Optimal Financial Regulation

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Job Market Paper
November 2019

Abstract

I show that when the banking sector's assets comprise large excess reserves and loans, jointly determined capital regulation and interest-on-excess-reserves (IOER) policies provide welfare gains. In general equilibrium, falling IOER is associated with a proportional fall in deposit rate only when IOER is above zero bound. This leads to a faster fall in bank's interest expenses than its interest incomes. Given any lending level, lower net interest expenses enhances bank solvency. Nonetheless, the risk-weighted capital regulation remains unchanged and hence becomes socially costly. I show that jointly determined policies achieve welfare gains by loosening the capital requirement and lowering IOER to expand the credit flow, while bank failure likelihood remains constant. Conversely, lowering IOER below the zero bound is associated with a nonresponsive deposit rate that leads to growing net interest expenses and worsening bank solvency. I show that a stricter capital constraint together with a lower IOER provide social value.

Keywords: Capital regulation, monetary policy, asset pricing, corporate finance

[1]Email: `h.ramian@imperial.ac.uk`. I am greatly indebted to my advisors Franklin Allen, Harjoat Bhamra, Alex Michaelides and Savitar Sundaresan for their continuous supports and their guidance through this project. I am thankful to Patrick Bolton, Andrea Buraschi, Gilles Chemla, Pasquale Della Corte, Christopher Hansman, Marcin Kacperczyk, Paymon Khorrami, Zaici Li, David Miles, Tarun Ramadorai, Atiyeh Yeganloo, Yun Him Adrian Lam and Paolo Zaffaroni for their valuable feedback and numerous helpful conversations. I would like to thank Cláudia Custódio, Adam Denny, Marco Francischello, Can Gao, Chryssi Giannitsarou, Rajkamal Iyer, Lu Liu, Maria-Teresa Marchica, Nikolaos Rapanos, Oren Schneorson, Yi Zhang and many other seminar participants for their feedback and comments. A special thanks to Imperial College London Presidential Scholarship that supported me throughout this research. All remaining errors are mine.

1 Introduction

Over the past decade, oversized excess reserves of the banking sector has comprised over one-third of the total assets of major central banks in charge of 40% of the world economy[2]. Interest-on-excess-reserves (IOER) is one of the levers used by policymakers to regulate reserves. The transmission mechanism from IOER to capital requirement regulation is an important consideration with welfare implications because conflicting impacts of the two policies may lead to over-regulation of the banking sector and disruptions in credit flow to the real sector. Alternatively, two policies may lead to under-regulation and re-expose the banking sector to heightened default risk and possibly bank failure with socially undesirable outcomes.

Each macroprudential policy addresses distortions associated with one aspect the economy.[3] Nonetheless, the policymaker's ability to provide welfare gains through a broad range of levers is limited by the understanding of the interconnecting channels among levers. The aftermath of the 2008 financial crisis highlighted the lack of analytical frameworks to integrate multiple policies and their welfare implications. This provides motivation to raise the following two questions. First, what is the optimal capital regulation of the banking system in an environment where household's valuation of the bank net worth arises endogenously? Second, how does the effectiveness of this financial regulation depend on the monetary policy?

A comprehensive capital constraint that provides welfare gains considers three simple components: (i) how is the bank funded? (ii) what is the risk profile of bank's assets? (iii) what is the valuation of bank net worth? Existing studies focusing on (i) show that government-guarantees provide welfare gains by preventing self-confirming runs on bank debt, even if not originally justified by fundamentals (Diamond and Dybvig (1983)). Nonetheless, government-guarantees break the link between cost of debt and borrower's default risk and lead to under-capitalization of the banking system. This gives rise to an alternative distortion generated by more frequent bank failure and motivates capital regulation which provides welfare gains by lowering socially undesirable defaults (Martin et al. (2014), Allen et al. (2015)).[4] However, studies that concentrate on the liabilities provide limited predictions about the importance of bank asset composition. I show that effectiveness of optimal capital regulation depends on the asset side of the bank balance sheet, particularly when the monetary policy targets reserve management.

A large strand of literature focusing on (ii) shows that conditioning the risk profile of bank's asset side to its capital provides welfare gains (Brunnermeier and Sannikov (2014), Gertler and Kiyotaki (2015b)). However, this literature considers that households as the ultimate provider

[2]In September 2019, depository institutions in the United States held more than \$1.35T of funds in excess reserves that accounts for more than 40% of total balance sheet size of the Federal Reserves. The ECB holds over €1.9T in excess reserves forming a similar share relative to the consolidated balance sheet of the Eurosystem

[3]comprises a broad range of policy instruments supported by appropriate institutional arrangements governing their implementation (IMF (2011)).

[4]For further reference see Brunnermeier (2009), Gorton (2009), Adrian and Shin (2009), Hanson et al. (2011), Kiyotaki and Moore (1997), Allen and Gale (2000), Rochet and Tirole (1996), Freixas and Parigi (1998), McAndrews and Roberds (1995), Aghion et al. (1999), Stein (2012b).

of financing, in the form of debt or equity, play a limited role or that the supply of financing is fixed. I show that household's optimal consumption-saving behaviour has important implications for equilibrium cost of debt that is a determinant of banking sector's default risk. Specifically, this equilibrium mechanism predicts that as the cost of debt falls, unrelaxed capital constraint becomes socially costly, a gap that this papers addresses with a general equilibrium framework.

This paper provides a framework to understand the interconnection between risk-weighted capital regulation[5] and IOER. First, I develop a risk-weighted capital requirement regulation in a stochastic general equilibrium set-up and show that it offers welfare gains by lowering the likelihood of bank failure and its associated distortions that are ultimately borne by society. Equilibrium mechanism predicts that when a tighter capital constraint requires the bank to raise capital from the equity market, lower bank demand for debt financing leads to lower deposit rate only when IOER is above the zero bound. Lower interest expenses is associated with a lower bank default risk which enhances bank's solvency, given any lending level. Given an unrelaxed capital constraint, the bank extends lending until the marginal increase in bank net worth from additional lending revenues equates marginal decrease in its net worth due to added risk to the asset side. Conversely, when IOER is very low, or possibly below zero, the equilibrium deposit rate remains strictly positive because deposit investors always require compensation for their time preference. Specifically, this nonproportional responsiveness of the equilibrium deposit rate to IOER indicates that the interest incomes from excess reserves fall faster than the interest expenses on deposits. As a result of growing net interest expenses, the bank becomes less able to meet its debt liabilities, given any lending level, and its default risk increases[6].

Nonetheless, the optimal capital regulation remains intact when bank's solvency changes in response to changes in the monetary policy. Specifically, when IOER is above zero bound, a contractionary monetary policy that enhances bank solvency implies that a relaxed capital constraint provides further welfare gains. This is because of the following two reasons. First, as IOER falls, a capital constraints that is too tight requires the bank for raise further capital. When the capital markets are imperfect, additional equity-financing incurs welfare costs without providing additional gains. Brokerage fees and asymmetric information through secondary markets lead to distorions that are borne by the ultimate providers of capital. Second, given the additional enhanced solvency gains under falling IOER, the bank is able to satisfy an unrelaxed capital constraint and maximize its net worth by expanding its balance sheet size. In particular, the bank subject to a tight capital constraint, extends lending until the additional risk of its asset side offsets the additional safety of a tigher capital constraint. The model in this context allows this as an equilibrium outcome. However, this requires the bank to draw a significant amount of

[5]Bank capital requirement regulation has formed an integral component of global financial regulatory architecture. Regulators' wider economic outlook is conveyed to the banking system through partnerships with banks to ensure their capital structure meet certain standards. The primary source of regulatory guidance for such regulation has been the voluntary set of standards suggested by the Basel Committee on Banking Supervision.

[6]This notion is described in an ongoing work in Brunnermeier and Koby (working paper) which is referred to as the '*reversal rate*'.

funds from the households, particularly in the form of deposits. Given the endogenous household sector, depositors require a higher deposit rate to forgo consumption. However, given a falling IOER together with a decreasing return to scale technology within the lending sector, the bank is unable to generate such high returns to its financiers. As a result, an excessively high capital constraint may not lead to welfare gains.

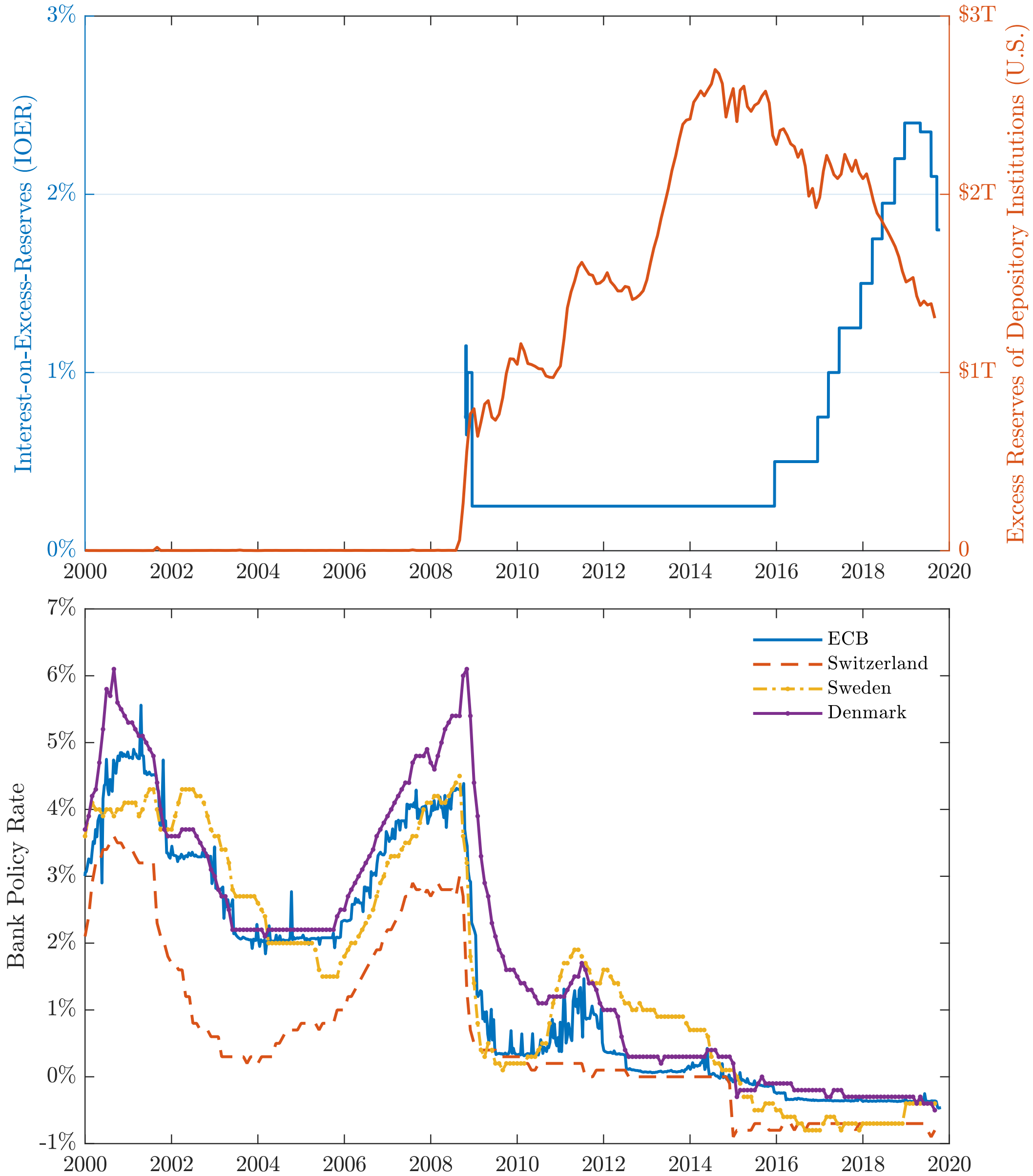


Figure 1: The top figure illustrates excess reserves balances of the depository institutions in the U.S. on the right axis, and interest-on-excess-reserve paid by the Federal Reserves on the left axis. The figure on the bottom shows the base rates paid on excess reserves by the European, Switzerland, Sweden and Denmark central banks.

