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Discussion Paper No. 2020-E-3

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JAPAN

IMES Discussion Paper Series 2020-E-3
March 2020

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Abstract

This paper studies capital requirements and their welfare implications in a dynamic general equilibrium model of banking. I embed two, less commonly considered but important, mechanisms. Firstly, banks choose entry and exit, which lets the number of banks change endogenously. Strengthening capital requirements reduces banks' franchise value and damages their liquidity providing function through the extensive margin. Secondly, since equity issuance is costly for banks, they precautionarily hold capital buffers against future liquidity shocks. This behavior makes present capital requirements only occasionally binding. My model shows that the optimal capital requirement would be lower than that in the literature because of the expanded negative effects of capital requirements. To maintain financial stability without damaging banks' liquidity provision, strengthening capital requirements needs to be accompanied by reducing the cost of equity issuance for banks.

Keywords: Bank capital requirements; Occasionally binding constraints; Endogenous default; Entry and exit; General equilibrium model
JEL classification: E00, G21, G28

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This paper is one chapter of my PhD thesis, undertaken at the University of Wisconsin-Madison. I am grateful to the members of my dissertation committee, Kenneth West, Enghin Atalay, Oliver Levine, and especially my main advisor, Dean Corbae for invaluable guidance. I would like to thank Saleem Bahaj, Xavier Freixas, Kalin Nikolov, Francesco Zanetti, and staff at the Bank of Japan for their helpful comments. I also appreciate the comments of seminar participants at the University of Wisconsin-Madison and VSBF 2018. All remaining errors are my own. Views expressed in this paper are those of the author and do not necessarily reflect the official views of the Bank of Japan.

1 Introduction

The rationale for bank capital requirements is to mitigate moral hazard problems caused by banks and depositors due to deposit insurance and limited liability. Because of deposit insurance, depositors do not care about whether their banks default or not. In this case, banks can always raise deposits at risk-free rates, regardless of the risks they are taking. Furthermore, a combination of deposit insurance and limited liability keeps banks from internalizing wider economic costs generated by their defaults. Increasing bank capital requirements would reduce the frequency of bank defaults by reducing their leverage, or increasing "skin-in-the-game", and would limit those moral hazard problems.[1] A reduction of bank defaults means a reduction of social losses. Increasing capital requirements, on the other hand, encourages banks to issue equity rather than collect deposits in financing their investments. This would be negative for social welfare because equity capital cannot provide households with liquidity services; only deposits can. Another reason why issuing equity may have negative implications for social welfare is that there are problems caused by informational asymmetries between equity issuers and investors.[2] Consequently, capital requirements can be both positive and negative for social welfare.

In this paper, I develop a dynamic general equilibrium model of banking in order to study capital requirements and their implications for social welfare. In the model, infinitely-lived heterogeneous banks intermediate funds from households to entrepreneurs, who can hold productive capital in the economy. Banks are allowed to accumulate their own capital by both retaining past earnings and issuing equity. Banks' only assets are loans, which are financed by deposits and equity capital. In considering the welfare implications of capital requirements, I combine two, less commonly considered but important, mechanisms as follows.[3]

The first extension is to determine the number of banks endogenously through entry and exit decisions. This extension allows me to explore the impact of bank capital requirements on the size and competitiveness of the banking industry. One current

[1]See Admati et al. (2013), Admati and Hellwig (2014, 2018), and Myerson (2014), for example.

[2]A bank's decision to issue equity is likely to be interpreted by the market as a "bad signal" about the issuing bank's value (Bolton and Freixas (2006)). This possible undervaluation of equity issuers could generate social welfare losses.

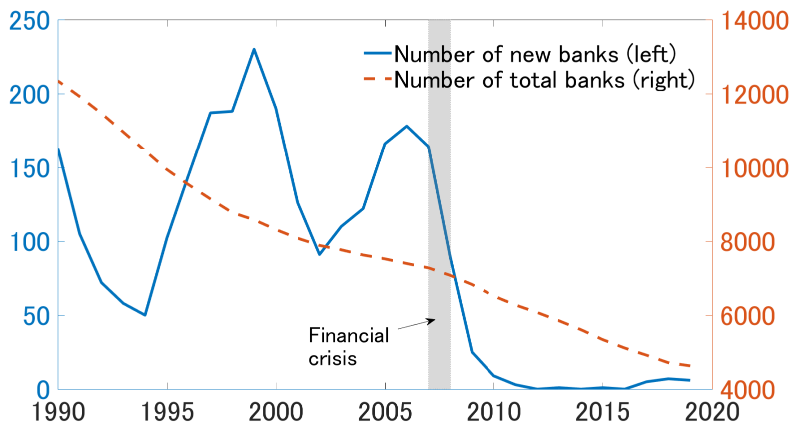
[3]My model is built upon the banking sector framework of Corbae and D'Erasmo (2014). They focus mainly on the business cycle effects of capital requirements, while my focus is on their welfare implications. To do so, I extend Corbae and D'Erasmo's (2014) modeling of the household and production sectors.

concern for U.S. policy makers is that, as shown in Figure 1, the rate of new bank formation declined dramatically after the financial crisis of 2008 and this has accelerated a decline in the total number of commercial banks since then. This decline could be attributable to stricter bank regulations imposed in response to the crisis (Adams and Gramlich (2016) and McCord and Prescott (2014)). Potential negative impacts of increasing capital requirements on the number of banks would merit consideration by bank regulators. How new regulations on banks can affect their competitiveness and market structure is also important from a policy perspective.[4] Endogenizing the number of banks makes it possible to deduce some implications of capital requirements for such concerns of policy makers. To be concrete, in my model, banks compete with each other in the loan market; specifically, if the expected value of banking business is greater than the entry cost, new banks enter the market and compete with incumbent banks to the point where expected value falls to the entry cost à la Hopenhayn (1992). The harsher the capital requirement is, the more banks need to hold capital and resort to costly equity issuance. Therefore, their profitability, or franchise value, declines and fewer banks enter the industry. As a result of this, the number of new entrants decrease in the industry, thereby (i) reducing the total number of banks and (ii) making the industry more concentrated. Taking the effects through the extensive margin into account in this way contributes to a dramatic reduction of banks' liquidity supply to the economy.

[4]For example, the Prudential Regulation Authority (PRA), which is a part of the Bank of England, had a secondary competitive objective. The PRA is supposed to investigate whether or not prudential interventions negatively affect market competitiveness by, for example, creating barriers to entry for new banks and preventing effective competition among banks. For details, see Dickinson et al. (2015Q4) and the following website of the PRA.

https://www.bankofengland.co.uk/prudential-regulation/secondary-competition-objective

Figure 1: Number of new banks and total banks in the U.S.



Note: Source: FDIC

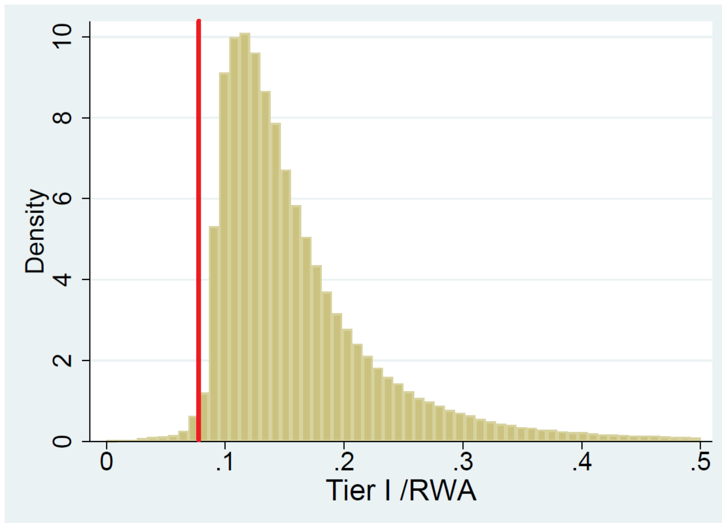
The second extension in my model is to make banks' equity finance costly and allow their deposit collection to be exposed to shocks. In this setting, increasing precautionary capital buffers in the present by retaining profits means a reduction of costly equity issuance in the future. This encourages infinitely-lived banks to hold more capital now than required by their regulators. In short, bank capital requirements are only occasionally binding.[5] This implication is confirmed by the data. Figure 2 shows the distribution of Tier1 capital to risk-weighted assets (RWA) ratios for U.S. commercial banks from the fourth quarter of 2010 to the third quarter of 2017.[6] Following the Basel Accord, U.S. authorities categorize banks whose capital ratios are ($\frac{\text{Tier 1}}{\text{RWA}} \geq 8\%$) as "well capitalized". One can see that banks hold more capital than required. In addition, the size of this buffer differs by bank. Most of the previous theoretical literature assumes bank capital requirements to be always binding. Due to this assumption, increasing the requirement by a specific amount increases banks' capital holdings by the same amount, thereby improving financial stability through an increase of "skin-in-the-game". However, the marginal impact of elevating capital requirements on banks' capital holdings has not been illuminated fully for the case where the requirements are

[5]The fact that banks have excess capital over regulatory minimum requirements has been widely acknowledged and empirically investigated (Flannery and Rangan (2008), Lindquist (2004), Angora et al. (2011), and Nier and Baumann (2006)). These papers argue that banks accumulate capital buffers as "self-insurance" against costs related to market discipline if they fall below the regulatory minimum capital ratio. In line with these studies, banks in my model accumulate capital buffers for precautionary motives too.

[6]Basel III was agreed upon by the Basel Committee on Banking Supervision in the fourth quarter of 2010.

not binding. My model attempts to do this.

Figure 2: Distribution of the capital ratio for U.S. commercial banks



Note: Source: Call Reports from 2010Q4 (when Basel III was agreed upon) to 2017Q3. The capital ratio is defined as the ratio of Tier1 capital to risk weighed assets (rcon7206 in Call Reports). Following the Basel Accord, the FDIC categorizes those banks whose capital ratios are ($\frac{\text{Tier 1}}{\text{RWA}} \geq 8\%$) as "well capitalized".

My model has the following implications. The first implication is that the negative impact of bank capital requirements on social welfare can be greater than conventionally believed in the literature. Due to the endogenously determined number of banks, increasing capital requirements contributes to reducing the number of banks and deposits supplied to the economy significantly through the extensive margin, despite the fact that deposits provide important liquidity services to households.

The second implication is that, although bank capital requirements are only occasionally binding, banks actually increase their capital holdings when the requirements are strengthened because their precautionary motives remain. This benefits financial stability by reducing bank defaults.

The third implication is that the positive effect of strengthening capital requirements is partly offset by a side effect of dynamic banking. Facing an infinite time horizon, banks care about both current and future profits (franchise value). Strengthening capital requirements decreases banks' franchise value and encourages them to default.[7]

[7]This result is consistent with Hellmann et al. (2000) and Sarin and Summers (2016). Hellmann et

Lastly, the optimal capital requirement that maximizes social welfare is estimated to be lower than that in the previous literature. This is because the negative consequence (the reduction of deposits) is augmented while the positive consequence (the reduction of bank defaults) is mitigated.

I also investigate how these welfare implications change in response to changes in relevant model parameters. In line with Admati et al. (2013) and Admati and Hellwig's (2014, 2018) findings, I show that reducing the value of the parameter that determines the equity issuance cost for banks pushes up the optimal capital requirement by mitigating the reduction of deposits supplied by banks to the economy through the extensive margin. This is because reducing equity issuance cost encourages new banks to enter the industry, even when the requirements are harsher. One policy implication is that to maintain financial stability without damaging banks' liquidity provision, the strengthening of capital requirements needs to be accompanied by a reduction in the cost of equity issuance for banks. Moreover, I show that increasing the value of the parameter that controls the liquidation cost of defaulted banks pushes up the optimal capital requirement. The reason is that the parameter represents the size of the negative externality that banks do not internalize due to limited liability. The larger the value is, the more beneficial are capital requirements for social welfare. Even though my model does not explicitly include an element of systemic risk (i.e., a large negative externality caused by bank defaults), increasing the parameter can be interpreted as taking into account some of the effects that systemic risk has on social welfare.

The remainder of the paper is organized as follows. Section 2 reviews the literature. Sections 3 introduces the model. Section 4 defines equilibrium. Section 5 presents a calibration of the model for the U.S. economy. Section 6 shows a quantitative analysis, checks its robustness, and discusses how its differences in model settings from previous studies could affect policy implications. Section 7 concludes.

2 Related Literature

This study contributes to theoretical analyses of bank capital requirements by explicitly considering two mechanisms: the endogenously determined number of banks and

al. (2000) insist that bank capital requirements alone cannot achieve Pareto-efficient outcomes because they harm banks' franchise value and encourage them to engage in risky behavior. This side effect of capital requirements is absent in models in which banks live for only one period, as in Clerc et al. (2015) and Mendicino et al. (2018).

occasionally binding capital requirements.[8] These help to glean more useful welfare implications of capital requirements. Those implications are difficult to gain by analyzing partial equilibrium models developed for different purposes, such as those proposed by De Nicolo et al. (2014), Van den Heuvel (2002), and Corbae et al. (2016). For this reason, there are many papers that quantitatively investigate the welfare implications using general equilibrium frameworks, including Begenau (2019), Clerc et al. (2015), Mendicino et al. (2018), Van den Heuvel (2008), Malherbe (2019), Martinez-Miera and Suarez (2014), and Van den Heuvel (2016).

The welfare implications of bank capital requirements vary depending on the model environment and what externalities bank capital requirements are expected to mitigate. This paper adds to the literature by embedding the two mechanisms mentioned above and coming up with new welfare implications. My model improves Corbae and D'Erasmo's (2014) modeling of households and firms.[9] Nguyen (2015) also constructs a general equilibrium model of banking in which banks choose entry and exit. He focuses on the impact of bank capital requirements on economic growth by embedding an endogenous growth channel, while I am interested in the impact of bank capital requirements on social welfare with more detailed economic environments. To be more concrete, I allow banks to compete with each other in the loan market while Nguyen (2015) keeps banks from doing so by assuming that they are engaged in banking businesses on their own islands. In my model, taking into account competition among banks makes it possible to glean additional welfare implications of capital requirements by considering changes in the level of competition in response to changes in the level of capital requirements.

