as far apart from the general equilibrium as the steady-state analysis would suggest.

6.5. *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 analyse 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(a), Figure 14(a) 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. Figure 14(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

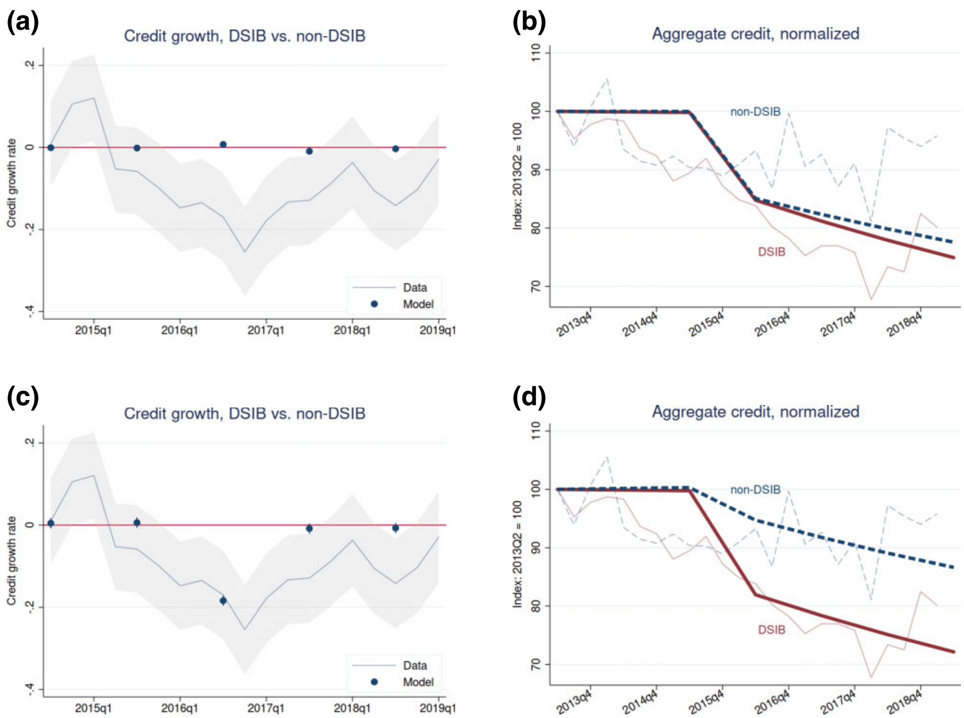

FIGURE 14

DSIB versus non-DSIB lending in the model - baseline (upper panels) and differential tax parameters (bottom panels): (a) Estimated marginal effects (baseline); (b) Normalized total lending (baseline); (c) Estimated marginal effects (diff. tax. param.); and (d) Normalized total lending (diff. tax. param.)

Notes: (left panels): The solid line represents estimated coefficients from the data (Figure 3(a)), and the shaded area represents the 95% confidence interval of estimated coefficients. The 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 panels): Thin solid and dashed lines are data aggregate credit by DSIB and Supplementary non-DSIB, respectively, normalized to 100 in 2013Q2 (Supplementary Appendix Figure 24). Thick lines are model counterparts, where each year in the model is associated with the second quarter in the data.

regulating systemically important banks, such as "more intensive 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] The bottom panels of Figure 14 present the results of this exercise, which can be easily compared

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 Supplementary Appendix E). 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.

to the baseline results shown in the upper panels. As is evident, the more intensive supervision 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 1.59% and 0.62%, respectively, down from 3.57% and 0.92% before the reform. Under the disproportionate supervision, these averages flip to become 1.05% and 1.20%.

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 Supplementary Appendix F. To highlight the role of shadow lenders in the economy, as well as the role of the reform design and implementation, we analyse 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 kicks in unexpectedly in 2016.

Figure 15 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 Supplementary Appendix F.4.

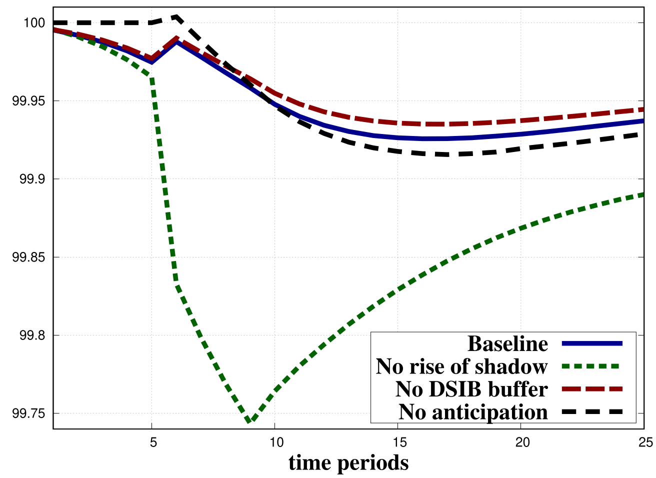

FIGURE 15

Output paths over transition under different scenarios

8. CONCLUSION

In this article, 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 article can be used to inform future research about the quantitative impact of such changes on financial intermediation markets.

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Supplementary Data

Supplementary data are available at *Review of Economic Studies* online.

Data Availability Statement

The data and code underlying this research are available on Zenodo at https://doi.org/10.5281/zenodo.8333077.

REFERENCES

AGUIAR, M., CHATTERJEE, S., COLE, H.L., *et al.* (2016), "Chapter 21 - Quantitative models of sovereign debt crises", in TAYLOR, J.B. and UHLIG, H. (eds) *Handbook of Macroeconomics* (Elsevier) Vol. 2, 1697–1755. https://doi.org/10.1016/bs.hesmac.2016.04.005.