I show that a joint regulation including a positively correlated capital regulation and IOER provides social value when IOER remains above zero bound. The join policy expands credit flow to the real economy while it addresses distortion associated with costly bank failure. On the contrary, when IOER is below zero, the policymaker is able to provide social benefits by a joint policy that is characterized by the negatively correlated financial regulatory and monetary instruments. This non-monotonic relationship provides motivation for an integration between two the policymakers in charge of IOER and capital regulation[7]. Each lever is able to address one distortion to provide welfare gains whereas a joint policy that considers the interconnections between both levers is able to provide further benefits. Particularly, an optimal IOER policy addresses overreliance on idle excess reserves while capital regulation addresses inefficiencies of costly bank failure.

Interest expenses, or alternatively interest incomes[8], associated with oversized excess reserves are an integral consideration for the policymaker. A narrower spread between lending rate and IOER is an incentive for the banks to invest further funds in reserves. However, large quantities of interest payments are ultimately financed from taxation which strains government funds that are intended to serve multiple purposes. Specifically, in this paper, deposit insurance is a tax-financed service that provides a guarantee for deposits held at the banks by deposit investors when banks default. This service offers social benefits by preventing self-confirming runs on bank deposits due to lack of confidence, although unwarented by fundamentals, in bank ability to meet its debt liabilities in full. I show that as IOER increases, first, the policymaker increases taxation in order to finance interest expenses which leads to a lower size of the financial sector and lower real economic activity. Second, credit flow by the banking sector to the real economy is further decreased because, on the margin, risky lending becomes less attractive relative to reserves.

When IOER is below zero, reserves provide interest incomes for the policymaker leading to a lower taxation because part of funds intended for deposit insurance is financed from paying negative interests. This mechanism increases the size of the financial sector but leads to a lower output because credit flow to the real sector is substituted with further reserves investment. In particular, the banking sector's overall response to increasing share of total assets invested in reserves is driven by the trade-off between lower net worth valuation—due to heightened default risk as a result of widened net interest expenses—against gains in net worth valuation due to lower default risk associated with lowered lending.

This result relies on the assumption that banks are unable to hold cash and therefore find it optimal to store large quantities of their funds in reserves even if the interest rate on this investment falls below zero. Figure (1) shows the the quantities of funds held in excess reserve deposit facilities a the Federal Reserve during the past twenty years. This provides one explanation in support of the argument why the banking system did not rely heavily on storing funds in the form of cash hoarding, instead, the balances held in excess reserve dramatically increased in the

[7]In the U.S, The Federal Open Market Committee (FOMC) is in charge of monetary policy that includes setting IOER, whereas capital regulation is implemented by Financial Supervision Committee, in the United Kingdom, interest rate policy is decide by the Bank of England while bank regulation is implemented by the Financial Services Authority (FSA).

[8]During 2018:Q3-2019:Q3, excess reserves balances of depository institutions in the U.S. received nearly \$2.43B in net interest incomes given an average IOER of 1.85% which is equivalent to approximately 10% to total excess reserves balance in 2008:Q3. A central bank's interest earnings ordinarily are transferred as tax revenues to the Treasury, by the Federal Reserves or other major central banks, whereas interest expenses on reserves need to be financed from the Treasury.

United States from under \$45B to over \$1T within a from from the financial crisis. The same argument applies to the European banking system. The second common feature that is described in Figure (1) is that these large quantities of funds remains significant different from pre-2008 balances. In particular, funds held at the Federal Reserves seems to be even negatively correlated with the IOER which is consistent with the prediction of the model in this paper. Irving Fisher argued that when a commodity can be stored costlessly over time, then the lower bound in terms of units of that commodity will always remain positive or at least zero.[9] However, generalization of this result to this context is less straightforward because storage of large quantities of funds is costly even for the banking sector. The model in this paper does not explicitly introduce storage cost for funds but relies on the following empirical observations that excess reserves balance of banking sectors across 25% world economy remained positive when central banks lowered IOER to negative territory.

In this paper, household's valuation of deposit and equity arises endogenously. A key feature that remains within an open area of research when considered in conjunction with and an endogenous default possibility and endogenous dividend stream. The equilibrium price of equity is determined by households' preferences for earning from bank dividend against its default risk. As bank extends lending, on the one hand its share price is bid up due to higher embedded cashflow but on the other hand, increased exposure to aggregate uncertainty lowers its expected share price through default risk. When the bank is highly leveraged, each additional unit of equity provides a sizable contribution to its net worth because default risk is relatively a more important driver of its share price. As bank's capital structure comprises further equity relative to total assets, marginal contribution of equity to reduce default risk diminishes and equity's higher cost relative to debt becomes a more important consideration for its net worth.

The general equilibrium framework in this paper shows that equity premium compensation to risk-averse investor falls as the equity-to-asset ratio in bank capital structure increases. When the bank raises capital through the equity market, first, its share price falls due to a higher demand for capital because the equity investor requires compensation to forgo consumption. However, a fall in share price is less steep because a risk-averse equity investor prices lower riskiness of their investment.

This paper is organized to provide a brief overview of existing and ongoing studies that examine interconnections between capital regulation and IOER in Section (2). I develop a dynamic general equilibrium model in Sections (3)-(6) to study the implications of financial regulation on welfare, real economy and fragility of banking sector. Section (7) provides a numerical solution and Section (8) discusses welfare and asset pricing implications. Section (9) concludes.

[9]The Theory of Interest, Irving Fisher, pp52.

2 Background

Financial regulation provides social value by addressing distortions that intermediaries fail to internalize. Diamond and Dybvig (1983) show that deposit insurance provides social value by preventing self-confirming runs on bank debt, especially when panic-based runs are not originally justified by fundamentals. However, deposit insurance increases bank's willingness to over-rely on debt financing because heightened default risk as a result of under-capitalization is no longer captured by the cost of debt.

Bank capital requirement regulation has formed an integral component of global financial regulatory architecture. Regulators' wider economic outlook is conveyed to banking system through partnerships with banks to ensure their capital structure meet certain standards[10] in relation to risk profile of their assets. A bank with higher exposure to riskier borrowers is required to hold more capital with the intention of increasing bank's ability to meet its debt liabilities should the borrowers become unable to repay their liabilities to the bank[11]. Anat Admati and Martin Hellwig have written comprehensive studies to recommend capital requirement policies that set forth stricter risk-weighted capital structures to increase bank's stake in risk taking to decrease the bank failures that are socially undesirable[12].

Bank failures have important implications for welfare consideration by the financial regulation because bankruptcies in the banking system is associated with realized losses that are estimated to be about 30% of ex-post total assets. These losses include expenses that arise only when a bankruptcy is triggered which involves lengthy legal processes, costly liquidation and sale of assets, lost charter value, past realized losses[13]. James (1991) estimates that a bankruptcy process is associated with 30% loss of bank's total assets due to legal and liquidation proceedings. Similarly, Andrade and Kaplan (1998) and Korteweg (2010) show that bankruptcy cost can vary between 10% to 23% of total assets within non-financial firms and between 15% to 30% of total assets for financial firms. Almeida and Philippon (2007); Acharya et al. (2007) and Glover (2016) provide comprehensive studies that examine bankruptcy cost according to several measurements and show that in some cases these costs can account for more than 30 cents on the dollar.

Financial regulation internalizes bankruptcy costs that is otherwise ignored by individual banks and sets a minimum (risk-weighted) capital requirement policy to lower the possibility of bank failure and by this means its associated deadweight loss. Academic and professional literature has studied the impact of capital requirement on banks within macroeconomic settings

[10]The primary source of regulatory guidance for such regulation has been the voluntary set of standards suggested by the Basel Committee on Banking Supervision

[11]These standards have drawbacks, for example, their heavy reliance on privately provided credit ratings leads to inaccuracies and creates distortions. Credit ratings are less accurate than credit spreads and the standards neither distinguish among issues within a particular rating category nor among issues with different spreads.

[12]Such policies are yet to be adopted by the regulators into the financial system. Kern Alexander (2015) addresses international efforts to regulate bank capital requirements and leverage which are negated by factors such as asymmetric lobbying against stricter rules.

[13]Losses on assets that occur prior to the bank's failure but are not reported on the bank's balance sheet at the time of the failure.

(Gertler et al., 2012; Bianchi et al. (2016), Christiano and Ikeda, 2014; Landvoigt and Begenau (2016); Chari and Kehoe, 2015) to show how the financial accelerator effect slows down when bank's capital is subject to less fluctuations due to the introduction of capital requirements. The key mechanism that motivates setting capital requirement works through the bank decision to that fails to internalize the effect their own borrowing on financial stability and its feedback effect.

The first contribution of this paper is to extend the finding of existing literature with a general equilibrium approach in which banking system is exposed to uninsurable uncertainty through loans to borrowers. The introduction of aggregate uncertainty is a key ingredient as it creates a close resemblance to an economy that faces potential loss of productivity and financial crises due to inability of borrower to raise further funding at sector level to meet debt contracts. General equilibrium framework has significant implications to incorporate interrelated feedback between lenders whose decision to provide financing to the banking system is dependent on profitability of equity investment and dividend payouts under defaults and solvencies, and borrowers whose valuation of future cashflow incorporates their shareholder's preferences.