[8] As a theoretical study on occasionally binding capital constraints, Elizalde et al. (2007) investigate banks' precautionary motives by using a simple partial equilibrium model. In their model, funding by capital is more expensive than funding by deposits. Banks face idiosyncratic shocks to loan valuation and a negative shock reduces banks' capital significantly. They find that if banks can freely recapitalize ex-post (after a shock occurs), they have no incentive to hold capital ex-ante (before a shock occurs). On the other hand, if they cannot recapitalize ex-post at all, banks hold positive amounts of capital ex-ante. This is because if their capital is negative after the shock occurs, they have no choice but to exit and lose their franchise value. In order to prevent the loss of their franchise value, they may hold a positive amount of capital ex-ante even though capital is more expensive than deposits. I extend Elizalde et al. (2007) to the case in which recapitalization is possible but not free.

[9] In Corbae and D'Erasmo (2014), banks are engaged in Stackelberg-type imperfect competition. The authors analyze not only steady states but also business cycle effects by considering aggregate shocks, using a method similar to Krusell and Smith (1998).

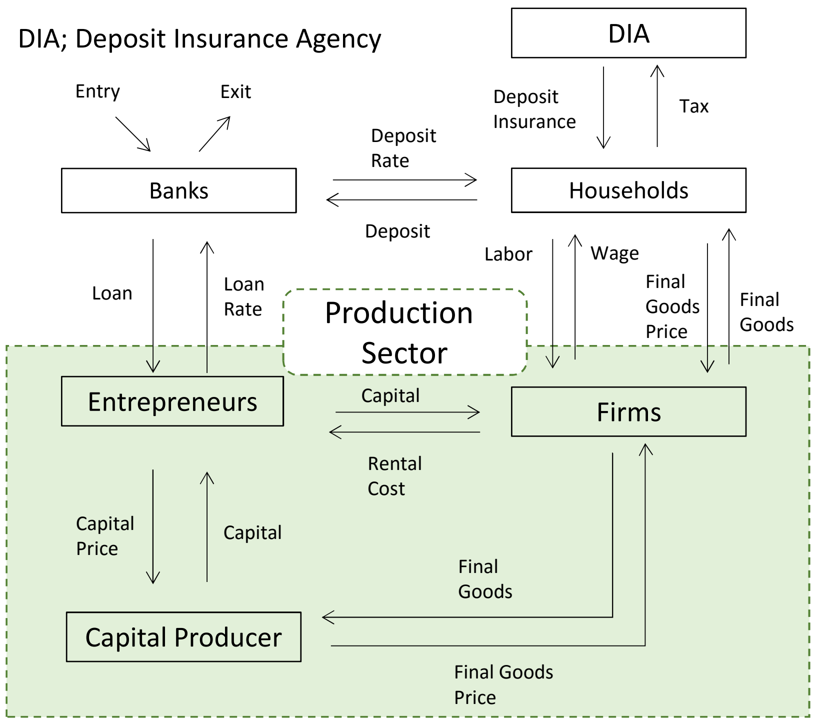
3 Environment

There are two goods in the economy: consumption (final) goods and capital goods. The economy is populated by households and entrepreneurs. Households supply labor to firms and provide deposits to banks. Entrepreneurs are the only agents who can own and maintain productive capital, which they can rent to firms. The entrepreneurs act as the agents of households and seek to maximize dividends paid to households. Banks (which are owned by households) make loans to entrepreneurs using deposits and equity capital. Banks can perfectly diversify the risk that individual borrowers face, as in Diamond (1984). Banks can default on the deposit contract with households and entrepreneurs can default on the loan contract with banks.[10] When a bank defaults on deposits, the bank is liquidated by a deposit insurance agency (DIA) and the DIA repays the deposits using revenues from a lump-sum tax levied on households.[11] Firms produce consumption (final) goods using capital goods and labor supplied by households. A capital producer produces capital goods from consumption (final) goods. There is no aggregate uncertainty in the economy and I will focus solely on the stationary equilibrium in the quantitative part of this paper. Figure 3 shows an overview of the model.

[10] Since banks can perfectly diversify the individual risk of their borrowers, their loans are basically riskless (borrower defaults damage banks' equity capital only deterministically through the reduction of retained earnings). Hence, borrower defaults do not lead to bank defaults directly. However, some banks do default on the equilibrium path when their continuation value becomes less than zero. This can occur because some banks, facing funding shocks, need to issue equity capital in order to satisfy capital requirements. Since equity issuance is costly, some of them find it better to choose to default (and obtain a zero value due to limited liability) rather than continue by satisfying the requirements.

[11] DIA is a governmental organization which provides deposit insurance. In the U.S., it corresponds to the FDIC.

Figure 3: Overview of the model



3.1 Households

Households of measure one are identical, risk averse, and live forever. They make deposits d_t in the banks. Deposits are fully guaranteed by the DIA, so they receive $R_t^D d_{t-1}$ whether the bank defaults or not. They value consumption c_t and liquidity services d_t from deposit holdings while they disvalue working l_t.[12] Furthermore, households obtain dividends from capital producers Π_t^c, entrepreneurs c_t^e, and banks DIV_t. The household budget constraint is

$$c_t + d_t \leq w_t l_t + R_t^D d_{t-1} - T_t + \Pi_t^c + c_t^e + DIV_t \tag{1}$$

where T_t is a lump-sum tax for deposit insurance and w_t is the wage.

The objective function of households is defined as

[12] Obtaining utility from liquidity services is similar to Van den Heuvel (2008) and Begenau (2019) and can be interpreted similarly to "money-in-utility" (Sidrauski (1967b,a)). Thanks to this assumption, the funding cost of deposits is cheaper than that of equity capital for banks, which means the Modigliani-Miller theorem does not hold and banks' liability composition has an impact on welfare.

$$E_t\left[\sum_{i=0}^{\infty}(\beta)^{t+i}u(c_{t+i},l_{t+i},d_{t+i})\right]=E_t\left[\sum_{i=0}^{\infty}(\beta)^{t+i}\left[\log(c_{t+i})+\log(1+\theta\frac{d_{t+i}}{c_{t+i}})-\frac{\varphi}{1+\eta}(l_{t+i})^{1+\eta}\right]\right] \tag{2}$$

where $u(c,l,d)$ is the household's utility function, β is the discount factor, θ is the utility weight on liquidity services, η is the inverse of the Frisch elasticity, and φ is the marginal disutility of labor.[13]

3.2 Entrepreneurs

I follow Clerc et al. (2015) in modeling entrepreneurs. There is a continuum of identical, infinitely-lived entrepreneurs of measure one who maximize dividends to households. Hence, they act as the agents of households.[14] They are the only agents who can own and maintain the capital stock. They retain some fraction of profits as net worth and can also borrow b_t from banks at the contractual and state non-contingent rate of R_t^F to finance the purchase of capital. Their resource constraint is

$$q_t^K k_t - b_t = n_t^e \tag{3}$$

where q_t^K is the price of capital, k_t is the amount of capital entrepreneurs hold at the end of period t, and n_t^e is their net worth.

Entrepreneurs rent capital to the firms who produce the consumption (final) goods. At the beginning of period $t+1$, an idiosyncratic shock to the entrepreneur's efficiency unit of capital occurs. Because of this, her efficient capital holdings becomes $\omega_{t+1}^e k_t$, where ω_{t+1}^e is the idiosyncratic shock. The shock is independently and identically distributed across entrepreneurs and time according to a log-normal distribution with an expected value of one and variance σ_e^2.[15] Then, she receives r_{t+1}^K per efficiency

[13] This utility function with respect to (c,d) is a special case of Van den Heuvel (2008). It yields a constant deposit rate $R^D=\frac{1-\theta}{\beta}$ and inelastic deposit supply at this rate. An inelastic deposit supply is assumed in most of the previous literature on banking (Corbae et al. (2016), Corbae and D'Erasmo (2014), De Nicolo et al. (2014), and Nguyen (2015)). This is contrary to Begenau (2019), in which banks face an inelastic deposit supply, which is the key factor for her main result. In this paper, I use a relatively simple assumption for the deposit market for model tractability and focus instead on the loan market and banks' entry and exit dynamics. In the latter part of this paper, I discuss how the difference between these assumptions could impact the main result.

[14] Entrepreneurs are easily integrated into households as in Mendicino et al. (2018). However, the model implications are not changed by this.

[15] This shock is introduced to rationalize the existence of default in equilibrium, which is usually

unit of capital as the rental rate of capital. Her final wealth W^e_{t+1} at period $t+1$ becomes $W^e_{t+1} = \omega^e_{t+1}\left\{r^K_{t+1} + (1-\delta)q^K_{t+1}\right\}k_t - R^F_t b_t$ if she repays the loan (R^F_t is state non-contingent) and it becomes $W^e_{t+1} = 0$ if she defaults on the loan, where δ is the depreciation rate of capital.[16] Following the CSV framework[17], when an entrepreneur defaults on her loan, the bank recovers only a fraction $1-\mu^e$ of the gross return of the capital available to the defaulted entrepreneur, where μ^e represents auditing costs incurred by the bank. Hence, the bank recovers

$$(1-\mu^e)\omega^e_{t+1}\left\{r^K_{t+1} + (1-\delta)q^K_{t+1}\right\}k_t$$

from non-performing loans.

The objective function of an entrepreneur at period t is defined as

$$\max_{c^e_{t+1}, n^e_{t+1}} (c^e_{t+1})^{\chi^e}(n^e_{t+1})^{1-\chi^e} \tag{4}$$

where n^e_{t+1} is the amount retained for the next period, c^e_{t+1} is the dividends to the households, and χ^e is an exogenous parameter.[18] She is subject to the following budget constraint at period $t+1$

$$c^e_{t+1} + n^e_{t+1} \leq W^e_{t+1}. \tag{5}$$

Retained earnings are aggregated and distributed to entrepreneurs equally at the end of each period so that they are identical at the beginning of each period.

used in the BGG framework (Bernanke et al. (1999)). The shock is best thought of as capturing some form of economic obsolescence of capital held by each entrepreneur, as in Gertler and Karadi (2011) and Gertler et al. (2012).

[16]While the loan rate is state contingent in the original BGG model (Bernanke et al. (1999)), I assume it is state non-contingent, following Clerc et al. (2015) and Mendicino et al. (2018). However, this point is irrelevant for the results because I assume the economy is at the steady-state in the later analyses.

[17]The size of idiosyncratic shocks can be verified by paying some auditing cost (costly state verification).

[18]By using this objective function, entrepreneurs distribute χ^e of their profits to households and retain the rest for the next period. Mendicino et al. (2018) integrate entrepreneurs into households by assuming some fraction of workers randomly become entrepreneurs while the same fraction of entrepreneurs randomly become workers at every period. In the equilibrium of this setting, entrepreneurs only pay dividends upon retirement and they maximize their net worth until then. Hence, the equilibrium results do not change by assuming χ^e corresponds to the switching rate between workers and entrepreneurs.

3.3 Banks

The banking sector is similar to Corbae and D'Erasmo (2014).[19]

At the end of period $t-1$, a bank with equity e_t chooses the amount of dividends div_t to pay to households (i.e., shareholders) and how much bank capital

$$n_t = e_t - div_t \tag{6}$$

to hold in the next period. At the beginning of period t, the amount of deposits experiences an idiosyncratic shock D_t (liquidity shock). Banks hit with the liquidity shock choose whether to default and exit or repay and continue in business. If a bank defaults, its value is zero due to limited liability. If a bank chooses to continue, the bank makes loans

$$L_t = n_t + D_t \tag{7}$$

to the entrepreneurs.

When making these choices, banks are subject to several constraints. In order to continue their business, banks must hold a positive amount of capital at the beginning of the period

$$n_t = e_t - div_t \geq 0. \tag{8}$$

Furthermore, banks are subject to the capital requirement

$$\Phi_t \equiv \frac{n_t}{L_t} \geq \phi \tag{9}$$

where Φ_t is the capital-to-loan ratio and ϕ is the capital requirement policy.

The bank's equity e_{t+1} at the end of the period can be expressed as

$$e_{t+1} = E(L_t, D_t) = \widetilde{R}^F_{t+1} L_t - R^D_{t+1} D_t - \kappa \tag{10}$$

where $\widetilde{R}^F_{t+1}$ is the aggregate return of diversified loans and κ is the fixed cost of operating in the loan market. Notice that $\widetilde{R}^F_{t+1} \neq R^F_t$ (the contractual rate) since some borrowers do not repay the loans and default. When borrowers default, the aggregate return of

[19] In Corbae and D'Erasmo (2014), there are two types of banks (big banks and fringe banks) which are engaged in Stackelberg-type imperfect competition. For simplicity, I model only one type of banks who are perfectly competitive price takers.

loans $\widetilde{R}^F_{t+1}$ is reduced, which damages the bank's equity through the reduction of their retained earnings. As for the deposit rate R^D_t, this rate is exactly the same as the rate in the households' budget constraint (1) because of deposit insurance. Liquidity shocks D_{t+1} are i.i.d across banks and follow an AR(1) process

$$\log D_{t+1} = (1-\rho)\overline{\log D} + \rho \log D_t + \epsilon_{t+1}$$

where $\epsilon_t \sim N(0, \sigma^2)$. The parameters associated with this process are estimated later. New entrants enter with zero equity and finance their initial capital externally. Figure 4 summarizes the timeline of events in each period.

In period t, the bank's objective function is the expected discounted value of dividends

$$E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \Theta(div_{t+i}) \tag{11}$$

where $\Lambda_{t,t+i}$ is the households' stochastic discount factor and $\Theta(\cdot)$ is the function

$$\Theta(d) = \begin{cases} d & \text{if } d \geq 0 \\ d(1+a) & \text{if } d < 0. \end{cases} \tag{12}$$

Notice that negative d is not negative dividends, but rather equity issuance (recapitalization), which is assumed to be costly, as in Cooley and Quadrini (2001), Hennessy and Whited (2007), and Corbae and D'Erasmo (2014). The parameter a is the equity issuance cost and expresses how costly recapitalization is. This cost is due to problems caused by informational asymmetries between equity issuers and investors.[20] This parameter is estimated later.