ALIAGA-DÍAZ, R., OLIVERO, M. P. and POWELL, A. (2018), "Monetary Policy and Anti-Cyclical Bank Capital Regulation", *Economic Inquiry*, **56**, 837–858.

AMITI, M. and WEINSTEIN, D.E. (2018), "How Much Do Idiosyncratic Bank Shocks Affect Investment? Evidence from Matched Bank-Firm Loan Data", *Journal of Political Economy*, **126**, 525–587.

BAKER, M. and WURGLER, J. (2015), "Do Strict Capital Requirements Raise the Cost of Capital? Bank Regulation, Capital Structure, and the Low-Risk Anomaly", *American Economic Review: Papers & Proceedings*, **105**, 315–320.

BEGENAU, J. and LANDVOIGT, T. (2022), "Financial Regulation in a Quantitative Model of Modern Banking System", *The Review of Economic Studies*, **89**, 1748–1784.

BIANCHI, J. and BIGIO, S. (2022), "Banks, Liquidity Management and Monetary Policy", *Econometrica*, **90**, 391–454.

BLATTNER, L., FARINHA, L. and REBELO, F. (2020), "When Losses Turn into Loans: The Cost of Undercapitalized Banks", Unpublished manuscript.

BUCHACK, G., MATVOS, G., PISKORSKI, T., *et al.* (2018a), "Fintech, Regulatory Arbitrage, and The Rise of Shadow Banks" (Working Paper 23288, NBER).

BUCHACK, G., MATVOS, G., PISKORSKI, T., *et al.* (2018b), "The Limits of Shadow Banks" (Working Paper 25149, NBER).

CORBAE, D. and D'ERASMO, P. (2021), "Capital Requirements in a Quantitative Model of Banking Industry Dynamics", *Econometrica*, **89**, 2975–3023.

DAVYDIUK, T. (2019), "Dynamic Bank Capital Requirements", Unpublished manuscript.

DEMPSEY, K. P. (2022), "Capital Requirements with Non-Bank Finance", Unpublished manuscript.

DE NICOLÒ, G., GAMBA, A. and LUCCHETTA, M. (2014), "Microprudential Regulation in a Dynamic Model of Banking", *Review of Financial Studies*, **27**, 2097–2138.

FARIA-E-CASTRO, M. (2020), "A Quantitative Analysis of the Countercyclical Capital Buffer", Unpublished manuscript.

GOEL, T. (2019), "Banking Industry Dynamics and Size-Dependent Capital Regulation", Unpublished manuscript.

GOLDSMITH-PINKHAM, P., SORKIN, I. and SWIFT, H. (2020), "Bartik Instruments: What, When, Why, and How", *American Economic Review*, **110**, 2586–2624.

IRANI, R. M., IYER, R., MEISENZAHL, R. R., *et al.* (2021), "The Rise of Shadow Banking: Evidence from Capital Regulation", *Review of Financial Studies*, **34**, 2181–2235.

JAMILOV, R. and MONACELLI, T. (2020), "Bewley Banks", Unpublished manuscript.

JIMÉNEZ, G., ONGENA, S., PEYDRÓ, J.-L., *et al.* (2012), "Credit Supply and Monetary Policy: Identifying the Bank Balance-Sheet Channel with Loan Applications", *American Economic Review*, **102**, 2301–2326.

KASHYAP, A. K., STEIN, J. C. and HANSON, S. (2010), "An Analysis of the Impact of "Substantially Heightened" Capital Requirements on Large Financial Institutions", Unpublished manuscript.

KHWAJA, A. I. and MIAN, A. (2008), "Tracing the Impact of Bank Liquidity Shocks: Evidence from an Emerging Market", *American Economic Review*, **98**, 1413–1442.

KIM, U. and JUNG, H. (2019), "Monetary Policy's Risk-Taking Channel in Consideration of Bank's Profit and Asset Structure: Evidence from Korea" (Bank of Korea Working Paper), 2019-7, [in Korean].

KISIN, R. and MANELA, A. (2016), "The Shadow Cost of Bank Capital Requirements", *The Review of Financial Studies*, **29**, 1780–1820.

LEE, H. and PALUSZYNSKI, R. (2022), "Intangible Capital and Shadow Financing", Unpublished manuscript.

LUCAS, R. E. (1978), "On the Size Distribution of Business Firms", *The Bell Journal of Economics*, **9**, 508–523.

MANKART, J., MICHAELIDES, A. and PAGRATIS, S. (2020), "Bank Capital Buffers in a Dynamic Model", *Financial Management*, **49**, 473–502.

MORAIS, B., PEYDRÓ, J.-L., ROLDÁN-PEÑA, J., *et al.* (2019), "The International Bank Lending Channel of Monetary Policy Rates and QE: Credit Supply, Reach-for-Yield, and Real Effects", *The Journal of Finance*, **74**, 55–90.

NGUYEN, T. T. (2014), "Bank Capital Requirements: A Quantitative Analysis", Unpublished manuscript.

RÍOS-RULL, J.-V., TAKAMURA, T. and TERAJIMA, Y. (2020), "Banking Dynamics, Market Discipline and Capital Regulations", Unpublished manuscript.

VAN DEN HEUVEL, S. J. (2008), "The Welfare Cost of Bank Capital Requirements", *Journal of Monetary Economics*, **55**, 298–320.