Another consideration that factors into regulator's decision to set capital requirement is take into account lender's ability and willingness to participate in equity investment of banking system. Setting stricter capital requirement implies that households, as ultimate provider of financing, need to take a smaller position in risk-free investments such as deposits, and larger position in risky investment which eventually forms bank's capital. When households are reluctant to participate in stock market or purchase risky equities, increasing capital requirements amounts to additional resistance by banking sector because marginal price of capital has to increase significantly to convince holders of risk-free assets to rebalance their portfolios which leads to falling risk-free rate (deposit rate) and widening equity premium.

The last ingredient that regulator takes into account when deciding on capital regulation is the efficiency of financial market that intermediates funds from investors to equity borrowers. Although deposit investment is costless in most economies[14], equity investment requires services from financial intermediaries such as investment banks and brokers. These costs include underwriting fees, broker's bid-ask spreads, etc. that are charged to lenders or borrowers throughout intermediation process which lower the ultimate equity investment's return to lenders or dampens raised capital that reaches borrowers. In this context, regulator considers such costs through intermediation process as a secondary deadweight loss that is socially undesirable and intends to lower when a decision on capital regulation is evaluated. Specifically, when financial markets are perfectly efficient and intermediations fees are zero, regulator is only concerned with recommending sufficiently high level of capital that eliminates bank failures. This sets an upper bound on capital regulation, however, as intermediation fees increases, regulator considers this deadweight loss against costly bankruptcies and recommends a capital regulation policy that balances welfare

[14] Fees, minimum deposit limits, and many transaction costs are in place but in general deposit investment is a more accessible financial investment relative to equity purchases that incurs intermediation fees

gains of higher bank capital associated with less frequent failures versus gains associated with lower funds channelled through costly intermediation.

Bank asset holding include cash or its equivalents, reserves, Treasuries and other risk-free investments and loans to borrower. Stricker risk-weighted capital regulation requires more equity per unit of risky investment limits the share of risky asset holding and increases the share of assets in risk-free investments. In this context, reserves deposit facility that is available to the banking system serves as a risk-free investment that increases when bank's capital regulation amounts to lower loans. Since 2008, excess reserves[15] held by the banking system with the central banks dramatically increased in the U.S. banking system from \$45 billions in September 2008 to nearly \$1 Trillion by January 2009. Keister and McAndrews (2009) and Ennis (2018) show that part of such changes in holding reserves is explained by the implications of heightened uncertainty and low productivity that lead the banking system to seek out a safe investment to avoid bankruptcies that rose during the 2007-2008 financial crisis. Unlike required reserves that are mandatory deposits, excess reserves are voluntary deposits that receive IOER paid by central bank to the banking system which can be positive, zero or negative. As IOER is decreased, excess reserves become a less attractive investment which are substituted for by loans to business sector. However, this portfolio rebalancing due to IOER is interrelated with risk-weighted capital requirement across bank's balance sheet which leads to a tighter capital requirement.

The dependencies between IOER and risk-weighted capital requirement has important implication that calls for a joint response by the monetary authority in charge of IOER and financial regulator in charge of capital requirement. From welfare perspective, capital requirement is a policy tool that is able to counter with the deficiency caused by bankruptcy cost and intermediation fees that the banking sector fails to internalize. Without further deficiencies, any IOER that results in changes in capital requirement is irrelevant to welfare. However, a joint policy tool that include IOER needs to consider that although reserves provide financial stability, they are an unproductive investment and interest payments on reserves has to be funded from taxes. A financial regulator that is in charge of IOER and capital regulation and offer deposit insurance raised taxes or ex-ante insurance premium to be able to pay any interest expense on reserve and compensate deposit holder when the banks fails. The choice of taxation is an important factor that determines whether deposit insurance can provide full compensation in any default state.in particular, when taxes are equivalent to outstanding deposits less the reserves then depositors are guaranteed to receive their funds even if the bank fails due to an adverse shock to its borrowers who become unable to repay their liabilities to the bank. As taxes fall short of the amount deposits less reserves, the deposit insurance is able to offer only partial insurance to depositors in real terms.

This deficiency arises due to the choice of taxation in relation to the capital structure and

[15]Excess reserves are fund that are deposited to central banks in additional to required reserves, that are mandated to be held as a proportional of total assets for legal requirements. While required reserves increases grew modestly over the past decade, excess reserves have grown with an unprecedented rate.

asset allocation of banking system. A joint financial regulatory policy that compensates reserves by IOER has to take into account that interest expenses are a further force that lower taxation which limit the ability of deposit insurance to compensate deposit holders. Consequently, the interaction between IOER and other policy tools is associated with a welfare implication which has to be considered when deciding an optimal IOER that has interactions with capital requirement regulation. The social value of bank equity and social value of reserves are two consideration to policy makers that counter bankruptcy cost and deposit insurance's ability and have to decided jointly.

3 The Model

Assume time is discrete, with dates $t = 0, 1, 2, \ldots$. The economy consists of three sectors including a representative household, a representative bank (commercial bank or intermediary) and a financial regulator. First, the household is an infinitely-lived dynasty who lives off financial wealth. At each date-t, the household chooses optimal consumption-saving and portfolio allocation to two investment opportunities, deposits and equity. The deposit is a risk-free investment compensated at gross interest rate $R_{D,t+1}$ by the banking sector and benefits from deposit insurance guarantee. The equity is a risky investment that is subject to stochastic return $\mathbb{E}_t[R_{E,t+1}] > R_{D,t+1}$ and is protected by limited liability such that in a default state, investor is only responsible up to its original investments. Section (3.1) discusses the households' preferences in more details.

Second, a representative banking sector is in charge of intermediating funds from the households to borrowers by accepting deposits and issuing equity to raise capital. The bank invests its financings in two purposes: issue a commercial loan portfolio that earns stochastic return $R_{L,t+1}$ per each unit of investment, or invest in reserves held at the central bank to earn risk-free interest-on-reserves $R_{X,t+1}$. At the end of each period, Bank's liabilities consist of deposits plus interest which must be honored for the bank to remain bank solvent in which case earnings from loans and reserves are transferred to deposit holders, and then equity investors. The bank, however, is able to declare bankruptcy when it is unable to meet its liabilities in which case deposit holders are compensated partially by the bank and equity value is zero. Section (3.2) discusses the banking sector's valuation problem and defaults in details.

Third, a financial regulator provides the following three services: offers deposit insurance, sets the minimum risk-weighted capital requirement, and accepts reserve deposits from the banking sector. Deposit insurance is a guarantee that compensates depositors in full in default states. The minimum risk-weighted capital requirement considers a welfare maximizing objective that internalizes costly bankruptcy that both the households and banking sectors ignore. Lastly, accepting deposits from the banking system is a form of reserves deposit facility. Section (3.3) discusses the regulators problem in details.

The solution methodology is organized with the following set-up. Section (4) presents the optimal behaviour of the households and the banking sector without regulator's minimum capital requirement intervention and discusses general equilibrium implications, followed by the optimal interest-on-reserves policy at the end of the subsection. Second, the regulator's problem to set the minimum capital requirement is presented together with bank's problem subject to the regulatory constraint in Section (5), followed by general equilibrium implications, given an exogenous interest-on-excess-reserves rate. Lastly, Section (6) presents a general equilibrium model with both the optimal interest-on-reserves and minimum capital requirement policies and discusses the interactions. Deposit insurance service is provided by the regulator across Sections (3)-(6).

3.1 Preferences

An infinitely-lived representative household finances consumption from financial wealth and maximizes her preferences described by recursive utility proposed by Epstein and Zin (1991) and Weil (1990):

$$\{C_t^*, D_{t+1}^*, E_{t+1}^*\}_{t=0}^{\infty} \in \underset{\{D_{t+1}, E_{t+1}\}}{\arg\max}\ \mathbb{E}_0 \left[U(C_t, \mathbb{E}_t U_{t+1})\right] \tag{3.1}$$

$$U(C_t, \mathbb{E}_t U_{t+1}) = \left\{(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta\left(\mathbb{E}_t U_{t+1}^{1-\gamma}\right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}\right\}^{\frac{1}{1-\frac{1}{\psi}}} \tag{3.2}$$

where at each date-t, the investor decides on optimal consumption and portfolio allocation subject to the intertemporal budget constraint described below, receives utility from real consumption C_t, $\beta \in (0,1)$ is the subjective discount factor, γ is the coefficient of relative risk aversion, and ψ is the elasticity of intertemporal substitution (EIS). The investor's attitude towards static risk is separated from intertemporal substitution of consumption and the investor is assumed to have preferences for early resolution of uncertainty such that $\gamma > \frac{1}{\psi}$ throughout the model. The conditional expectation operator $\mathbb{E}_t[.]$ evaluates investor's probabilistic assessment of different outcomes one-step ahead.

The investment environment includes risk-free deposit investment D_{t+1} that is chosen at date-t backed by deposit insurance receiving gross deposit interest R_{t+1}^D, and risky bank equity E_{t+1} with stochastic gross return protected by limited liability,

$$R_{E,t+1}^+ = \max\left\{\frac{P_{E,t+1} + \Pi_{E,t+1}}{P_{E,t}}, 0\right\} \tag{3.3}$$

where $P_{E,t}$ and $\Pi_{E,t}$ are the price of equity and dividend, respectively. Equity investment is assumed to be subject to a linear underwriting cost $\kappa \in (0,1)$. The intertemporal budget constraint is,

$$P_{C,t}C_t + \underbrace{D_{t+1} + E_{t+1}}_{\text{Saving}} = \underbrace{(1-\tau_{t+1})}_{\text{Premium}}\left(\underbrace{\overline{R_{D,t}D_t}}_{\text{Deposit Insured}} + \underbrace{R_{E,t}^+(1-\kappa)E_t}_{\text{Limited Liability}}\right) + \underbrace{Tr_{t+1}}_{\text{Transfer}} \tag{3.4}$$

where τ_{t+1} is a fraction of household income that is taxed and $Tr_t \geq 0$ is a transfer that the household receives from the regulator described in section (x). The right-hand-side of equation (3.4) describes investor's wealth W_t which evolves at rate $R_{W,t+1}$ between two consecutive dates t and $t+1$ according to:

$$R_{W,t+1} = (1-\tau_{t+1})(1-\theta_{t+1})R_{D,t+1} + (1-\tau_{t+1})\theta_{t+1}(1-\kappa)R_{E,t+1} + \frac{Tr_{t+1}}{W_t} \tag{3.5}$$

where θ_{t+1} is the portfolio weight on risky asset. The household's value function is,

$$V_t = \left\{(1-\beta)\left(\frac{C_t}{W_t}\right)^{1-\frac{1}{\psi}} + \beta\left(1-\frac{C_t}{W_t}\right)^{1-\frac{1}{\psi}}\left(\mathbb{E}_t\left[V_{t+1}^{1-\gamma}R_{W,t+1}^{1-\gamma}\right]\right)^{1-\frac{1}{\psi}}\right\}^{\frac{1}{1-\psi}} \tag{3.6}$$

3.2 Bank Problem

The representative risk-neutral bank serves a central role in the economy. First, the bank finances its operations by accepting deposits $\mathcal{D}_{t+1}$ and issuing equity to form its capital $\mathcal{E}_{t+1}$. Second, the bank acts as a conduit to intermediate funds from the households to borrowers[16].