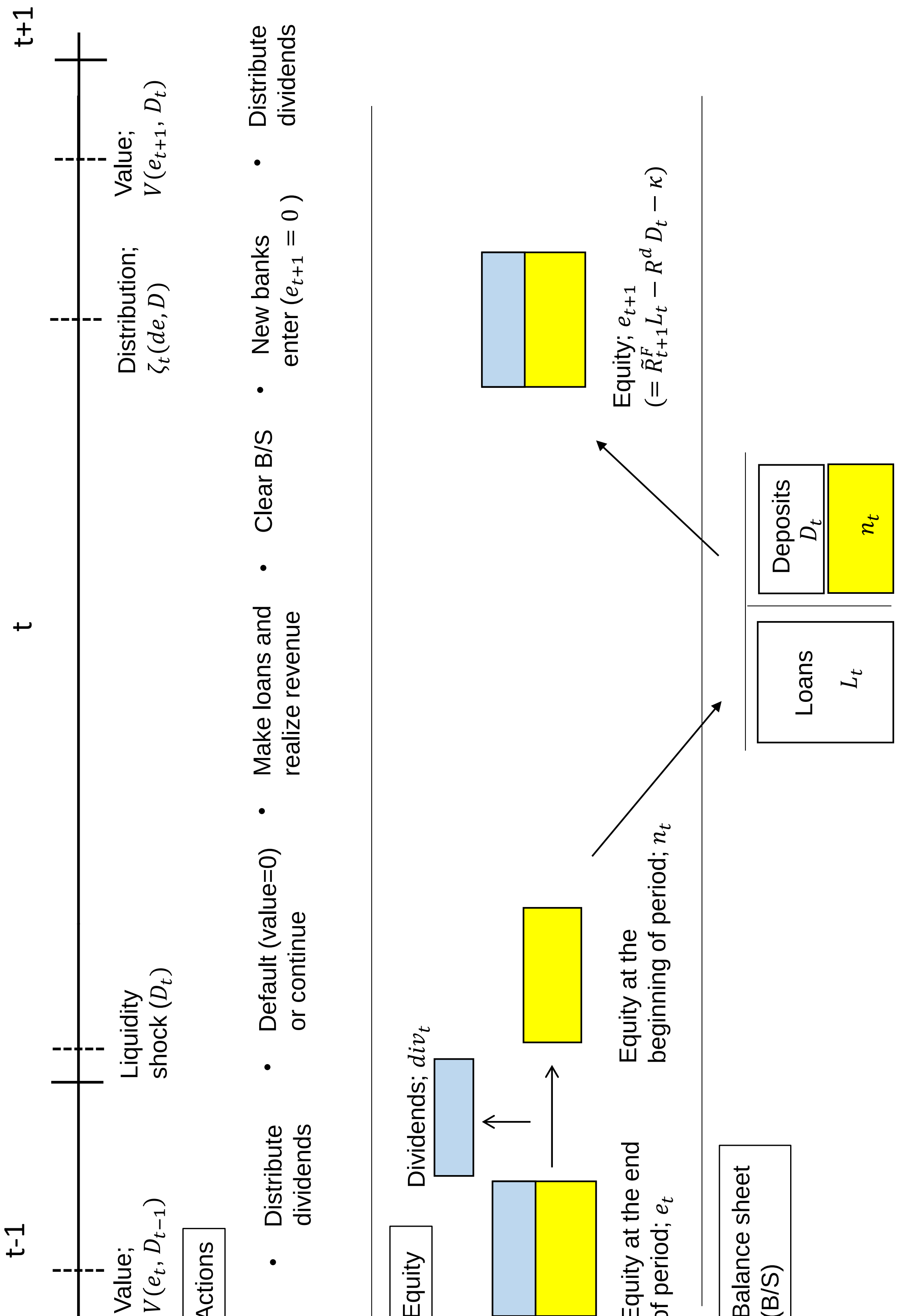
If a bank defaults and exits, its assets are liquidated by the DIA. The losses incurred by the DIA, given by

$$\underbrace{R^D_{t+1} D_t}_{\text{Deposit obligation}} - \underbrace{\xi \widetilde{R}^F_{t+1} L_t}_{\text{Liquidated value of assets}}, \tag{13}$$

are covered by the lump-sum tax levied on households, where $\xi \leq 1$ is a parameter associated with the liquidation costs of the assets. In my model, social losses associated

[20] A bank's decision to issue equity is likely to be interpreted by the market as a bad signal about the issuing bank's value (Bolton and Freixas (2006)).

Figure 4: Timeline for banks



with bank defaults come from these liquidation costs.

3.4 Firms and the Capital Producer

Firms produce consumption goods from capital rented from entrepreneurs k_{t-1} and labor supplied by households l_t using the standard Cobb-Douglas production function

$$y_t = A_t k_{t-1}^{\alpha} l_t^{1-\alpha} \tag{14}$$

where A_t is productivity.[21]

Households own the capital producer. The capital producer produces capital goods using consumption goods and sells them to entrepreneurs at price q_t^K. As in Gertler, Kiyotaki and Queralto (2012), in order to produce $I_t = k_t - (1-\delta_t)k_{t-1}$ of new capital, the capital producer needs to spend $\left[1 + g\left(\frac{I_t}{I_{t-1}}\right)\right] I_t$ of consumption goods, where $g(\cdot)$ is the investment adjustment cost function. Hence, the objective function of the capital producer is

$$E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \Pi_{t+i}^c = E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left\{ q_{t+i}^K I_{t+i} - \left[1 + g\left(\frac{I_{t+i}}{I_{t+i-1}}\right)\right] I_{t+i} \right\} \tag{15}$$

where $\Lambda_{t,t+i}$ is the household's stochastic discount factor and Π_{t+i}^c is the profit distributed to households in each period. I use the functional form

$$g\left(\frac{I_t}{I_{t-1}}\right) \equiv \frac{\psi^K}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{16}$$

which implies $q^K = 1$ in the stationary equilibrium.

4 Equilibrium

4.1 Household Decision Making

Households maximize their objective function (equation (2)) subject to their budget constraint (equation (1)). The first-order conditions of this problem are

$$c_t + d_t = \omega_t l_t + R_t^D d_{t-1} - T_t + \Pi_t^c + c_t^e + DIV_t \tag{17}$$

[21] Since firms' profits are always zero, their ownership is irrelevant.

$$\varphi {l_t}^{\eta} = \frac{\omega_t}{c_t + \theta d_t} \tag{18}$$

$$\frac{1-\theta}{c_t + \theta d_t} = \beta E_t \left[\frac{R^D_{t+1}}{c_{t+1} + \theta d_{t+1}} \right]. \tag{19}$$

Equation (18) is the household's intratemporal consumption-labor optimality condition. Equation (19) is the household's intertemporal consumption optimality condition. This describes the trade-off between current and future consumption. When households postpone consumption to tomorrow, they obtain utility from deposit holdings today, which is deducted as $\frac{\theta}{c_t+\theta d_t}$ from today's marginal utility of consumption $\frac{1}{c_t+\theta d_t}$ on the left-hand side of equation (19).

4.2 Entrepreneur Decision Making

At the end of period $t+1$, entrepreneurs solve equation (4) subject to equation (5). The solution is

$$c^e_{t+1} = \chi^e W^e_{t+1} \tag{20}$$

$$n^e_{t+1} = (1-\chi^e) W^e_{t+1} \tag{21}$$

and the value of their objective function is equal to $(\chi^e)^{\chi^e}(1-\chi^e)^{1-\chi^e} W^e_{t+1}$. Hence, the decision problem of an entrepreneur when making the default decision is

$$W^e_{t+1} = \max \left\{ \underbrace{\omega^e_{t+1} \left\{ r^K_{t+1} + (1-\delta) q^K_{t+1} \right\} k_t - R^F_t b_t}_{\text{Repay}}, \underbrace{0}_{\text{Default}} \right\}. \tag{22}$$

Let

$$R^K_{t+1} = \frac{r^K_{t+1} + (1-\delta) q^K_{t+1}}{q^K_t} \tag{23}$$

denote the gross return per efficiency unit of capital obtained in period $t+1$ from the capital owned in period t. Then, there exists a threshold for the idiosyncratic shock $\bar{\omega}^e_{t+1}$ above which the entrepreneur repays her loan. This threshold is defined as

$$\bar{\omega}^e_{t+1} \equiv \frac{R^F_t b_t}{R^K_{t+1} q^K_t k_t} = \frac{x^e_t}{R^K_{t+1}} \tag{24}$$

where $x^e_t \equiv \frac{R^F_t b_t}{q^K_t k_t}$ denotes entrepreneurial leverage. Since bank loans are perfectly diversified over entrepreneurs, an entrepreneur at period t solves the contracting problem

$$\max_{x^e_t, k_t} \underbrace{E_t \left[\left(1 - \Gamma^e \left(\frac{x^e_t}{R^K_{t+1}} \right) \right) R^K_{t+1} q^K_t k_t \right]}_{=E_t[W^e_{t+1}]} \tag{25}$$

subject to the participation constraint of the bank

$$E_t \left[\left(\Gamma^e \left(\frac{x^e_t}{R^K_{t+1}} \right) - \mu^e G^e \left(\frac{x^e_t}{R^K_{t+1}} \right) \right) R^K_{t+1} q^K_t k_t \right] = \underbrace{E_t \left[\widetilde{R}^F_{t+1} \right]}_{\text{Expected return of diversified loans}} \left(\underbrace{q^K_t k_t - n^e_t}_{=b_t (\text{Amount of loans to the ent.})} \right) \tag{26}$$

where $\Gamma^e(\cdot)$ and $G^e(\cdot)$ are functions which, following BGG, are defined as follows:

$$\Gamma^e(\omega) \equiv \underbrace{\int_0^\omega \omega' f^e(\omega') d\omega'}_{\text{Return from defaulted loans}} + \underbrace{\omega \int_\omega^\infty f^e(\omega') d\omega'}_{\text{Return from repaid loans}} \tag{27}$$

$$G^e(\omega) \equiv \int_0^\omega \omega' f^e(\omega') d\omega. \tag{28}$$

Notice that the borrowing rate R^F_t is a part of the loan contract. Hence, it can be treated as a decision variable of the entrepreneur in period t. However, by defining x^e_t as a function of R^F_t, I can treat it, rather than the original R^F_t, as the choice variable. The first order condition of this program is

$$\frac{E_t \left[\Gamma^{e\prime}(\bar{\omega}^e_{t+1}) \right]}{E_t \left[\Gamma^{e\prime}(\bar{\omega}^e_{t+1}) - \mu^e G^{e\prime}(\bar{\omega}^e_{t+1}) \right]} = \frac{E_t \left[(1 - \Gamma^e(\bar{\omega}^e_{t+1})) R^K_{t+1} \right]}{E_t \left[\widetilde{R}^F_{t+1} \right] - E_t \left[(\Gamma^e(\bar{\omega}^e_{t+1}) - \mu^e G^e(\bar{\omega}^e_{t+1})) R^K_{t+1} \right]}. \tag{29}$$

Since the retained profits n^e_t are aggregated over entrepreneurs, its law of motion is expressed using equations (21) and (26), as follows:

$$
\begin{aligned}
n^e_{t+1} &= (1-\chi^e)(1-\Gamma^e(\bar{\omega}^e_{t+1}))R^K_{t+1}q^K_t k_t \\
&= (1-\chi^e)\frac{(1-\Gamma^e(\bar{\omega}^e_{t+1}))R^K_{t+1}}{E_t\left[\widetilde{R}^F_{t+1}\right] - E_t\left[(\Gamma^e(\bar{\omega}^e_{t+1}) - \mu^e G^e(\bar{\omega}^e_{t+1}))R^K_{t+1}\right]} E_t\left[\widetilde{R}^F_{t+1}\right] n^e_t. \qquad (30)
\end{aligned}
$$

4.3 Bank Decision Making

At the end of period $t-1$, a bank with equity e_t and idiosyncratic shock D_i solves the following problem given the loan rate $\widetilde{R}^F_t$ and the deposit rate R^D_t

$$
V(e_t, D_i) = \max_{div_t, L_t, n_t} \Theta(div_t) + \beta \sum_j P(D_i|D_j) \max\left\{ \underbrace{V(e_{t+1}, D_j)}_{\text{Repay}(x=0)}, \underbrace{0}_{\text{Default}(x=1)} \right\} \qquad (31)
$$

subject to equations (6), (7), (8), (9) and (10), where $V(e, D_i)$ is the value of the bank and $P(D_i|D_j)$ is the transition matrix from D_i to D_j. I define the default policy $x(e, D)$ as

$$
x(e, D) = \begin{cases} 0 & \text{Repay and Continue} \\ 1 & \text{Default and Exit} \end{cases} \qquad (32)
$$

and other policies

$$
\begin{aligned}
L_t &= L(e_t, D_i) \\
div_t &= div(e_t, D_i) \\
n_t &= n(e_t, D_i)
\end{aligned}
$$

as the solutions of the above problem.

4.4 Entrance of New Banks and Stationary Distribution

Entry dynamics are similar to Hopenhayn (1992), Gomes (2001), and Corbae and D'Erasmo (2014) in the sense that entry decisions are made before idiosyncratic shocks are realized. Since entrants have zero equity initially ($e_t = 0$), the free entry condition implies

$$\sum_i V(e=0,D_i)f(D_i)=\Upsilon \tag{33}$$

where $f(D)$ is the distribution of deposits for entrants. I assume $f(D)$ is the stationary distribution implied by the transition matrix $P(\cdot|\cdot)$. Υ is the entry cost. Notice that since new entrants have zero equity, they initially have to use costly external finance to raise capital. Let the mass of banks in state (de, D_i) and the mass of new entrants be denoted by $\zeta_t(de, D_i)$ and B, respectively (see Figure 4 for timing). By using the policy functions above, I can express the law of motion of the distribution $\zeta_t(de, D_i)$ as

$$\begin{aligned}\zeta_{t+1}(de', D_j) = \int \sum_i P(D_i|D_j)\cdot\zeta_t(de, D_i)\cdot\mathbb{I}\{x(E(L(e,D_i),D_i),D_j)=0\}\cdot\mathbb{I}\{de' \ni E(L(e,D_i),D_i)\}\\ + B\cdot\mathbb{I}\{de'\ni 0\}\cdot f(D_j).\end{aligned} \tag{34}$$

where $\mathbb{I}\{\cdot\}$ is an indicator function and $E(\cdot,\cdot)$ is the function in equation (10). The first term on the right-hand side represents the distribution of incumbent banks and the second term represents new entrants. A stationary distribution is a distribution ζ^* satisfying $\zeta_{t+1}=\zeta_t=\zeta^*$. Once the stationary distribution is derived, the aggregate deposits (D_{tot}), aggregate loans (L_{tot}), aggregate dividends (DIV_{tot}) and lump-sum tax for deposit insurance (T_{tot}) are computed by aggregating over banks using the stationary distribution.

$$\text{Deposits} \;:\; D_{tot} = \int\sum_i D_i\zeta^*(de, D_i) \tag{35}$$

$$\text{Loans} \;:\; L_{tot} = \int\sum_i L(e,D_i)\zeta^*(de, D_i) \tag{36}$$

$$\text{Dividends} \;:\; DIV_{tot} = \int\sum_i div(e,D_i)\zeta^*(de, D_i) \tag{37}$$

$$\begin{aligned}\text{Lump}-\text{sum Tax} \;:\; T_{tot} = \int\sum_{i,j} P(D_i|D_j)\mathbb{I}\{x(E(L(e,D_i),D_i),D_j)=1\}\\ \times\left\{\underbrace{R^D D_i}_{\text{Deposits obligation}} - \underbrace{\xi\widetilde{R}^F L(e,D_i)}_{\text{Liquidated value of assets}}\right\}\zeta^*(de,D_i)\end{aligned} \tag{38}$$

4.5 Definition of Stationary Competitive Equilibrium

In the following quantitative analysis, I focus solely on the stationary competitive equilibrium. This allows me to remove all time subscripts and expectation operators.

Given the capital requirement policy parameter ϕ, a stationary competitive equilibrium is a set of

(i) policy and value functions for banks $\{div(e, D), L(e, D), n(e, D), x(e, D), V(e, D)\}$, a stationary distribution of banks $\zeta^*(e, D)$ and aggregate bank variables $\{D^*_{tot}, L^*_{tot}, DIV^*_{tot}, T^*_{tot}\}$

(ii) household policy variables $\{c^*, d^*, l^{s*}\}$

(iii) entrepreneur policy variables $\{x^{e*}, \bar{\omega}^{e*}, n^{e*}, c^{e*}, b^*, k^{s*}\}$

(iv) firm policy variables $\{y^*, k^{d*}, l^{d*}\}$ and capital producer policy variables $\{k^{s*}, \Pi^{c*}\}$

(v) prices, lump-sum taxes, and dividends $\{q^{K*}, r^{K*}, w^*, \widetilde{R}^{F*}, R^{F*}, R^{D*}, T^*, \Pi^{c*}, DIV^*\}$ and mass of new entrants B^*

such that

1. Given (v), (i) solves the bank's problem.
2. Given (v), (ii) solves the household's problem.
3. Given (v), (iii) and (iv) solves each agent's problem.
4. The loan market, deposit market, capital good market, and labor market clear.

$$\begin{aligned} d^* &= D^*_{tot} \\ b^* &= L^*_{tot} \\ k^{d*} &= k^{s*} \\ l^{d*} &= l^{s*} \end{aligned}$$

5. $V(e, D)$ satisfies the free entry condition (33), and
6. The DIA's budget constraint is satisfied: $T^*_{tot} = T^*$.

The computational method is similar to Hopenhayn (1992). The free entry condition pins down the equilibrium price (here, the loan rate $\widetilde{R}^{F^*}$) and the labor market clearing condition pins down the mass of new entrants B^*. More detail is shown in the appendix.

5 Calibration

I set each period in the model to be one year. First, I calibrate the dynamics of deposits, which govern liquidity shocks in the model. I use panel data constructed from the Call Reports of U.S. commercial banks, which I transform to a yearly basis. The sample period is 1976-2013, which is same period as Corbae and D'Erasmo (2014).

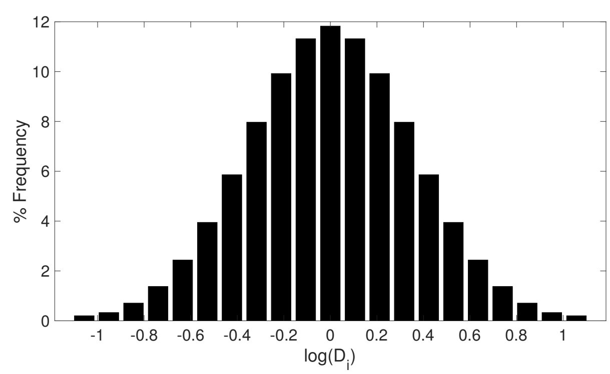
5.1 Dynamics of Deposits

Following Corbae and D'Erasmo (2014), I estimate the following AR(1) process for deposits $D_{i,t}$ for bank i in period t:

$$\log D_{it} = (1-\rho^{D})D_0 + \rho_D \log D_{it-1} + k_1 t + k_2 t^2 + \gamma_i + u_{it} \tag{39}$$

where t and t^2 denote linear and quadratic time trends, γ_i is the bank fixed effect, and u_{it} is i.i.d and distributed $N(0, \sigma_D^2)$. The result is shown in Table 1. Then, I apply the method of Tauchen (1986) to the AR(1) process in equation (39) in order to obtain a finite state Markov process $P(D_i|D_j)$. The mean D_0 in equation (39) is just a normalization factor and not directly relevant. Hence, I normalize the mean deposit unit to one ($\overline{D} = 1$). I discretize this process into 21 states $(D_1, ..., D_{21})$. The stationary distribution implied by this process is shown in Figure 5.

Figure 5: Stationary distribution of deposits



Note: I apply the method of Tauchen (1986) to the estimate of (39) after normalizing the mean of deposits to one ($\overline{D} = 1$). I discretize this process into 21 states.

5.2 Calibrated Model Parameters

The parameterization for the nonbank agents is mainly based on Clerc et al. (2015) (adjusted to a yearly basis) and is shown in Table 1. Parameters specific to my model (i.e., parameters for the banking sector) are estimated using U.S. data and are also shown in Table 1. The household's discount factor is set to $\beta = 0.95$ to target banks' capital cost, as in Corbae and D'Erasmo (2014) and De Nicolo et al. (2014). For the utility weight on liquidity services, I choose $\theta = 0.0418$ by targeting the deposit rate $R^D(= \frac{1-\theta}{\beta}) = 1.0086$, following Corbae and D'Erasmo (2014). For the capital requirement, I choose $\phi = 0.08$ based on the U.S. standard of a "well capitalized" bank.[22] The liquidation cost of loans is set to $\xi = 0.7$ based on Granja et al. (2017), who empirically investigate the value of sold banks, which is also consistent with Corbae and D'Erasmo (2014). For the payout ratio of entrepreneurs χ^e and variance of entrepreneurial shocks σ_e^2, I choose $\chi^e = 0.08$ and $\sigma_e^2 = 0.3$ by targeting corporate leverage (30 percent; Graham et al. (2015)) and entrepreneurs' default rate (2.3 percent; Corbae and D'Erasmo (2014)) jointly. The consistency between the data and model moments is shown in Table 2. Finally, the fixed cost, equity issuance cost and entry cost are estimated jointly by targeting the default rate, average capital ratio, and interest margin of banks. The fixed cost is critical for the default rate since it directly reduces the franchise value of banks. The equity issuance cost a influences bank's precautionary behavior. When $a = 0$, banks facing liquidity shocks can freely recapitalize so they have no incentive to hold capital buffers. On the other hand, when a is large, they try to hold larger capital buffers to avoid costly equity issuance. Hence, the equity issuance cost has an impact on banks' average capital ratio. In my model, this parameter is calibrated to $a = 1.0$. The entry cost influences the interest margin of banks through the free entry condition. The consistency between the data and model moments is shown in Table 2. In reality, banks face not only idiosyncratic liquidity shocks, but also other shocks such as those associated with monetary policy, foreign exchange rates, and other aggregate economic conditions. All of these dimensions of uncertainty increase banks' precautionary motives, which might cause them to hold more capital. My model does not capture these factors. This could be one reason why my model has trouble matching the average capital ratio.

[22]Following the Basel Accord, the FDIC categorizes those banks whose capital ratios are greater than eight percent as "well capitalized".

Table 1: Model parameters

Parameter		Value	Target (Source)
Marginal disutility of labor	φ	1.00	Clerc et al. (2015)
Elasticity of labor	η	1.00	Clerc et al. (2015)
Default cost of entrepreneurs	μ^e	0.30	Clerc et al. (2015)
Productivity	A	1	Normalization
Capital share in production	α	0.30	Clerc et al. (2015)
Capital depreciation rate	δ	0.1	Clerc et al. (2015)
Capital adjustment cost	ψ^K	2.00	Clerc et al. (2015)
Household discount factor	β	0.95	Cost of bank capital 5% (Corbae et al. (2014))
Utility weight on liquidity services	θ	0.0418	Deposit rate 0.86% (Corbae et al. (2014))
Capital requirement	ϕ	0.08	Capital requirement (FDIC)
Default cost of banks	ξ	0.70	Corbae et al. (2014), Granja et al. (2017)
Dividend payout of entrepreneurs	χ^e	0.08	Corporate leverage (Debt/Assets) 30% Graham et al. (2015)
Variance of entrepreneurial shock	σ_e^2	0.3	Default rate of entrepreneurs 2.3% (Corbae and D'Erasmo (2014))
Persistency of id shock	ρ_D	0.84	Call Reports (1976-2013)
Std. dev of id shock	σ_D	0.19	Call Reports (1976-2013)
Fixed cost	κ	0.034	Annual bank default rate 0.7% (FDIC)
Equity issuance cost	a	1.0	Average capital ratio 17% (Call Reports (2015Q3))
Entry cost	Υ	0.038	Interest margin of banks 4%

Note: Source: RCFD2200 in Call Reports for deposits. RCON7206 in Call Reports for capital ratio.

Table 2: Model and target moments

Moment	Target	Model
Corporate leverage (%)	30	33
Default rate of entrepreneurs (%)	2.3	2.5
Default rate of banks (%)	0.7	0.6
Avg. capital ratio (%)	17	12
Interest margin (%)	4.0	4.0

6 Results

For the parameter values in Table 1, I find an equilibrium where bank defaults (exits) occur along the equilibrium path.

6.1 Equilibrium Bank Value, Decision Rules and Distribution

Figure 6 shows banks' value functions and default decisions for three values of the idiosyncratic shock (D_1, D_{11}, D_{21}). When a bank's equity decreases, the slope of the value function becomes steeper. This is because its equity is not enough to satisfy the capital requirement, so it must issue new equity. Since more capital is needed for banks in D_{21} than those in D_{11} or D_1, the slope of the value function for D_{21} becomes steeper much earlier. When their value become smaller than zero, banks choose to default. The thresholds of equity under which they default depend on the value of the idiosyncratic shock. This threshold is lower for banks in good states because they have larger continuation values and less incentive to default than banks in bad states.

Figure 6: Banks' value functions and default decisions

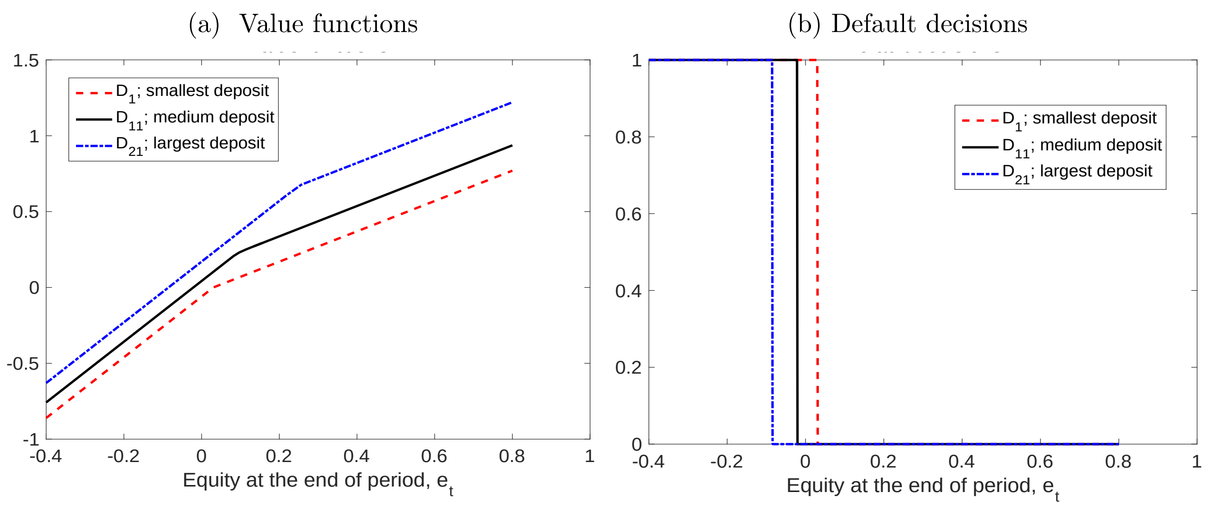
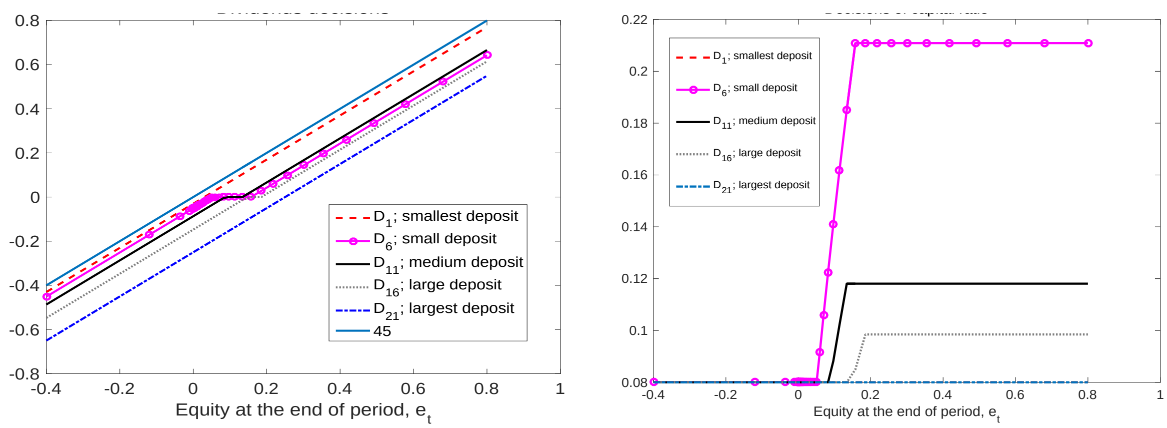


Figure 7 shows banks' dividend and capital ratio decisions. I plot the cases of five idiosyncratic shocks $(D_1, D_6, D_{11}, D_{16}, D_{21})$. Negative dividends correspond to new equity issued. When banks' equity at the end of a period is small, they issue just enough equity to satisfy the capital requirement ($\phi^f = 0.08$). When their equity at the end of a period becomes large enough to satisfy the capital requirement without equity issuance, banks in states D_6, D_{11} and D_{16} accumulate their equity capital as buffers over the required level ($\phi^f = 0.08$) rather than distribute them to households as dividends. This is why dividend decisions plateau for those banks. On the other hand, banks in states D_1 and D_{21} have just enough capital and do not accumulate capital buffers over the required level. Banks in state D_1 are likely to default and exit in the next period, so they have less incentive to accumulate capital against future liquidity shocks. Banks in the best state (D_{21}) already have accumulated enough capital and do not need any more capital in the future. Hence, they have no incentive to accumulate any more capital.