The investment environment that the bank faces includes loans as a form of risky investment and risk-free reserves deposited at a deposit facility offered by the regulator. Therefore, at each date-t the bank decides how to finance its operations by choosing an optimal capital structure and a portfolio allocation to maximize the present value of the following cashflow described by:

$$\underbrace{\mathcal{E}_{t+1}R_{E,t+1}}_{\text{Shareholder Value}} = \max\left\{\underbrace{\underbrace{R_{X,t+1}X_{t+1}}_{\text{Reserve Income}} + \underbrace{R_{L,t+1}L_{t+1}}_{\text{Loan Portfolio}}}_{\text{Total Reveune}} - \underbrace{R_{D,t+1}\mathcal{D}_{t+1}}_{\text{Total Cost}}, 0\right\}$$

where X_{t+1} and L_{t+1} are investments made by the bank in the reserves deposit facility and loans granted, each receiving gross interest-on-reserves and stochastic loan rate, respectively. The right-hand-side of equation (3.7) is the total shareholder value that bank is able to generate after paying out its deposits and its interest. The bank balance sheet at each date consists of debt $\mathcal{D}_{t+1}$, capital $\mathcal{E}_{t+1}$, reserves X_{t+1} and loans L_{t+1}:

$$L_{t+1} + X_{t+1} = \mathcal{D}_{t+1} + \mathcal{E}_{t+1} \tag{3.7}$$

Let η_{t+1} and ω_{t+1} denote equity-to-assets and loan-to-assets ratios derived from banks balance sheet at each period, respectively[17], such that $(\eta_{t+1}, \omega_{t+1}) \in [0,1]\times[0,1]$. The risk-neutral bank

[16]The intermediation process is a key service that reduces potential costs which lenders and borrowers would have faced throughout a dis-intermediated economy. A banking sector offers an important welfare improving implication by minimizing searching and monitoring costs across sectors. Although such associated cost are only assumed implicitly in this study, the welfare improving implications form the basis for the presence of a banking sector.

[17]As section (x) shows, in equilibrium the optimal capital structure decision η^*_{t+1} and portfolio allocation by the bank ω^*_{t+1} take interior solutions. This implies that in equilibrium bank's capital structure includes both debt and capital and its portfolio allocation includes both reserves and loans.

Assets		Liabilities	
Reserves $(1-\omega_{t+1})$	X_{t+1}	Deposits $(1-\eta_{t+1})$	D_{t+1}
Loans (ω_{t+1})	L_{t+1}	Shareholder Value (η_{t+1})	E_{t+1}
Balance Sheet Size	A_{t+1}		

Table 1: The table describes bank's balance sheet with deposits and equity forming the liabilities side and reserves and loans forming the assets side.

maximizes economic profit according to,

$$\max_{\eta_{t+1},A_{t+1},\omega_{t+1}} \int_{\Delta_h} M_{t,t+1} div_{t+1} dF(z) \tag{3.8}$$

Subject to,

$$X_{t+1} + L_{t+1} = \mathcal{D}_{t+1} + \mathcal{E}_{t+1} \tag{3.9}$$

$$\eta_{t+1} \geq \overline{\eta}_{t+1} \tag{3.10}$$

$$(\eta_{t+1}, \omega_{t+1}) \in [0,1] \times [0,1] \tag{3.11}$$

where A_{t+1} is the total balance sheet size and $M_{t,t+1}$ is the stochastic discount factor[18] of the households who own bank's equity that is taken as given from bank's perspective when making decision on its capital structure. The bank discounts expected economic profit at date-$t+1$ with respect to probability space $(\Omega, \mathscr{F}, F)$ to choose decisions given the price of equity and deposit interest.

Equation (3.9) is bank's balance sheet constraint where X_{t+1}, L_{t+1}, $\mathcal{D}_{t+1}$ and $\mathcal{E}_{t+1}$ are reserves, loans, deposits and equity components of the balance sheet, respectively. The bank chooses total balance sheet size, and the following two fractions, equity-to-asset and loan-to-assets ratios, over the solvency region. Equation (3.10) is the minimum capital requirement constraint that stipulates for any balance sheet size, the bank must raise a certain fraction $\overline{\eta}_{t+1}$ of its total liabilities through equity funding.

Defaults — The bank is only concerned with the solvency region defined by Δ_h. The solvency region is determined by the end-of-period loan rate that breaks even between revenues and outstanding liabilities formulated according to the following ex-post condition,

$$\underbrace{R_{p,t+1}A_{t+1}}_{\text{Total Revenues plus Interest Income/Expense}} = \underbrace{R_{D,t+1}\mathcal{D}_{t+1}}_{\text{Total Liabilities plus interest payment}} \tag{3.12}$$

where $R_{p,t+1} = (1-\omega_{t+1})R_{X,t+1} + \omega_{t+1}R_{L,t+1}$ denotes the gross return on bank portfolio. Given bank's decisions η_{t+1}, A_{t+1} and ω_{t+1}, equation (3.12) pins down a unique gross loan rate $R_{b,t+1}$ in the state space that makes the bank break-even or just able to pay off its debt-holders. Specifically,

[18]Details in section (x)

at loan rate $R_{b,t+1}$, the bank is collecting only a fraction of its outstanding loans which together with reserves enables the bank to remain just solvent with the value of its shareholders equal to zero:

$$R_{E,t+1} \;=\; \frac{R_{p,t+1}A_{t+1} - R_{D,t+1}\mathcal{D}_{t+1}}{\mathcal{E}_{t+1}} \;=\; 0 \tag{3.13}$$

Assuming a strictly positive beginning-of-period equity value $\mathcal{E}_{t+1} > 0$, then condition (3.12) implies that because $A_{t+1} > \mathcal{D}_{t+1}$ then $R_{p,t+1} < R_{D,t+1}$. The threshold loan rate is given by:

$$R_{b,t+1}(\eta_{t+1}, \omega_{t+1}; R_{X,t+1}, R_{D,t+1}) \;=\; \max\left\{\frac{1-\eta_{t+1}}{\omega_{t+1}}R_{D,t+1} - \frac{1-\omega_{t+1}}{\omega_{t+1}}R_{X,t+1}, 0\right\} \tag{3.14}$$

Henceforth the shorthand break-even loan rate $R_{b,t+1}$ specifies the default and solvency regions $\Delta_f := [0, R_{b,t+1})$ and $\Delta_s := [R_{b,t+1}, \infty)$, respectively over the possible loan outcome in the state space. The default threshold is known at date-t when the bank decides on its funding and asset allocation decisions. Specifically, higher equity-to-asset ratio (ceteris paribus) enables the bank to withstand a greater adverse shock e.g. higher non-performing loans, and remain solvent, thus $R_{b,t+1}$ is weakly decreasing in η_{t+1}. In an extreme case, when the bank is over-capitalized such that it is able to cover its exposure to risky loans with capital alone ($\omega_{t+1} < \eta_{t+1}$), then $R_{b,t+1}$ is equal to zero and constant in η_{t+1}. Conversely, higher loan-to-asset ratio (ceteris paribus) worsens bank's ability to withstand adverse outcomes and therefore $R_{b,t+1}$ is weakly increasing in ω_{t+1}. Similarly, in an extreme case when the bank is over-capitalized then $R_{b,t+1}$ is equal to zero for any $\omega_{t+1} < \eta_{t+1}$. The break-even loan rate $R_{b,t+1}$ is increasing in deposit rate because higher deposit rate increases interest payments to bank's debt holders which increases the likelihood of ending up in a default outcome. Conversely, $R_{b,t+1}$ is decreasing in interest-on-reserves because higher interest-on-reserves contributes as an interest income to bank and extends its ability to meet its liabilities. Interestingly, $R_{b,t+1}$ is independent of bank's balance sheet size A_{t+1} because of implicit constant return to scale (CRS) assumption on loan section[19]. Intuitively, this implies that the bank may choose any balance sheet size but the key driver of its default depends on η_{t+1}, ω_{t+1}, $R_{X,t+1}$ and $R_{D,t+1}$ only, because the compositions inside the balance sheet determines ability to withstand adverse outcomes for any arbitrary balance sheet size.

The bank faces bankruptcy when its end-of-period revenues $R_{p,t+1}A_{t+1}$ is strictly less than its outstanding liabilities $R_{D,t+1}\mathcal{D}_{t+1}$. The probability of default depends on the properties of aggregate shock to bank's borrowers who repay their own liabilities to the bank:

$$\mathbb{P}\left(\text{Default}_{t+1}\right) \;=\; 1 - \mathbb{P}\left(R_{p,t+1}A_{t+1} \geq R_{D,t+1}\mathcal{D}_{t+1}\right) \tag{3.15}$$

[19] When, however, the loan section exhibits a decreasing return to scale framework such that larger scale is associated with lower effective return per unit, the balance sheet size matters to $R_{b,t+1}$ precisely because larger A_{t+1} implies lower return on loan section which accordingly limits bank's ability to meet its liabilities for a given adverse outcome (I have solved for this case as well but now in the process of including it for the subsequent draft).

In a default state, realized loan rate is strictly less than the threshold[20] $R_{b,t+1}$ and subsequently the bank is forced into bankruptcy and its proceeds are distributed to the debt holders on pro rata basis[21]. Limited liability condition prevents equity investors to internalize losses beyond their initial equity investments which indicates that in any default state, the bank is subsequently unable to fully compensate its debtors and the risk is partially passable to deposit accounts. This introduces the possibility of Diamond-Dybvig financial panic where depositors may start to withdraw their funds in anticipation of a potential default. Deposit insurance offered by the regulator rules out this specific financial panic by promising depositors a guarantee on their risk-free investments.

The bank solves the problem in (3.8) by choosing first, total balance sheet size (A_{t+1}) and funding composition η_{t+1} given the price of equity and deposit rate[22]. The solution to the bank problem on the funding side thus are two demand functions or 'twin demands' for capital that are jointly determined by price of equity, deposit rate, and also any asset allocation choice ω_{t+1} from the assets side of the bank balance sheet. The bank trades with the households to pin down equilibrium capital structure and their prices, given any ω_{t+1}. Third the bank considers interest-on-reserves and loan rate to pin down its portfolio allocation which overall solve the bank problem.