Figure 7: Bank dividend and capital ratio decisions

(a) Dividend decisions (b) Capital ratio decisions

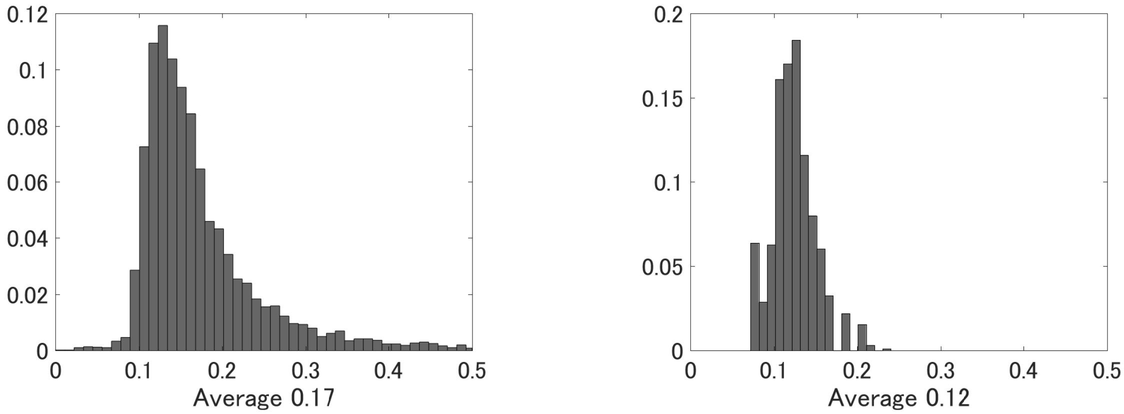


Note: Capital ratio is defined in equation (9).

Figure 8 shows the distribution of the capital-to-assets ratio in both the data and my model. In my model, the capital constraint is binding for only 6 percent of banks. Other banks have more capital than required, which is consistent with the data. Nevertheless, the model does not replicate the rich distribution of the data, which might be due to the reason mentioned in the previous section.

Figure 8: Distribution of bank capital ratio

(a) Capital Ratio (data) (b) Capital Ratio (model)

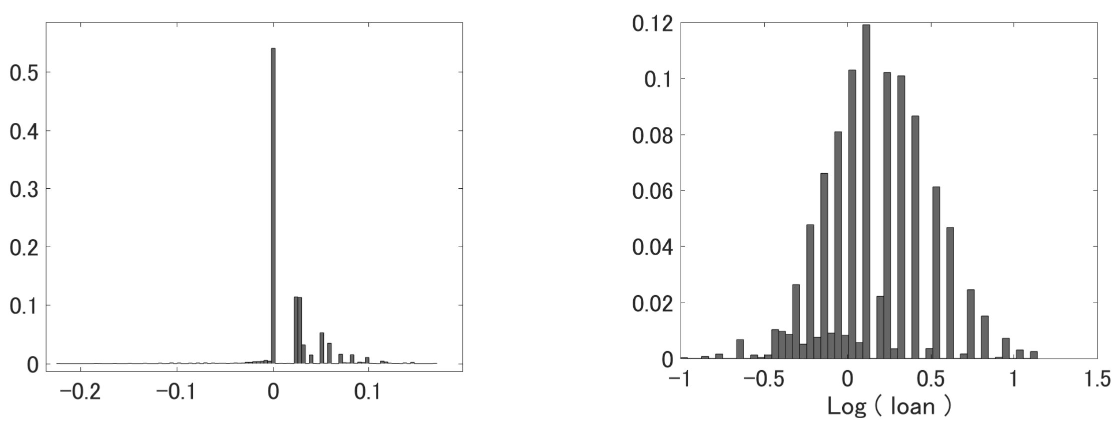


Note: Source: Call Reports 2015Q3. Capital ratio in the data is defined as ratio of Tier1 capital to risk weighed assets (rcon7206 in Call Reports).

Figure 9 shows the distribution of dividends and loans in the model. Again, negative dividends correspond to equity issued. The distribution of dividends has a concentrated mass at zero, which means many banks have zero dividends. As we saw in Figure 7, many banks accumulate capital as buffers against future liquidity shocks instead of distributing equity as dividends.

Figure 9: Distribution of dividends and loans

(a) Distribution of dividends (model) (b) Distribution of loans (model)



Note: Negative dividends mean equity issuance.

6.2 Counterfactual

In this section, I investigate the relationship between capital requirements and macroeconomic variables and determine the optimal capital requirement (henceforth, OCR) that maximizes social welfare. When the capital requirement increases, the social losses associated with bank defaults decrease (which is good for the economy) while the liquidity provision to the economy also deceases (which is bad for the economy). The OCR balances these positive and negative effects and maximizes welfare.

Figure 10 shows the steady-state average capital ratio, bank default rate, and associated tax for deposit insurance as a function of the capital requirement. The tax is normalized by output (hence, T/y in the model). For the quantitative analysis of welfare, this value (the amount of tax for deposit insurance) is important because it represents the social cost of bank defaults, which capital requirements are targeted to reduce. In the benchmark calibration of my model (with $\phi = 0.08$), $T/y = 0.0003$.[23] According to the FDIC, the estimated losses (which correspond to T in my model) from 1988 (when the first Basel accord was introduced) to 2017 is \$177 billion. During this period, nominal GDP summed to \$350 trillion. Hence, the data counterpart of this value is 0.0005 (=\$177 billion/\$350 trillion). Taking into account that the capital requirements were smaller than 8 percent when they were initially introduced in 1988, these values match well. While the amount of the tax is not a target of the calibration, these values are close to each other, which indicates model credibility for welfare analyses. This is a big advantage of my model because none of the quantitative studies on the OCR (which we saw in Section 2 and will revisit later) investigate these actual costs for deposit insurance and they do not check whether their models replicate these costs or not. Models in which banks are identical generally overvalue these costs for deposit insurance because, in reality, failed banks are relatively small banks.[24] My model with heterogeneous banks captures this fact, similarly to Corbae and D'Erasmo (2014), which is one reason why their model can replicate the actual costs for deposit insurance well.

Even though the capital requirement is only occasionally binding, banks increase their capital ratios in order to prevent capital constraints from binding in the future. Strict capital requirements are effective at reducing the bank default rate and associ-

[23] In Corbae and D'Erasmo (2014), this value is 0.0007.

[24] According to the FDIC, the average assets of failed banks between 1988 and 2017 was \$587 million while the average assets of all banks in that period was \$891 million.

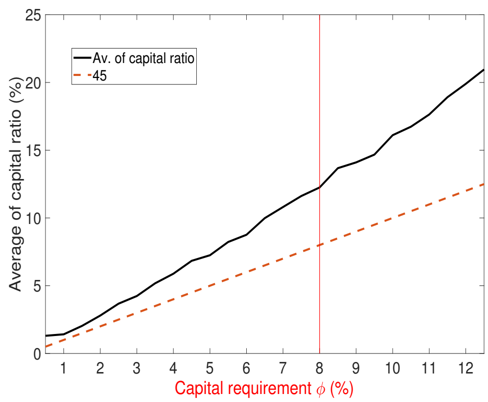
ated tax for deposit insurance. However, larger capital requirements appear to have diminishing returns and become marginally less effective. At the current level of capital requirement ($\phi = 0.08$), the effect on the default rate is small. This supports the finding of Van den Heuvel (2008), who argues that "the current capital requirement cannot be justified unless a slight decrease in this ratio leads to a sudden and large increase in the number of bank failures".

Next, Figure 11 shows how the steady-state mass of banks, mass of new entrants, and total credit and liquidity supplies change as a result of changing the capital requirement. The mass of banks increases when the capital requirement is low ($\phi \leq 0.025$). While the mass of new entrants decreases, the bank default rate also decreases. Overall, the number of banks increases since the effect of the latter is stronger than that of the former in this region. However, the mass of banks decreases when the capital requirement is high ($\phi > 0.025$).[25] Total credit supply and liquidity supply decrease monotonically with increased capital requirements.

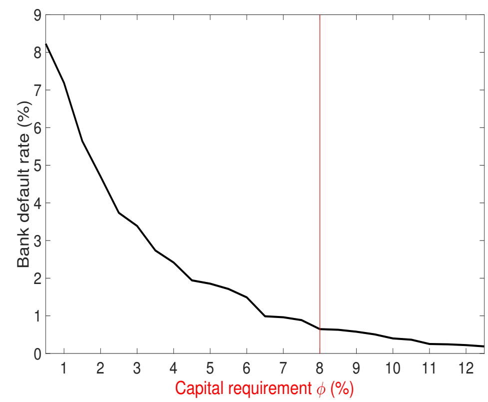
[25] The impact of recent stricter regulations on the number of banks through the reduction of new entry is empirically studied in McCord and Prescott (2014) and Adams and Gramlich (2016).

Figure 10: Steady-state average capital ratio, bank default rate, and tax for deposit insurance

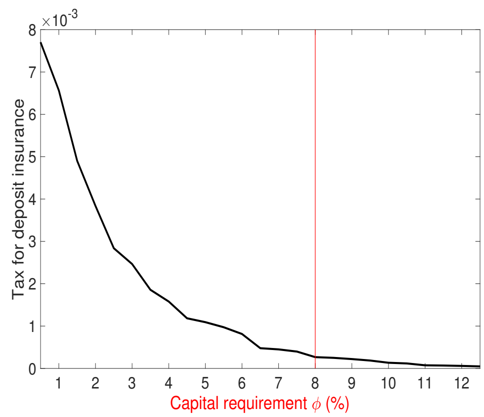
(a) Average of capital ratio



(b) Bank default rate



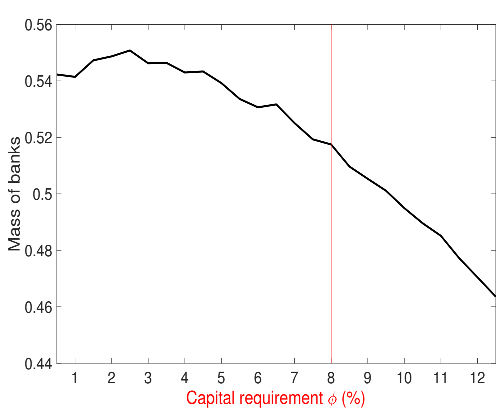
(c) Tax for deposit insurance



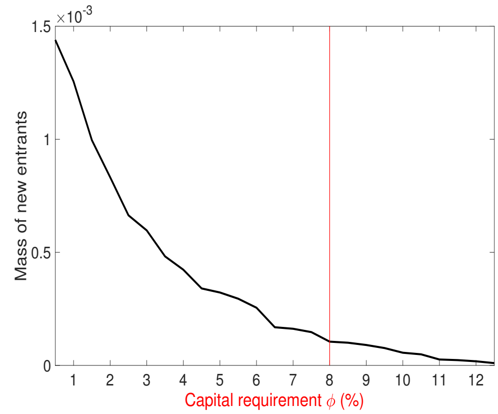
Note: Tax for deposit insurance is normalized by output.

Figure 11: Steady-state mass of banks, mass of new entrants, total credit supply and total liquidity supply

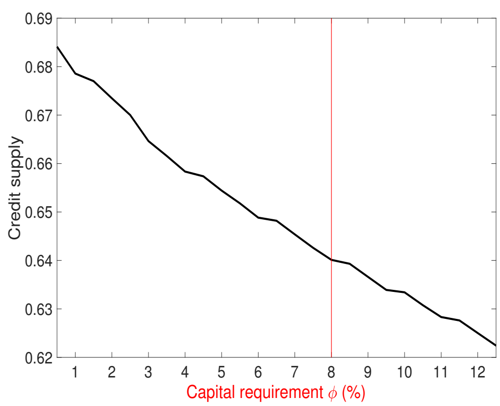
(a) Mass of banks



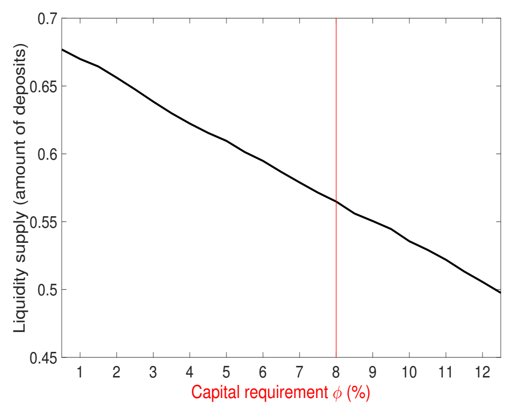
(b) Mass of new entrants



(c) Credit supply



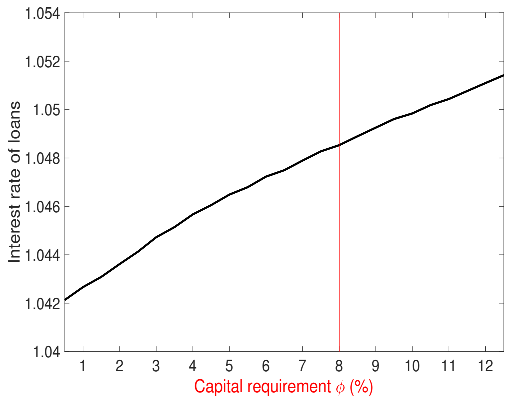
(d) Liquidity supply (amount of deposits)



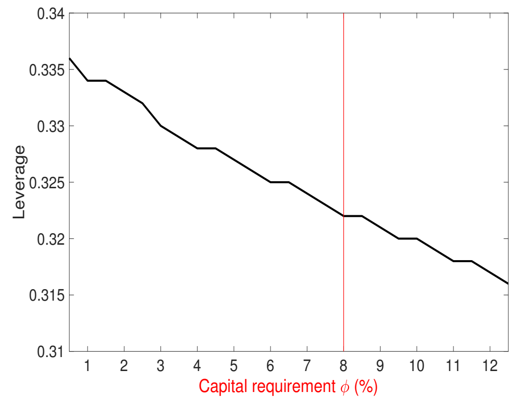
We saw how variables in the banking sector change depending on the capital requirement above. Next, Figure 12 shows how the production sector responds to changes in the capital requirement. When the capital requirement increases, the interest rate on loans increases because banks' funding costs increase and banks supply less credit. As a result, entrepreneurs' leverage decreases because they shift from bank credit to their own wealth for funding, which leads to a reduction of their default rate. Since their own wealth cannot completely substitute for their lost credit from banks, their assets (i.e., productive capital) decrease.

Figure 12: Steady-state variables of the production sector

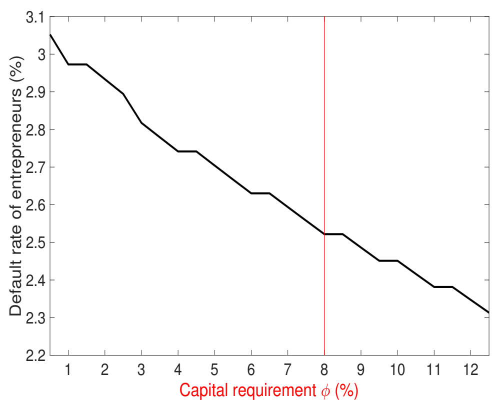
(a) Interest rate of loans



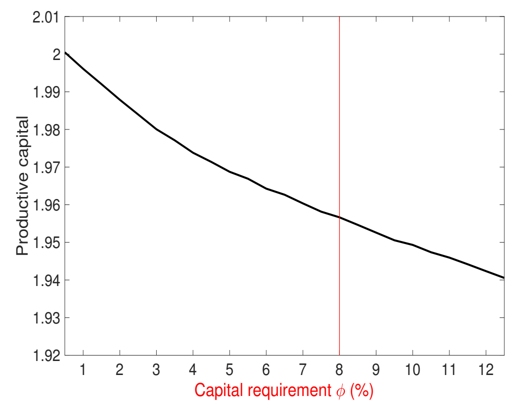
(b) Entrepreneurs' leverage (Banks' credit/Productive capital)



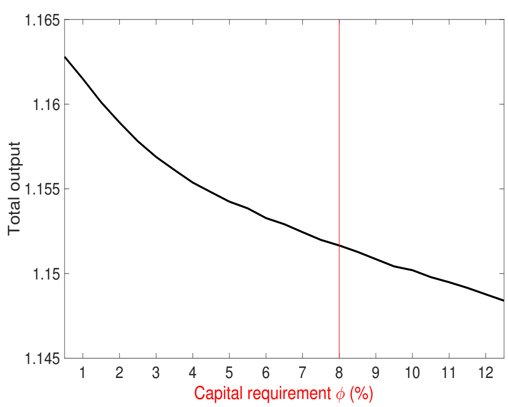
(c) Default rate of entrepreneurs



(d) Aggregate amount of productive capital



(e) Total output



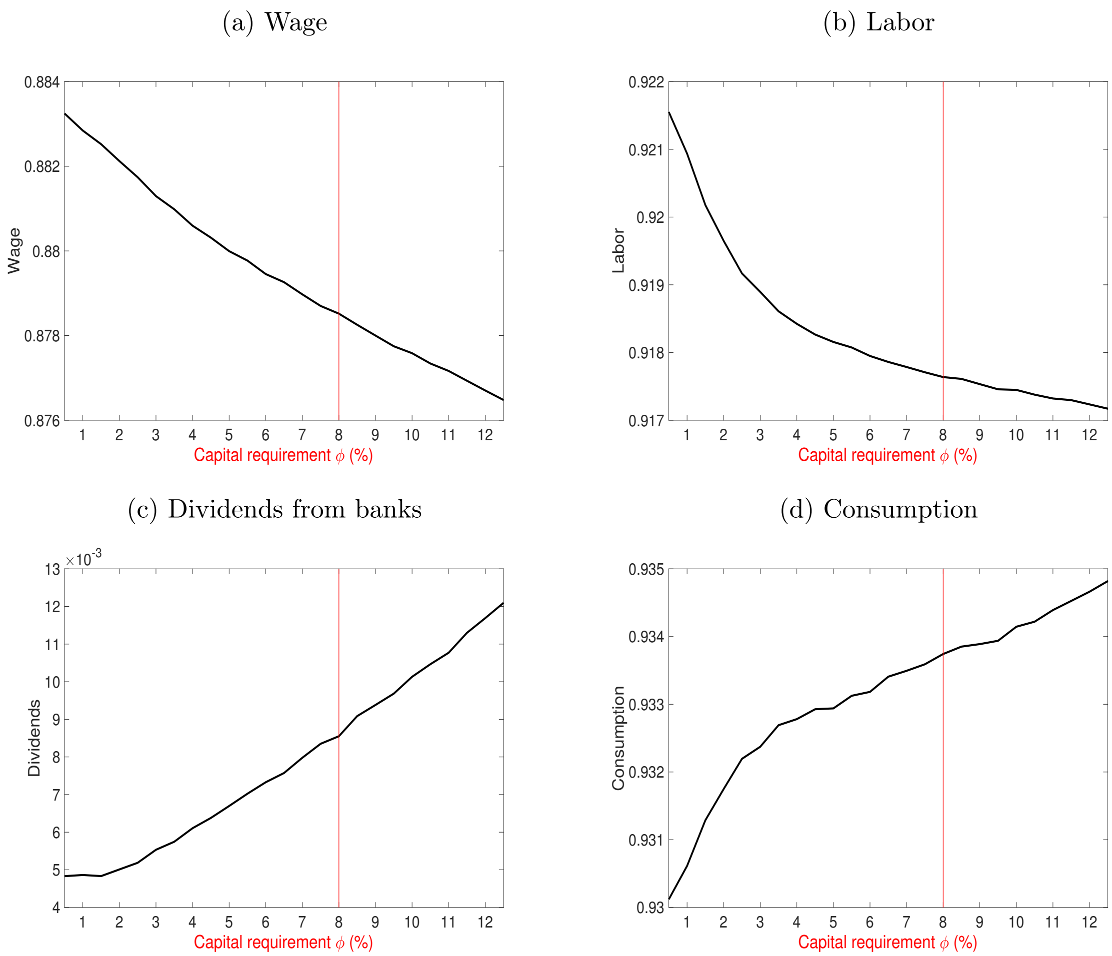
Finally, Figure 13 shows how households change their behavior in response to changes in the capital requirement. As we saw above, when the capital requirement increases, capital costs for entrepreneurs increase and their demand for labor decreases. As a result, wages decrease and households supply less labor, so households' wage income decreases. When the capital requirement increases, more bank income goes to the banks' owners (households) as dividends and less to depositors. This positive effect on dividends is stronger than the negative effect resulting from the reduction in the mass of banks caused by increasing the capital requirement. Therefore, the amount of total dividends that households obtain from the banking sector actually increases when the capital requirement increases. Using the household budget constraint, steady-state consumption can be expressed as

$$\underbrace{c^*}_{\uparrow} = \underbrace{\omega^* l^*}_{\downarrow} + \underbrace{(R^{D^*} - 1)d^*}_{\downarrow} - \underbrace{T^*}_{\downarrow} + \underbrace{c^{e*}}_{\rightarrow} + \underbrace{DIV^*}_{\uparrow} \tag{40}$$

where the asterisk denotes the equilibrium value. The impact of income reductions from wages and deposit interest are smaller than the impact of income increases from larger dividends from the banking sector and the smaller lump-sum tax for deposit insurance.[26] Overall, the amount of consumption increases as a result of a stricter capital requirement. Consumption increases especially steeply when the capital requirement is smaller ($\phi \leq 0.035$). This is because the capital requirement is effective at reducing bank defaults in this region (as shown in Figure 10), which reduces the lump-sum tax.

[26]While entrepreneurs' leverage decreases, the size of their assets also decreases. As a result, dividends from entrepreneurs c^e, which are proportional to their net worth (see equations (20) and (21)), do not change much.

Figure 13: Steady-state variables of households



Finally, I define social welfare gains associated with the policy change (from $\phi = 0.08$) as the permanent percentage increase in steady-state household consumption (consumption equivalence). More specifically, let (c_ϕ^{ss},l_ϕ^{ss},d_ϕ^{ss}) denote the steady-state levels of consumption, labor supply, and deposits, respectively, when the capital requirement is ϕ. Then the consumption equivalent social welfare gain from the benchmark case ($\phi = 0.08$) to ϕ, ΔW_ϕ, is defined as

$$\Delta W_\phi \equiv \frac{\Delta c_\phi^{ss}}{c_{0.08}^{ss}}$$

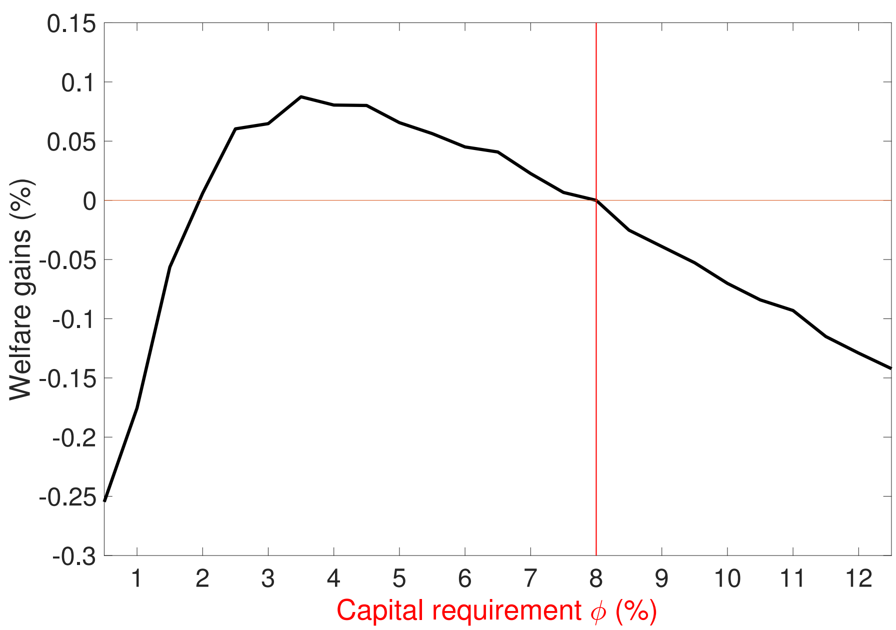
where Δc_ϕ^{ss} is defined as the value that satisfies the equation

$$u(c_{0.08}^{ss} + \Delta c_\phi^{ss}, l_{0.08}^{ss}, d_{0.08}^{ss}) = u(c_\phi^{ss}, l_\phi^{ss}, d_\phi^{ss})$$

where $u(c, l, d)$ is the household's utility function defined in equation (2).

Figure 14 shows the steady-state social welfare gains ΔW_ϕ for different levels of the capital requirement. In my model, the welfare-maximizing capital requirement is $\phi = 0.035$. At this capital requirement, social welfare is $\Delta W_{0.035} = 0.09$ percent higher than the benchmark case of $\phi = 0.08$.[27] This is consistent with Van den Heuvel (2008), who argues that the current level of capital requirements are too high to be welfare-maximizing. When $\phi \leq 0.035$, the positive impact of increased consumption on social welfare is larger than the negative impact of reduced liquidity services (deposits). Hence, welfare increases as the capital requirement increases in this region. However, when the capital requirement is above 3.5 percent, the reduction of bank defaults and the resulting tax become marginal and the negative impact of reduced liquidity services (deposits) becomes more influential. As a result, welfare decreases when $\phi > 0.035$. At the optimal level ($\phi = 0.035$), these effects balance each other and social welfare is maximized.

Figure 14: Steady-state welfare gains as a function of the capital requirement



Note: I define the social welfare gains ΔW associated with a policy change (from $\phi = 0.08$) as the percentage increase in steady-state household consumption.

[27]This value of social welfare gain is of the same order as those in Van den Heuvel (2008) and Begenau (2019). These are not trivial values compared to the welfare gains from other policies (e.g., welfare gains from using the optimal monetary policy (Lucas (2001) and Lucas (2003)).

6.3 Parameter Dependence

In this subsection, I investigate how changing model parameters affects the values of macro variables and the implications of bank capital requirements for social welfare. To this end, I focus on two parameters: the equity issuance cost a and the liquidation value of banks ξ.