Bank Borrowers and Production — For tractability, I assume that the bank grants loans to borrowers who have no alternative access to financing and engage in production activities in a non-financial sector. This assumption maintains bank's central role to act as an intermediary between households and ultimate borrowers, however, indicates that the non-financial sector is all-externally financed. First, the non-financial sector engages in a static production process which requires financing at the beginning of each period and pays off a stochastic outcome at the end of the period. Second, production process in the non-financial sector is subject to aggregate uncertainty which is non-diversifiable at sector level therefore bank as the lender is unable to diversify its commercial loan portfolio's risk across the non-financial sector. The underlying loan contract between the bank and its borrowers stipulates that a loan is considered non-performing when the borrower fails to repay the original borrowed amount plus interest that is decided between two counter-parties ex-ante. In any default state, the bank is allowed to seize borrower's total assets which together with the non-diversifiable risk profile implies the bank's loan section is non-performing in that default state.

[20] For instance, a default threshold $R_{b,t+1} = 0.75$ indicates that the (minimum) net loan rate that a bank can withstand to remain solvent is $R_{b,t+1} - 1 = -25\%$. When the bank realizes an ex-post loan rate $R_{L,t+1} < R_{b,t+1}$ then its total assets value falls below total liabilities and has to declare bankruptcy.

[21] The bankruptcy definition is stipulated by the debt contract between the bank and its debt-holders. Particularly when the bank denies repaying debt-holders in full, it can be forced into bankruptcy. The term liquidation within this context refers to enforcing debt contract to seize bank's (end-of-period) assets in the event of bankruptcy. It is worth mentioning that in the discrete-time model presented in this section, after bankruptcy a new bank is set up and continues its service by raising debt and capital.

[22] Subject to boundary constraints to ensure interior or corner solution.

In this context, because the non-financial sector in unable to raise financing directly from the households, it is also unable to redistribute dividends (if any) to households in a solvency state, and the banks also receives any dividend from the non-financial sector which effectively implies the bank serves as the owner of the non-financial sector. The outcome of the non-financial sector is the real economic output that is consumed in the goods market by the households.

Technology — The bank faces a log-normally distributed shock per unit of investment in loan section with the following Cobb-Douglas production technology that is subject to an exogenous aggregate shock z_{t+1},

$$h(L_{t+1}, z_{t+1}) \;=\; z_{t+1} L_{t+1}^{\alpha} \tag{3.16}$$

where $\log z_t = \mu_z + \sigma_z \epsilon_{t+1}$, $\epsilon_t \sim \mathcal{N}(0,1)$ and $\alpha \in (0,1]$.

3.3 Financial Regulator

The banking sector described in the previous section is only concerned with the solvency region. However, bank's capital structure includes funding that is raise through debt contracts which allow debt holders to force the bank into bankruptcy due to inability to honor debt contracts in full. James (1991) estimates that a bankruptcy process is associated with 30% loss of bank's total assets due to legal and liquidation proceedings. Similarly, Andrade and Kaplan (1998) and Korteweg (2010) show that bankruptcy cost can vary between 10% to 23% of total assets within non-financial firms and between 15% to 30% of total assets for financial firms. Almeida and Philippon (2007); Acharya et al. (2007) and Glover (2012) provide comprehensive studies that examine bankruptcy cost according to several measurements and show that in some cases these costs can account for more than 30 cents on the dollar.

In this context, bankruptcy cost is characterized by a proportional fraction $1 - \chi \in (0,1)$ of banking sector's total assets when a default occurs. Therefore, the financial regulator who is concerned with both solvency and default outcomes, considers such costs and sets a minimum (risk-weighted) capital requirement to maximize the following social welfare function.

$$\max_{Q_{X,t}, \overline{\eta}_{t+1}} \mathbb{E}_0 \left[U(C_t, \mathbb{E}_t U_{t+1}) \right] \tag{3.17}$$

subject to,

$$P_{C,t} C_t + D_{t+1} + E_{t+1} = (1 - \tau_{t+1}) \left(\frac{1 - \overline{\eta}_{t+1}}{Q_{D,t}} + \overline{\eta}_{t+1} (1 - \kappa) R_{E,t} \right) + Tr_{t+1} \tag{3.18}$$

and $\overline{\eta}_{t+1} \in [0,1]$ where the transfer function is

$$\frac{\mathrm{Tr}_{t+1}}{W_t} = \begin{cases} \tau_{t+1} - (1-\tau_{t+1})(1-\omega_{t+1})r_{X,t+1} & \text{if } z_{b,t+1} \leq z_{t+1} \text{ (non-default)} \\ \tau_{t+1} - (1-\tau_{t+1})(1-\omega_{t+1})r_{X,t+1} - \Lambda_{t+1} & \text{if } z_{s,t+1} \leq z_{t+1} < z_{b,t+1} \text{ (default)} \\ 0 & \text{if } z_{t+1} < z_{s,t+1} \text{ (inadequate deposit insurance)} \end{cases}$$

the term Λ_{t+1} shows uncovered share of debt contracts (uncompensated deposits in relation to the whole deposits plus promised interests) from the banking sector,

$$\Lambda_{t+1} = (1-\tau_{t+1}).\left(\frac{1-\eta_{t+1}}{Q_{D,t}} - \chi.R_{p,t+1}A_{t+1}\right)$$

where $r_{X,t+1} \equiv R_{X,t+1} - 1 = 1/Q_{X,t} - 1$ and that $r_{X,t+1} \lesseqgtr 0$ is the net interest-on-reserves offered on reserves deposit facility offered by the regulator to the banking sector, and $\overline{\eta}_{t+1}$ is the minimum (risk-weighted) capital requirement set on the banking sector.

First, social welfare function in (3.17) is identical to utility function of the households which regulator maximizes considering regulatory tools available in this context. Equation (3.18) characterizes regulators resource constraint that internalizes transfers to households.

Second, the regulator raises funds through a proportional taxation[23] τ_{t+1} from the households. These funds are available to the regulator to offer deposit insurance[24] in a default state and to cover interest expenses on reserves when interest-on-reserves are positive. The transfer function has no interaction with interest-on-reserves when interest-on-reserves is zero. When interest-on-reserves is negative, then reserves deposit facility provide an interest income to the regulator since the proportion of reserves $1-\omega_{t+1}$, scaled by after tax resources $1-\tau_{t+1}$ earns interest income when $r_{X,t+1} < 0$. Third, the regulator considers three possible outcome interval when

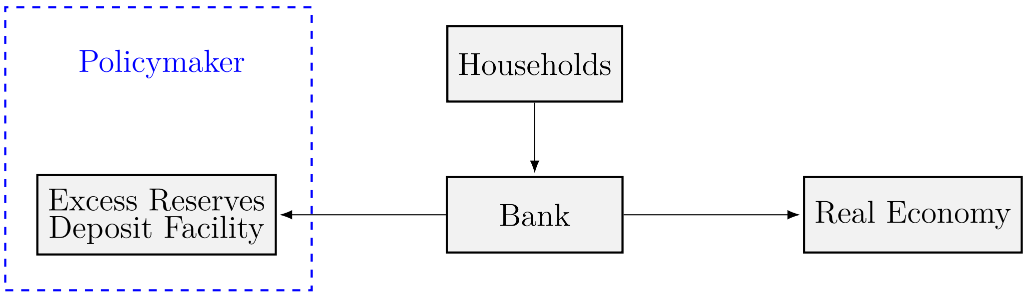


Figure 2: The diagram illustrates sectors in the economy. The households invest in bank equity and deposit their funds into bank deposit facility as a risk-free investment. The bank is given two investment opportunities: channel funds to real economy as a loan, and hold a share of its funds in the excess reserves deposit facility provided by the policymaker.

considering the transfer. The non-default region is characterized by the the aggregate shock

[23]The notion of taxation in this context is to simplify the analysis. The regulator uses these funds for the purpose of deposits insurance, which indicates that taxes serves as a ex-ante premium, and also to pay interest payments.

[24]Deposit insurance fee can be charged directly from the banking sector, however, in this context with a representative households sector and banking sector, applying the charges directly to household offers tractability.

outcome $z_{b,t+1} \leq z_{t+1}$ specifying that the banking sector remains solvent. The default region is characterized by $z_{s,t+1} \leq z_{t+1} < z_{b,t+1}$ specifying that due to realizing an large adverse shock, the banking sector's total assets falls below its debt liabilities. In this case, the bank defaults and its post bankruptcy process is described by $\chi.R_{p,t+1}A_{t+1}$ and the regulator compensates depositors out of its available resources which implies that although deposits are risk-free, households receive a smaller transfer. From a welfare perspective, the regulator considers fraction $(1-\chi).R_{p,t+1}A_{t+1}$ as a deadweight loss that is socially undesirable to the economy. Fourth, the choice of taxation is

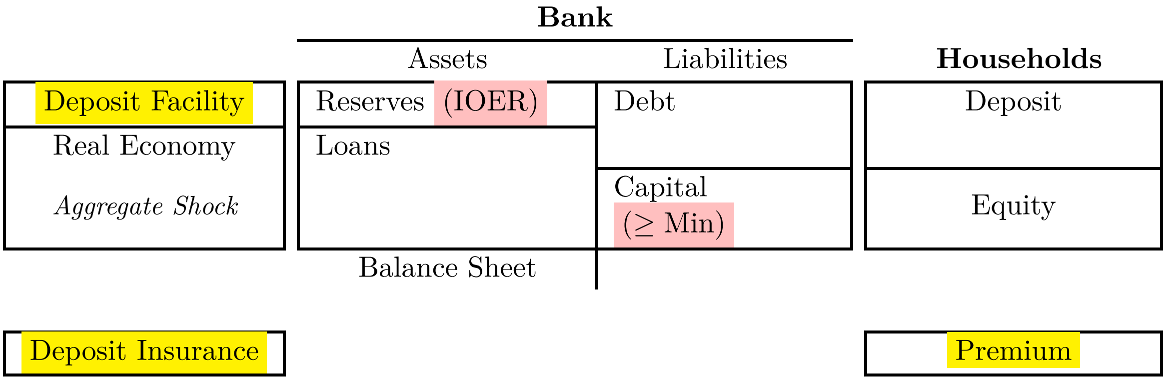


Table 2: The diagram describes flow of funds from households (deposit and equity) to the banking sector's liabilities (debt and capital) which subsequently is channelled to the real economy (lending) and excess reserves deposit facility. Policymakers services in charge of financial regulation and interest-on-excess-reserves is highlighted in the diagram. Premium is the taxation that policymaker raises at the beginning of each period, in anticipation of any defaults in the banking sector, to provide government guarantees to depositors. This resource also serves as a fund to pay any positive (negative) interest expenses on excess reserves deposit facility.

taken as given and the solution section considers the following two possible cases. When taxation is sufficiently large enough to provide full insurance on deposits. This case requires taxes to be equal to deposits (plus promised interest) less the reserves (plus interests) such that any resulting uncovered deposits within the banking sector can be covered by the taxes and reserves, for example, in an extreme case when the entire loan section of the banking sector is eliminated due to an adverse large shock. However, when taxation is insufficient to cover deposits in real terms, the regulator can offer only partial insurance on deposits.

4 Laissez-faire Intermediation

This section presents an equilibrium analysis without capital regulation. A welfare analysis based on the laissez-faire allocations provides a framework to measure social costs associated with the each distortion. The optimal behaviour of the households who are the providers of financing to the financial sector and ultimately the real economy are described in the following sub-section, followed by the optimal decision of the banking sector to raise financing in sub-section (4.2).

4.1 Supply of Financing

The household maximizes expected utility of future consumption stream subject to the intertemporal budget constraint. At each date-t, the household chooses optimal consumption and portfolio choice. The first order condition with respect to consumption yields the Euler equation,

$$1 \quad = \quad \mathbb{E}_t \left[M_{t,t+1} R_{W,t+1} \right] \tag{4.1}$$

where

$$M_{t,t+1} \quad = \quad \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\rho \frac{\gamma-1}{1-\rho}} \frac{V_{t+1}}{\left[\mathbb{E} V_{t+1}^{1-\theta} \right]^{\frac{1}{1-\theta}}} \tag{4.2}$$

denotes household's stochastic discount factor. Return on household's wealth includes both the equity and deposit returns in the solvency state and the deposit income only in the default state. Consumption-saving policy function is constant over time when the stochastic process governing equity return is i.i.d. therefore I conjecture that the consumption policy function $C_t = (1 - \varphi) R_{W,t} W_t$ solves the intertemporal problem as a special case with i.i.d. uncertainty[25] where φ is the marginal propensity to save (MPS). Solving for the value of MPS gives the following investment-to-wealth ratio in logarithmic units:

$$\log(\mathrm{MPS}_{t+1}) \quad = \quad \psi \log(\beta) + \frac{1 - \psi^{-1}}{\psi^{-1}} \left[\mathbb{E}_t r_{W,t+1}(\theta_{t+1}) + \frac{1}{2}(1-\gamma)\sigma_{r_W}^2 \right] \tag{4.3}$$

This ratio is positively related to investor's subjective discount factor or impatience parameter β, such that higher patience implies higher saving if $\psi < 1$ and $\gamma > 1$. The first order condition with respect to portfolio choice θ_{t+1} is given by:

$$\theta_{t+1}^* \quad = \quad \underbrace{\frac{\mathbb{E}_t \log R_{E,t+1} - \log R_{D,t+1} + \sigma_E^2/2}{\gamma \sigma_E^2}}_{\text{Merton's myopic demand}} + \underbrace{\frac{1}{\gamma \sigma_E^2} \log \Phi(R_{E,t+1} > 0)}_{\text{default disincentive}} \tag{4.4}$$

The first term on the right-hand-side describes Merton's (rational) myopic allocation to risky asset[26]. The second term denoted by $\Phi(.)$ characterizes the role of endogenous defaults and is measured by the probability of solvency of the underlying risky asset issuer that the household holds which appears in logarithmic units. This term is a negative factor to lower household's investment when defaults are possible. However, as the likelihood of solvency increases, the demand for the risky asset increases. In the limiting case when the underlying issuer is solvent in all states, $\log \Phi(.)$ is zero showing that household's demand simplifies to that of the Merton's model when a default is ruled out.

The optimal total investment (4.3) together with (4.4) fully characterize household's decisions to supply financing to the banking sector in the form of deposit and equity, given the deposit rate

[25] The conjecture follows the results in Giovannini and Weil (1989) and Campbell and Viceira (1999).

[26] Investment in risky asset does not depend on elasticity of intertemporal substitution when the shock to economy follows an i.i.d. process.

and the price of the equity:

$$
\begin{aligned}
D_{t+1}(Q_{D,t}, P_{E,t}) &= \Big[\mathrm{MPS}_{t+1}(\theta^*_{t+1}) \times (W_t - C^*_t)\Big] \times (1 - \theta^*_{t+1}) \\
E_{t+1}(Q_{D,t}, P_{E,t}) &= \Big[\mathrm{MPS}_{t+1}(\theta^*_{t+1}) \times (W_t - C^*_t)\Big] \times \theta^*_{t+1}
\end{aligned}
$$

where the supply of funds to the deposit market increases in deposit rate but decreases in equity return. Conversely, equity investment falls as the price of equity increases of the deposit rate increases.

4.2 Demands for Financing

The risk-neutral expected present value problem in (3.8) indicates that bank's funding and asset allocation decisions affect the following two channels[27]: first, the bank considers cost of capital when raising funds from the capital markets in order to maximize its profit. Second, extended allocation of funds to loans increases bank's cashflow. However, a high loan-to-assets ratio or a low equity-to-assets ratio decrease the possibility of remaining solvent which lower bank's profit through the expectation channel. Approximating the problem in (3.8) to separate the expectation (probability) channel from the (discounted) dividend channel gives[28]:

$$
\max_{\theta_{t+1}, A_{t+1}, \omega_{t+1}} \quad \underbrace{\Phi\Big[\lambda\big(R_{b,t+1}\big)\Big]}_{\text{Probability Channel}} \quad \times \quad \underbrace{\mathbb{E}_t\Big[M_{t,t+1} div_{t+1}\Big]}_{\text{Discounted Dividend Channel}} \tag{4.5}
$$

where the first term quantifies the explicit probability of solvency and the second term quantifies the discounted dividend[29]. The logarithmic quantile[30]

$$
\lambda(R_{b,t+1}) = \frac{\mu_z + \sigma_z^2 - \log(R_{b,t+1})}{\sigma_z} \tag{4.6}
$$

henceforth λ_{t+1}, is associated with log-normally distributed loan rate threshold $R_{b,t+1}$.

First, because $R_{b,t+1}$ is weakly decreasing in η_{t+1} (ceteris paribus), then $\Phi(\lambda_{t+1})$ is weakly increasing in η_{t+1} indicating that a higher equity-to-assets ratio increases the probability of solvency. This is because a higher equity-to-assets ratio lowers break-even threshold $R_{b,t+1}$ which corresponds to a lower standardized quantile $\lambda(.)$. Note that both functions $\Phi(.)$ and $\lambda(.)$ are strictly monotonic in their arguments. Second, because $R_{b,t+1}$ is weakly increasing in ω_{t+1} (ceteris paribus), then $\Phi(\lambda_{t+1})$ is weakly decreasing in ω_{t+1} indicating higher loan-to-assets ratio lowers the probability of solvency.

[27] Subject to balance sheet constraint (3.9) and boundary constraints (3.11).

[28] Appendix A.

[29] Doing so implies that (first) dividend is treated as a random variable without max[.] operator and can be both positive or negative, (second) $\mathbb{E}_t[.]$ is over both solvency and default regions. As an illustration consider that the kink on max$[div, 0]$ function over the state space is the exact break-even loan rate

[30] Because the loan is log-normally distributed, the problem can be written in terms of a standard Normal cumulative distribution function with standardized logarithmic quantiles.

The second term in (4.2) can be written as,

$$M_{t,t+1}div_{t+1} = M_{t,t+1}\Bigg[\underbrace{\frac{1-\omega_{t+1}}{Q_{X,t}}A_{t+1}}_{\text{Reserves plus IOR}} + \underbrace{\omega_{t+1}z_{t+1}A_{t+1}}_{\text{Loan plus interest}} - \underbrace{\frac{1-\eta_{t+1}}{Q_{D,t}}A_{t+1}}_{\text{Deposit Financing}} - \underbrace{\frac{\eta_{t+1}}{P_{E,t}}A_{t+1}}_{\text{Equity Investment}}\Bigg] \quad (4.7)$$

where $Q_{D,t} = 1/R_{D,t+1}$ and $Q_{X,t} = 1/R_{X,t+1}$ are the prices of deposits and reserves, respectively. The constant return to scale technology implies that A_{t+1} does not affect the probability channel and the risk-neural property implies that balance sheet size is linear in dividend channel.

First-Order-Condition (Balance Sheet Size) The first order condition of bank problem with respect to A_{t+1} is given by,

$$0 = \left[\frac{\partial}{\partial A_{t+1}}\Phi\left(\lambda_{t+1}\right)\right]\cdot \mathbb{E}_t\Big[M_{t,t+1}div_{t+1}\Big] + \Phi\left(\lambda_{t+1}\right)\cdot\frac{\partial}{\partial A_{t+1}}\mathbb{E}_t\Big[M_{t,t+1}div_{t+1}\Big] \quad (4.8)$$

decomposition in (4.2) results in the product rule in the first order condition above that tracks in impact of balance sheet size on marginal changes in present value of dividend, keeping probability of solvency constant, and marginal changes in probability of solvency while keeping the dividend channel constant. Re-arranging (4.16) gives:

$$\frac{\partial}{\partial A_{t+1}}\log\Phi\left(\lambda_{t+1}\right) = \frac{\partial}{\partial A_{t+1}}\log\mathbb{E}_t\Big[M_{t,t+1}div_{t+1}\Big] \quad (4.9)$$

an optimal balance sheet size decision $A^*(\eta_{t+1},\omega_{t+1},P_{E,t},Q_{D,t};Q_{X,t})$ by bank that solves problem (4.2) trades off percentage change in probability of solvency[31] $\%\Delta_A\Phi(.)$, against percentage change in expected present value of dividend $\%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$.