Figures 15 and 16 show the results of changing a. Welfare gains are computed as consumption equivalent gains from a specific benchmark calibration ($a = 1$ and $\phi = 0.08$). As a increases, banks accumulate larger capital buffers in order not to use costly equity issuance, and therefore the average capital ratio increases. When a increases, banks' franchise value decreases, which reduces the number of banks by discouraging new entrants. This results in a decrease of deposits, a negative impact on social welfare. Because of this, the OCR shifts downwards, as shown in Figure 16. The OCR is especially large (around 8 percent) when $a = 0$ (there are no equity issuance costs). This corresponds to the cases discussed in Admati et al. (2013) and Admati and Hellwig (2014, 2018). My modeling is different from theirs in that I allow only deposits to provide liquidity services.[28] Because of this difference, my OCR is lower than their OCRs. Finally, these results would suggest that in order to maintain financial stability without damaging banks' liquidity provision, strengthening capital requirements needs to be accompanied by reducing the cost of equity issuance for banks.[29]

Figures 17 and 18 show the results of changing ξ (the liquidation value of banks). Banks have no reason to consider ξ due to limited liability, and therefore their behavior does not change in response to changes in ξ. On the other hand, the smaller ξ, the larger the social costs, or tax for deposit insurance, generated by bank defaults. Because of this, the smaller ξ is, the more beneficial are capital requirements for social welfare. This pushes up the OCR, as shown in Figure 18. This consequence suggests that my model is able to describe the usefulness of bank capital requirements for reducing welfare losses in the presence of systemic risks. The makeup of my model does not explicitly include spillover effects of bank defaults.[30] The benchmark value of 0.7 for ξ mentioned in Section 5 refers to a specific average of liquidation costs for banks that actually failed, without considering the spillover effects. Nevertheless, reducing ξ from

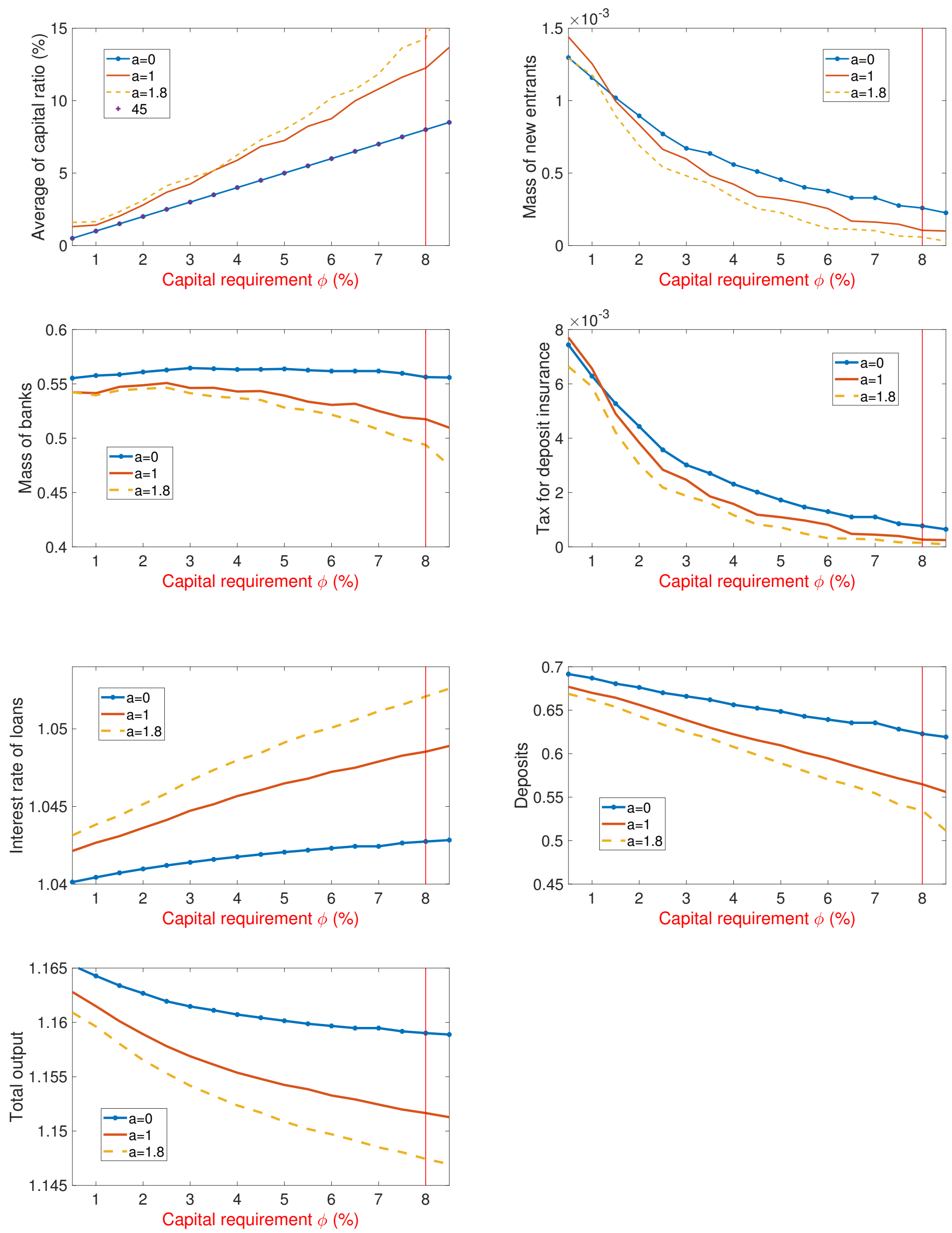
[28] Admati et al. (2013) and Admati and Hellwig (2014, 2018) allow equity capital to provide that service too when banks' leverage becomes lower and equity capital becomes safer.

[29] Admati et al. (2013) argue that regulators can mitigate equity issuance costs associated with asymmetric information by removing banks' discretion over payout and issuance decisions.

[30] The OCR in a model with systemic risks is explored in Martinez-Miera and Suarez (2014).

0.7 can be interpreted as taking into account some of those effects.[31]

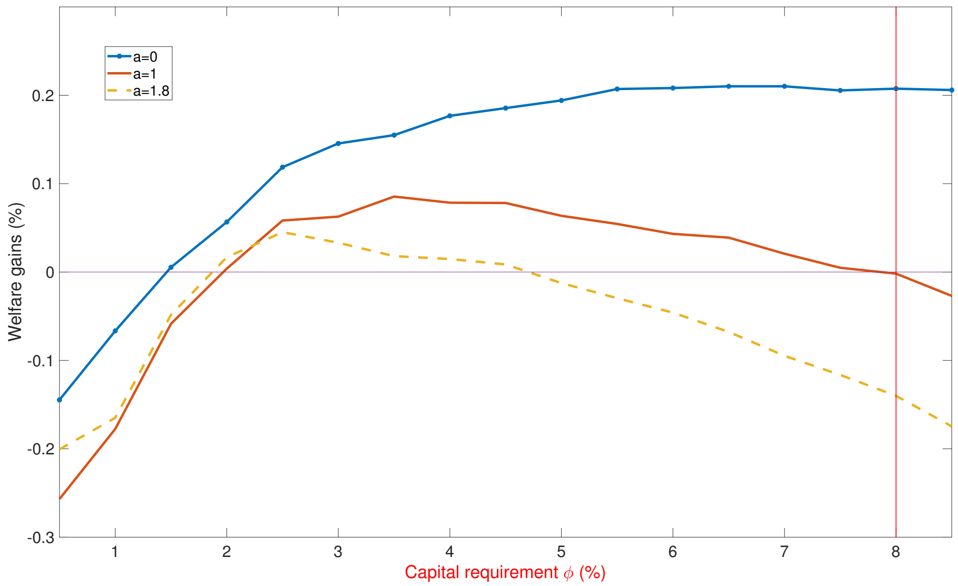
Figure 15: Aggregate variables depending on different values of equity issuance cost a.



Note: Tax for deposit insurance is normalized by output.

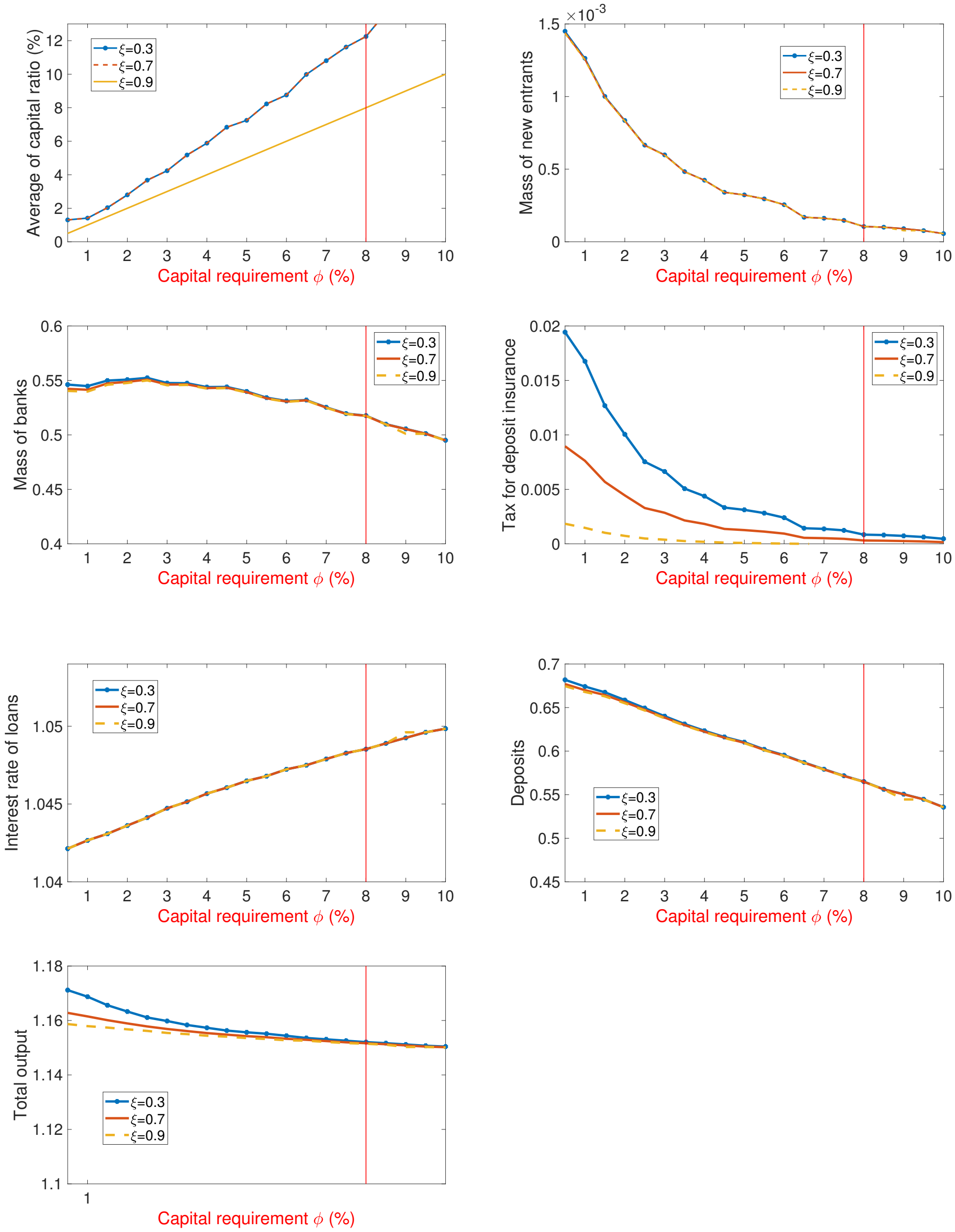
[31] In order to make the Basel requirement of 8 percent, ξ needs to be approximately 0.3 in Figure 18.

Figure 16: Steady-state welfare gains depending on different values of equity issuance cost a.



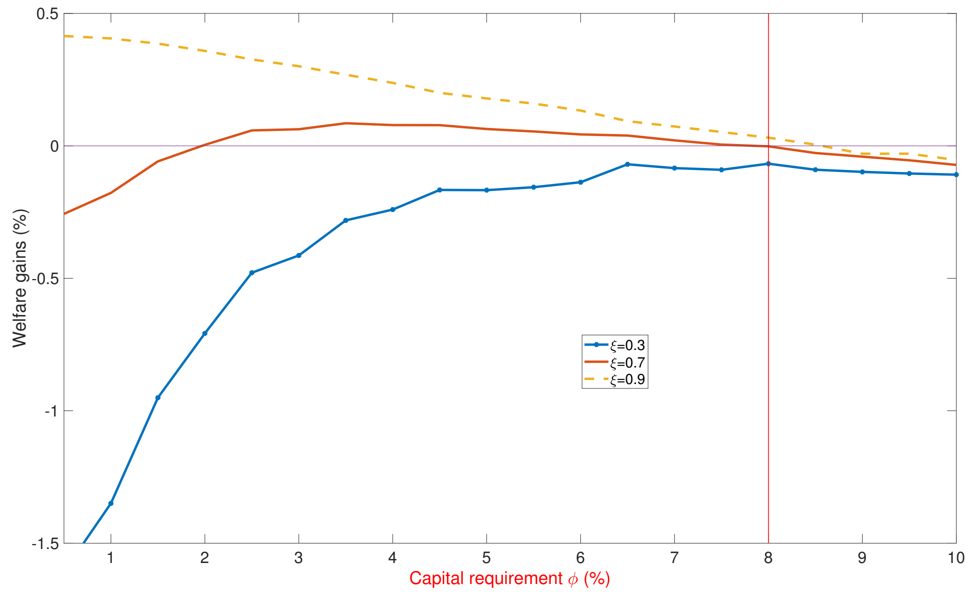
Note: Welfare gains are computed as consumption equivalent gains from the benchmark calibration ($a = 1$ and $\phi = 0.08$).

Figure 17: Aggregate variables depending on different liquidation value of assets ξ.



Note: Tax for deposit insurance is normalized by output.

Figure 18: Steady-state welfare gains depending on different liquidation values of assets ξ.



Note: Welfare gains are computed as consumption equivalent gains from the benchmark calibration ($\xi = 0.7$ and $\phi = 0.08$).

6.4 Discussion

I close this section by comparing the OCR computed in the previous subsection to other studies that investigate it based on general equilibrium models. The definition of the OCR is the same among all of the studies. It is the point at which the positive and negative effects generated by bank capital requirements balance each other out. The positive effect is the improvement in financial stability, such as the reduction of bank defaults and banks' risk exposure, while the negative effect is the reduction of credit and liquidity supply. As shown in Table 3, however, the value of the OCR differs by study, depending on the model environment. For example, it is 3.5 percent in my case but 12.4 percent in Begenau (2019). My model considers two elements which Begenau (2019) does not: the endogenously determined number of banks and costly bank default. By contrast, Begenau (2019) considers three elements which my model does not: banks' choice of riskiness of loans, inelastic deposit supply (IDS in the table), and aggregate risks over time.