First, the probability channel always motivates the bank to choose a smaller balance sheet size due to decreasing return to scale feature of the loan section. This is indicated by the sign of the term $\%\Delta_A\Phi(.)$ that is always negative for any balance sheet size. As the bank increases its balance sheet size, the marginal loan rate falls which reduces its ability to meet deposit expenses. Further, $\%\Delta_A\Phi(.)$ is increasing in price of deposit and price of equity because higher funding prices lower cost of financing, for example, when the bank is able to raise debt through deposits at a lower deposit rate then it faces a higher $\%\Delta_A\Phi(.)$ which indicates that the balance sheet size can increase on the margin. Similarly, when the degree of decreasing return to scale (α) falls, the probability channel become a stronger motivation to decrease balance sheet size because a lower α reduces marginal loan rate. As a special case when $\alpha = 1$ the probability channel become irrelevant to bank's decision making because the choice of balance sheet is independent of marginal return from loan section. In this special case the first order condition with respect to size only interacts with the dividend channel and the probability of solvency remains constant for any choice of size. Intuitively, this case indicates that the solvency is only driven by the

[31] A positive (negative) but constant $\%\Delta_A\Phi(.)$ indicates that probability of solvency increases (decreases) at a fixed rate, and when $\%\Delta_A\Phi(.)$ is zero then probability of solvency remains fixed.

composition of components inside the balance sheet and not the size itself and therefore any size is therefore optimal. More formally, the expectation operator[32] on the right hand size of equation (5.1) does not depend on endogenous variables and that the bank optimal decisions takes $M_{t,t+1}$ as given then,

$$0 \;=\; \Phi\Big[\lambda\Big(R_{b,t+1}\Big)\Big]\mathbb{E}_t\Big[M_{t,t+1}\frac{\partial}{\partial A_{t+1}}div_{t+1}\Big] \tag{4.10}$$

Since probability of solvency is always strictly positive because for any equity-to-assets and loan-to-asset ratios the bank can always remain solvent for an arbitrarily large loan rate outcome, then:

$$0 \;=\; \mathbb{E}_t\Big[M_{t,t+1}\frac{\partial}{\partial A_{t+1}}div_{t+1}\Big] \tag{4.11}$$

which results in the following first order condition that indicates, on the margin, the expected present value of cost of financing should be equal to the expected present value of one unit of investment return from bank's portfolio,

$$\mathbb{E}_t\left[M_{t+1}\left(\frac{1-\omega_{t+1}}{Q_{X,t}}+\omega_{t+1}z_{t+1}\right)\right] \;=\; \mathbb{E}_t\left[M_{t+1}\left(\frac{1-\eta_{t+1}}{Q_{D,t}}+\frac{\eta_{t+1}}{P_{E,t}}\right)\right] \tag{4.12}$$

the balance sheet size is always at its optimum when PV of financing cost equal PV of portfolio return. When, however, the PV of financing cost is greater than that of the portfolio return, the bank chooses balance sheet size equal to zero and when the PV of financing cost is lower than that of the portfolio return the bank choose a size that grows without bounds. Equilibrium mechanism, however, specifies that equation (4.12) must hold with equality which then establishes a condition between the prices of deposits, equity and reserves (and moments of loan).

In a more general case when $\alpha \in (0,1)$, right-hand-side of equation (5.1) summarizes the effect of dividend channel with the term $\%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$. Specifically, this term is monogenically decreasing in size because as the balance sheet grows (absent probability channel) lower marginal rate from loan section reduces the expected value of profit in resent value terms. The term $\%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ is very large when size is small and begins to fall as the size increases. When the marginal loan rate, together with bank's income from reserves become equal to cost of financing then $\%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ is zero which corresponds to the maximum present value of bank profit. Any further increase in the size beyond this limit amounts to a negative expected profit.

Further, the bank faces lower cost of financing when price of deposit and equity increase which accordingly enable the bank to increase the balance sheet size that is associated with a lower marginal loan rate. In a special case, when $\alpha = 1$ the dividend become linear in size which implies that the bank faces an indeterminate choice with respect to size. In this case, the expected return on bank portfolio must be equal to expect cost of financing, otherwise the optimal size

[32] Integral boundaries are the support for random variable over $[0, \infty)$.

increases without bound when investing in portfolio is always marginally more profitable than marginal cost of financing, or the size is zero when expected portfolio return is lower than cost of financing.

The solution to first-order-condition (5.1) is a unique choice of balance sheet that equates percentage change in probability of solvency and percentage change in expected dividend channel. When $\%\Delta_A\Phi(.) < \%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ bank is able to increase the size to obtain more profit at the expense of lowering the probability of solvency. When $\%\Delta_A\Phi(.) > \%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ then the balance sheet must shrink such that the solvency increases at the expense of lower dividend. Since $\%\Delta_A\Phi(.)$ is always negative and $\%\Delta_A\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ is monotonically decreasing in size, the optimal balance sheet size in a general case when $\alpha \in (0,1)$ is always smaller than the case when $\alpha = 1$.

Before discussing the optimal capital structure choice it is worth examining the relationship between optimal size and any funding composition on the liabilities side. Higher choice of equity-to-asset ration η_{t+1} increases bank's ability to withstand more adverse shock outcomes thus $\%\Delta_A\Phi(.)$ is increasing in η_{t+1} which indicates that the bank can increase its balance sheet size when its equity-to-assets ratio increases (ceteris paribus).

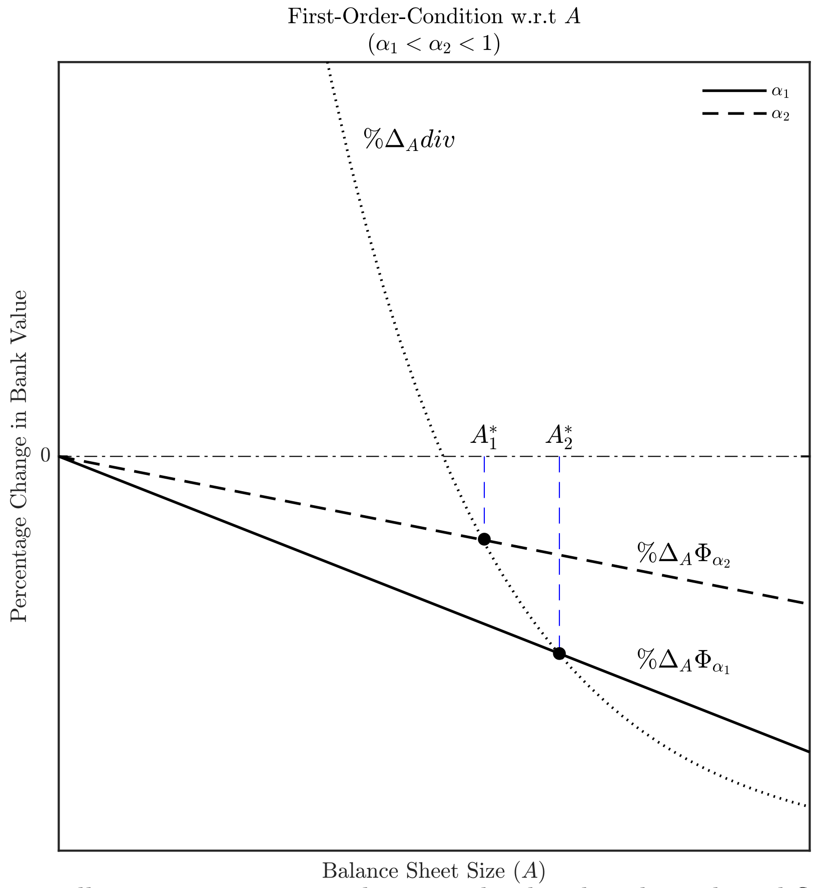


Figure 3: This figure illustrates percentage change in bank value through cashflow and solvency components when balance sheet size changes. The dotted lines shows that as balance sheet size grows, bank value increases at a decreasing rate when $\%\Delta_A div > 0$. When $\%\Delta_A div = 0$ increasing balance sheet size amount to no changes in cashflow channel. The solid line shows the solvency effect of increasing bank balance sheet size on its value

First-Order-Condition (Capital Structure) The first order condition with respect to capital structure is given by,

$$0 = \left[\frac{\partial}{\partial \eta_{t+1}}\Phi\left(\lambda_{t+1}\right)\right].\,\mathbb{E}_t\left[M_{t,t+1}div_{t+1}\right] + \Phi\left(\lambda_{t+1}\right).\frac{\partial}{\partial \eta_{t+1}}\mathbb{E}_t\left[M_{t,t+1}div_{t+1}\right] \tag{4.13}$$

using the decomposition in (4.2), the expression above is re-arranged as the following,

$$\frac{\partial}{\partial \eta_{t+1}}\log\Phi\left(\lambda_{t+1}\right) = \frac{\partial}{\partial \eta_{t+1}}\log\mathbb{E}_t\left[M_{t,t+1}div_{t+1}\right] \tag{4.14}$$

where similar to the previous part left-hand-side summarizes percentage change in probability channel due to changes in equity-to-asset ratio $\%\Delta_\eta\Phi(.)$. As the bank increases η_{t+1} probability of solvency increases because higher equity-to-asset ratio increases bank's ability to withstand adverse shock outcomes. Formally, this effect is captured by the sign of the term $\%\Delta_\eta\Phi(.)$ that is always positive for any choice of η_{t+1}. Further, increasing equity-to-asset ratio monotonically improves the chance of solvency however, when the bank is overcapitalised[33] the marginal gain in probability of solvency is very small and defaults are very rare. This is reflected by the slope of $\%\Delta_\eta\Phi(.)$ which is decreasing in η_{t+1}, specifically, when η_{t+1} is very small, the percentage change in probability of solvency is large because each additional unit of equity can considerably lower defaults. As η_{t+1} increases, $\%\Delta_\eta\Phi(.)$ decreases upto the point at which $\%\Delta_\eta\Phi(.)$ become very close to zero showing that the probability of solvency is reaching one[34] . Increasing equity-to-asset ratio beyond this limit has to impact on the solvency channel and as a result $\%\Delta_\eta\Phi(.)$ is weakly decreasing in η_{t+1}. Furthermore, $\%\Delta_\eta\Phi(.)$ is highly dependant on the price of deposits as the end-of-period interest expenses is an important determinant whether the bank remains solvent. Thus $\%\Delta_\eta\Phi(.)$ is decreasing in the price of deposit because the bank is able to withstand relatively more adverse shock when deposit interest expenses fall. Interestingly, the term $\%\Delta_\eta\Phi(.)$ is independent of the price of equity because defaults is only driven by debt contracts.

The right-hand-side of equation (4.14) summarizes the effect of capital structure choice on expected present value of bank profit. In particular, $\%\Delta_\eta\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ is negative and monotonically decreasing[35] in η_{t+1} when $P_{E,t} < Q_{D,t}$ as the bank considers equity more expensive relative to deposits due to its riskiness.

When $\%\Delta_\eta\Phi(.) < \%\Delta_\eta\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ is a driver to increase η_{t+1} which results in lower expect present value of dividend but increases the probability of solvency. When $\%\Delta_\eta\Phi(.) =$

[33] Over-capitalization is a relative term with respect to loan-to-asset ratio discussed in the next subsection. However, it is innocuous in to assume a bank is overcapitalised when its equity-to-asset and loan-to-asset ratios are close to each other which reflect a bank that hold enough equity to withstand a very large adverse shock to loans and remain solvent.

[34] In this case, the break-even threshold $R_{b,t+1}$ is equal to zero indicating that there is no possible loan outcome that set bank's total assets below its total liabilities. Note that when $R_{b,t+1} = 0$ (net ex-post loan rate is -100% i.e. all of bank loan section disappears in the extreme case) then $\lim \lambda(R_{b,t+1}) = \infty$ and the associated CDF is equal to one in the limit.