The arrows in the parentheses indicate the direction in which these model environments change the OCR. When banks face infinite time horizons and make dynamic decisions, increasing bank capital requirements damages banks' franchise value (the value which banks obtain by continuing their banking businesses) and raises their default or risk-taking incentives (franchise value effect).[32] Due to this franchise value effect, the OCR in the case of infinitely-lived banks is generally lower than that in the case of one-period-lived banks.

When households obtain utility directly from liquidity holdings (deposits), increasing capital requirements discourages banks from collecting deposits, thereby reducing households' utility. Hence, in this case, the OCR is lower than it would be otherwise.

When the number of banks is endogenously determined, as in my model, increasing capital requirements reduces banks' credit and liquidity supply through the extensive margin, or reduction in the number of banks. This amplifies the negative impact of capital requirements on social welfare. Therefore, the OCR in the case where the number of banks is endogenous is generally lower than that in the case where the number of banks is exogenous.

When banks choose the riskiness of their investments, they tend to take excessive risks due to limited liability and deposit insurance. Increasing bank capital requirements mitigates this moral hazard problem by boosting banks' "skin-in-the-game", which is called the "risk-shifting" effect of the requirements.[33] The presence of the risk-shifting effect generally increases the OCR. My model does not capture this effect because banks in my model invest in only one type of loan, which is perfectly diversified. Instead, in my model, a bank's leverage indicates the bank's credit worthiness and capital requirements work by reducing its leverage and default incentive, as in Malherbe (2019).

When banks have a default option and their default generates social losses, such as liquidation costs, increasing bank capital requirements reduces bank defaults with positive implications for social welfare. Therefore, the OCR in the case with costly

[32]How strict capital requirements damage banks' franchise value and affect financial stability is examined in seminal studies, including Hellmann et al. (2000), Sarin and Summers (2016), Repullo (2004), and Rochet (1992). Hellmann et al. (2000) especially insist that capital requirements alone cannot achieve Pareto-efficient outcomes because they harm banks' franchise value and encourage them to engage in gambling behavior.

[33]Risk shifting in the context of capital requirements is modeled in Hellmann et al. (2000), Admati and Hellwig (2014), Allen and Gale (2004), and Repullo (2004) and delved into with general equilibrium frameworks by Corbae and D'Erasmo (2014), Begenau (2019), Nguyen (2015), and Martinez-Miera and Suarez (2014).

default is larger than that in the case without bank defaults.[34]

When banks collect deposits from households in an inelastic fashion, as in Begenau (2019), increasing bank capital requirements reduces the interest cost of deposits. With decreasing returns to scale in bank lending, a reduction of funding costs encourages bank lending, which is good for the economy. This lets the OCR be larger than it would be otherwise.

When banks face aggregate risks or systemic risks which they cannot diversify, capital in the banking sector would be seriously damaged by these shocks. In this case, capital-constrained banks have to contract their credit supply to the economy dramatically and it becomes difficult for households to smooth their consumption. Bank capital requirements can mitigate this difficulty by preserving banks' capital and helping households to smooth their consumption. Hence, in an economy with aggregate risks, the OCR is generally larger than it would be otherwise.

There are two reasons why the OCR is estimated to be lower in my model than in other studies. The first reason is endogenization of the number of banks. This is performed by Nguyen (2015) too. However, banks do not compete with each other in his model; that is, banks face a common demand function for loans regardless of the number of banks. By letting banks compete, changing bank capital requirements in my model affects bank profits through two channels. One is simply the cost of funding for banks. The other channel is one that Nguyen (2015) does not consider. It is that a change in the competitiveness of the bank loan market is associated with a change in the profitability of bank loans. As a result, I find that increasing capital requirements has a greater impact on the number of banks and aggregate liquidity supply than what Nguyen (2015) shows.

Secondly, banks work in an infinite time horizon in my model. Strengthening bank capital requirements harms banks' franchise value and increases their default incentive. Figure 19 shows how both the value function and default decision change when capital requirements are strengthened from $\phi = 0.01$ to $\phi = 0.08$. The figure refers only to banks in state D_1 (the worst state) because they are likely to default the most in equilibrium. Strengthening capital requirements increases the lending rate of interest in the general equilibrium, thereby exercising a positive impact on banks' franchise value. Doing so also has a negative impact on that value by making their balance sheets depend on costly equity finance. On balance, strengthening capital require-

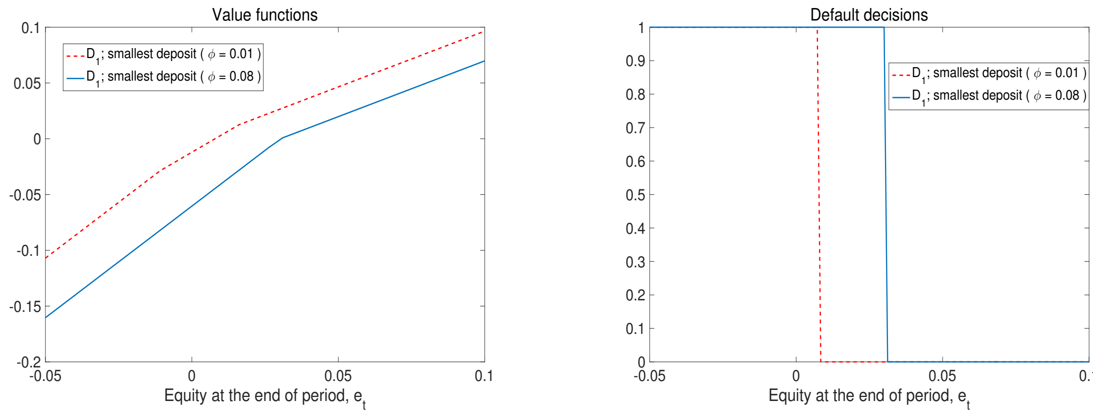
[34] As shown in Table 3, Nguyen (2015) considers bank defaults while abstracting from their cost for welfare.

ments decreases the franchise value of banks in state D_1. This is because the latter negative impact is larger than the former positive impact on those banks. In such a situation, banks' default incentive grows and the default threshold rises, as in Figure 19.

Figure 19: Value functions and default decision changes by strictness of capital requirement

(a) Value function changes by strictness of capital requirement

(b) Default decision changes by strictness of capital requirement



Finally, I mention an important caveat that my results do not offer any direct suggestions for the strictness of Basel III's risk-weight based capital requirement. My model cannot take into account different risk-weights on different assets, as in the Basel III requirement, because the model has only one type of bank asset (well-diversified loans), whose risk weight is simply one. Changing this weight results in changing the level of my OCR. When the weight is 0.5, with reference to Malherbe (2019), my OCR is 7 percent, a level that is close to the Basel III minimum capital requirement. My finding, meanwhile, could be more relevant to the Basel III minimum "leverage ratio", which requires banks to hold equity capital larger than 3 percent of total assets because this ratio is calculated without considering risk weights.

Table 3: Comparison with other studies

	Infinite time horizon of banks (↓)	DIU (↓)	Endogenous # of banks (↓)	Choice of riskiness of loans (↑)	Costly default (↑)	IDS (↑)	Aggregate or systemic risks (↑)	OCR
Martinez-Miera et al. (2014)				○			○	14%
Begenau (2019)	○	○		○		○	○	12.4%
Clerc et al. (2015)					○			10%
Nguyen (2015)	○		○	○				8%
Van den Heuvel (2008)		○		○	○			Current level (∼10%) is too high
Malherbe (2019)					○		○	Good time: 4.4% Bad time: 2.9%
This paper	○	○	○		○			3.5%

Note: OCR refers to "optimal capital requirement". DIU is "deposit-in-utility". IDS is "inelastic deposit supply". The arrow in the parentheses indicates the direction in which these environments change the OCR.

7 Conclusion

To study bank capital requirements and their implications for social welfare, I develop a dynamic general equilibrium model with heterogeneous banks. I embed two, less commonly considered but important, mechanisms. One is that the number of banks is determined endogenously as a result of their entry and exit decisions. This extension enables an investigation of the impact of capital requirements on the size and competitiveness of the banking sector. The other mechanism relates to banks' precautionary capital holdings. This makes bank capital requirements only occasionally binding; that is, banks tend to hold more capital than required. I then investigate how adding these mechanisms and associated ingredients may affect the welfare implications of capital requirements.

My findings are as follows. Firstly, a reduction of liquidity provision, a negative impact of bank capital requirements on social welfare, is amplified since strengthening the requirements discourages new entrants and reduces the total number of banks. Secondly, increasing capital requirements encourages banks to increase their capital holdings even if the requirements are not binding. Banks do so in order to prevent the requirements from binding in the future. Such an increase of bank capital reduces the frequency of bank defaults, thereby contributing to financial stability. However, this reduction of bank defaults, a positive impact of capital requirements on social welfare, is limited by the side effect of strengthening the requirements: a reduction of banks' franchise value that encourages banks to default. My calculation based on these positive and negative impacts shows that the optimal capital requirement should be lower than those in the previous literature. Finally, I change relevant model parameters to see how the implications change. I find that reducing equity issuance costs is beneficial for policy makers in achieving financial stability without damaging banks' franchise value and their liquidity providing functions.

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Appendix

A Computation

In this section, I describe my method of computation in detail. The computational algorithm is similar to Hopenhayn (1992). The free entry condition pins down the equilibrium price (here, the loan rate $\widetilde{R}^{F^*}$) and the labor market clearing condition pins down the mass of new entrants B^*.

First of all, I want to derive some important equations needed to solve the stationary equilibrium. Equations (29) and (30) at the stationary equilibrium (hence, time scripts and expectation operators are removed) imply

$$n^{e*} = (1-\chi^e)\frac{\Gamma^{e'}(\bar{\omega}^{e*})}{\Gamma^{e'}(\bar{\omega}^{e*}) - G^{e'}(\bar{\omega}^{e*})}\widetilde{R}^{F*}n^{e*}$$

$$\rightarrow \frac{1}{(1-\chi^e)\widetilde{R}^{F*}} = \frac{\Gamma^{e'}(\bar{\omega}^{e*})}{\Gamma^{e'}(\bar{\omega}^{e*}) - G^{e'}(\bar{\omega}^{e*})} \tag{41}$$

$$R^{K*} = \frac{1}{(1-\chi^e)(1-\Gamma^e(\bar{\omega}^{e*})) + \frac{(\Gamma^e(\bar{\omega}^{e*}) - \mu^e G^e(\bar{\omega}^{e*}))}{\widetilde{R}^{F*}}}. \tag{42}$$

Equation (26) in the stationary equilibrium (i.e., $q^{K*} = 1$ holds) implies

$$k^* = \frac{\widetilde{R}^{F*}b^*}{(\Gamma^e(\bar{\omega}^{e*}) - \mu^e G^e(\bar{\omega}^{e*}))R^{K*}}. \tag{43}$$

A.1 Stationary Competitive Equilibrium

In this subsection, I explain the algorithm for computing the stationary competitive equilibrium defined in subsection 4.5 for the benchmark case ($\phi = 0.08$). In this case, since the equilibrium price $\widetilde{R}^{F^*}$ is a target of calibration (the interest margin is $\widetilde{R}^{F^*} - R^{D*} = 0.04$), we do not have to satisfy the free entry condition. Rather, the free entry condition pins down the entry cost Υ. The basic algorithm is as follows.

1. Calculate $(\bar{\omega}^{e*}, R^{K*}, r^{K*})$ using equations (41), (42) and (23) under $R^{D*} = \frac{1-\theta}{\beta}$, $\widetilde{R}^{F*} = 0.04 + R^{D*}$, and $q^{K*} = 1$.

2. Solve the Bellman equations for banks under $R^{D*} = \frac{1-\theta}{\beta}$, $\widetilde{R}^{F*} = 0.04 + R^{D*}$, and $\phi = 0.08$.

3. Calculate the entry cost Υ using equation (33).

4. Guess an initial mass of new entrants, B_0.

5. Calculate the stationary distribution implied by the policy functions from step 2 and the mass of new entrants using equation (34).

6. Using the bank policies from step 2 and the stationary distribution from step 5, calculate the equilibrium aggregate variables in the banking sector using equations (35), (36), (37), and (38).

7. Calculate the aggregate productive capital k^* in equation (43) by substituting aggregate bank loans from step 6 into b^*. Also, calculate entrepreneurs' net worth $n^{e*} = k^* - b^*$.

8. Calculate entrepreneurs' dividends c^{e*} to households using equations (20) and (21) as $c^{e*} = \frac{\chi^e}{1-\chi^e} n^{e*}$.

9. Calculate the labor demanded and wage (l^{d*}, w^*) using the first order conditions of the firm's problem as $l^{d*} = k^* \left[\frac{r^{K*}}{\alpha}\right]^{\frac{1}{1-\alpha}}$ and $w^* = (1-\alpha)\left[\frac{k^*}{l^{d*}}\right]^{\alpha}$.

10. Given $(R^{D*}, w^*, DIV^*, T^*, c^{e*}, \Pi^{c*} = 0)$ and aggregate deposits $d^* = D^*_{tot}$ calculated above, the household's problem pins down their consumption and labor supply (c^*, l^{s*}).

11. Update the measure of new entrants B_0 and repeat steps 4 to 10 until the labor market clears $l^{d*} = l^{s*}$.

A.2 Counterfactual Analyses

In this subsection, I explain the algorithm for counterfactual analyses conducted in subsection 6.2. In this exercise, the equilibrium price $\widetilde{R}^{F^*}$ changes depending on the level of capital requirement $\phi = \phi_0$. Hence, the free entry condition must be satisfied to pin down $\widetilde{R}^{F^*}$. The basic algorithm is as follows. Since the mass of new entrants B does not impact the bank's problem, the equilibrium price level $\widetilde{R}^{F*}$ is determined by the free entry condition (from step 1 to step 3 below) independently from the equilibrium mass of new entrants B^*, which is determined by the labor market clearing condition (step 4 below).

1. Guess an initial price level $\widetilde{R}_0^F$.

2. Solve the Bellman equations for banks under $R^{D*} = \frac{1-\theta}{\beta}$, $\widetilde{R}^{F*} = \widetilde{R}_0^F$, and $\phi = \phi_0$.

3. Update the price level $\widetilde{R}_0^F$ and repeat steps 1 to 3 until the free entry condition is satisfied with entry cost Υ computed in subsection A.1.

4. Repeat steps 1 and 4 to 11 in the previous subsection.