[35] The assumption $P_{E,t} < Q_{D,t}$ relies on equilibrium outcome discussed in the subsequent sections but since suppliers of funding are risk-averse, then it is reasonable to restrict the discussion to cases in which price of equity is always below the price of deposits.

$\%\Delta_\eta \mathbb{E}_t[M_{t,t+1} div_{t+1}]$ the bank balances the marginal contribution of equity to solvency against expected dividend.

The marginal contribution of equity to expected economic profit through probability channel is a factor that bids up equity price against deposits price from bank's perspective. As the equity become mores scarce, the bank is willing to accept lower price today as equity's marginal probability contribution is very high.

Solving equation (4.14) for η^*_{t+1} gives,

$$\eta^*_{t+1} \quad = \quad \eta^*(A_{t+1}, \omega_{t+1}, P_{E,t}, Q_{D,t}; Q_{X,t}) \tag{4.15}$$

which is bank's optimal capital structure for any $Q_{D,t}$ and $P_{E,t}$. Particularly, η^*_{t+1} specifies that when the price of equity at date-t increases (ceteris paribus), bank increases its demand for equity financing because it is able to raise more funding per share. Conversely, when the price of deposit increases (ceteris paribus) the bank lowers η^*_{t+1} as equity becomes relatively more expensive than deposit financing and bank shifts its liabilities towards more debt[36]. Bank's funding decision is fully characterized by equations (5.1) and (4.14) which are solved for in equilibrium for deposit and equity prices in the following subsection.

First-Order-Condition (Asset Allocation) The first order condition with respect to capital structure is given by,

$$0 \quad = \quad \left[\frac{\partial}{\partial \omega_{t+1}} \Phi\left(\lambda_{t+1}\right)\right] . \, \mathbb{E}_t\left[M_{t,t+1} div_{t+1}\right] + \Phi\left(\lambda_{t+1}\right) . \frac{\partial}{\partial \omega_{t+1}} \mathbb{E}_t\left[M_{t,t+1} div_{t+1}\right] \tag{4.16}$$

using the decomposition in (4.2), the expression above is re-arranged as the following,

$$\frac{\partial}{\partial \omega_{t+1}} \log \Phi\left(\lambda_{t+1}\right) \quad = \quad \frac{\partial}{\partial \omega_{t+1}} \log \mathbb{E}_t\left[M_{t,t+1} div_{t+1}\right] \tag{4.17}$$

the left-hand-side summarizes percentage change in probability channel due to changes in loan-to-asset ratio $\%\Delta_\omega \Phi(.)$. As the bank increases $\omega t + 1$ probability of solvency decreases because higher loan-to-asset ratio increases exposure to shock outcomes and lowers bank's ability to withstand adverse shock outcomes. Formally, this effect is captured by the sign of term $\%\Delta_\omega \Phi(.)$ that is always negative for any choice of $\omega t + 1$. Further, increasing loan-to-asset ratio monotonically worsen chance of solvency however, when the bank is overcapitalised the marginal gain in probability of solvency is very small and defaults are very rare. This is reflected by $\%\Delta_\omega \Phi(.) = 0$ when $\omega_{t+1} \leq \eta_{t+1}$. As ω_{t+1} increases, $\%\Delta_\omega \Phi(.)$ increases monotonically reflecting growing chance of default due further exposure to aggregate shock.

The right-hand-side of equation (4.17) summarizes the effect of asset allocation on expected present value of bank profit. When $\%\Delta_\omega \Phi(.) < \%\Delta_\omega \mathbb{E}_t[M_{t,t+1} div_{t+1}]$ the bank increases $\omega t + 1$

[36]In an extreme case when the deposits (equity) price is very high, the bank finds optimal to raise more debt (equity) even outside $\eta^*_{t+1} \in [0, 1]$ interval. These cases are discussed later and eliminated as the funding composition can include zero equity at the very least.

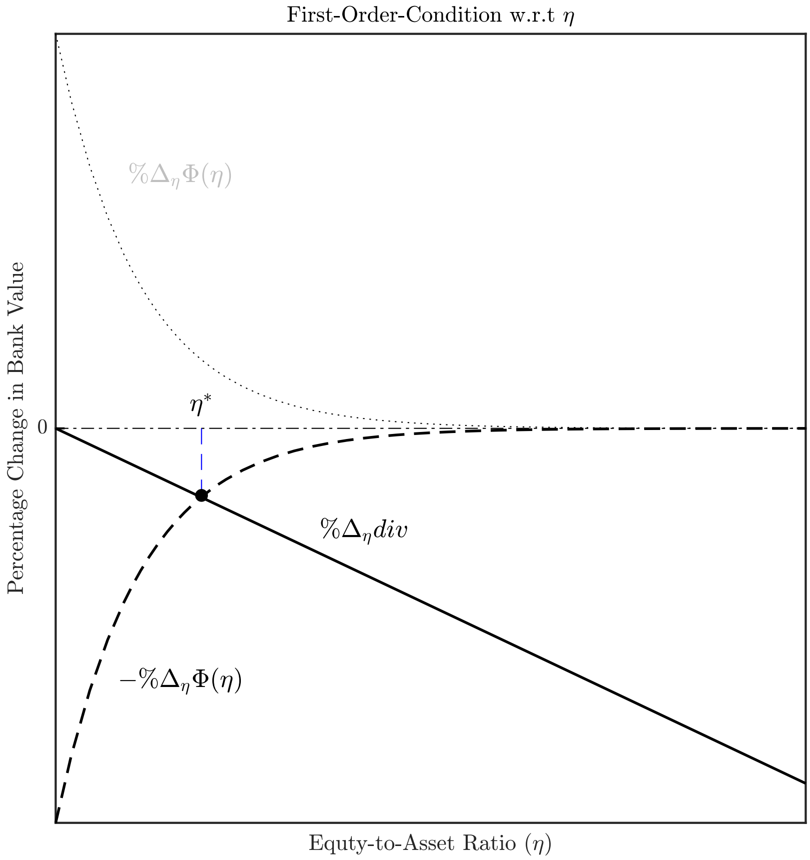


Figure 4: The figure illustrates percentage change in bank's value through cashflow and probability components. The solid line illustrates that bank's value falls when bank raises further financing through equity when equity is more costly than debt financing. The dashed line illustrates (times a negative to depicts first-order-condition) that bank's value increases through higher likelihood of solvency but at a decreasing rate because each additional unit of equity provide lower marginal contribution to solvency likelihood.

which results in lower expect present value of dividend at the expense of increasing the probability of default. When $\%\Delta_\omega\Phi(.) = \%\Delta_\omega\mathbb{E}_t[M_{t,t+1}div_{t+1}]$ the bank balances the marginal contribution of asset allocation (to loan) to solvency against expected dividend.

Solving equation (4.17) for $\omega t + 1^*$ gives,

$$\omega^*_{t+1} \quad = \quad \omega^*(A_{t+1}, \eta_{t+1}, P_{E,t}, Q_{D,t}; Q_{X,t}) \tag{4.18}$$

which is bank's optimal asset allocation choice for any $Q_{D,t}$ and $P_{E,t}$.

4.3 Laissez-faire Equilibrium

Market clearing conditions on the deposits and equity markets establish the following equilibrium conditions:

$$\underbrace{D_{t+1}(Q_{D,t}, P_{E,t}; Q_{X,t}, \omega_{t+1})}_{\text{Supply of Capital (household deposits)}} = \underbrace{\mathcal{D}_{t+1}(Q_{D,t}, P_{E,t}; Q_{X,t}, \omega_{t+1})}_{\text{Demand for Capital (bank debt)}} \tag{4.19}$$

$$\underbrace{E_{t+1}(Q_{D,t}, P_{E,t}; Q_{X,t}, \omega_{t+1})}_{\text{Supply of Capital (household equity)}} = \underbrace{\mathcal{E}_{t+1}(Q_{D,t}, P_{E,t}; Q_{X,t}, \omega_{t+1})}_{\text{Demand for equity (bank capital)}} \tag{4.20}$$

First, equation (4.12) from bank's first order condition with respect to balance sheet size determines a relationship between the price of deposits in terms of price of equity (and other variables that are determined later, e.g. allocation to loans, etc.). This condition clears the deposits market for a specific deposit prices, give any price of equity, $Q_{D,t}(P_{E,t})$. Second, the resulting market clearing deposit price $Q_{D,t}(P_{E,t})$ is solved for jointly with the equity market clearing condition for a specific price of equity, given other variables that are determined outside the funding markets.

5 Intermediation with Capital Regulation

The financial regulator maximizes social welfare function in (3.17) with respect to minimum capital requirement choice set on liabilities of the banking sector. This regulatory policy takes bank's asset allocation decision as given to find the optimal capital requirement conditional on ω_{t+1}, or henceforth the optimal risk-weighted capital requirement $\overline{\eta}^{*}_{t+1}(\omega_{t+1})$.

First-Order-Condition (RW-Capital Requirement) Marginal changes in $\overline{\eta}_{t+1}(\omega_{t+1})$ give the following FOC over the default and solvency regions, respectively:

$$0 = \int_{0}^{z_{b,t+1}} M_{t,t+1}\left[\frac{d\mathrm{Tr}_{t+1}}{d\overline{\eta}_{t+1}} - \frac{1}{Q_{D,t}}\right] dF + \int_{z_{b,t+1}}^{\infty} M_{t,t+1}\left[(1-\kappa)R_{E,t+1} - \frac{1}{Q_{D,t}}\right] dF + \mathscr{U}$$

where the first term shows the present value of marginal changes in $\overline{\eta}_{t+1}(\omega_{t+1})$ over the default region where the realization of shock is low $z_{t+1} < z_{b,t+1}$ such that banking sector's total assets fall below its debt liabilities. The regulator considers that equity income to households is zero and deposits plus interest is the only financial income households earn.

Further, over the default region, regulator evaluates changes in transfer function because bankruptcy requires the deposit insurance service to compensate depositors for any uncovered fraction of their deposit investments which is funded from regulator's resources. Once the bank defaults, its ex-post total assets falls further below its total liabilities due to bankruptcy cost that incurs in any default state which increases the amount that deposit insurance needs to pay to depositor to guarantee their investment in full.

The second term on the right-hand-side of equation (5.1) shows the present value of marginal changes due $\overline{\eta}_{t+1}(\omega_{t+1})$ over the solvency region where the households are able to receive financial income from equity and deposit investments. The transfer function remains unchanged over solvency because the bank honors its debt contracts and deposit insurance need not to intervene. The last term in equation (5.1) summarizes the direct welfare effect associated with bankruptcy cost exactly at the default threshold by comparing just-solvency against just-defaults outcome. Re-arranging equation (5.1) using the decomposition lemma discussed above gives[37],

$$0 \;=\; \underbrace{(1-\overline{\eta}_{t+1}+\kappa\overline{\eta}_{t+1})}_{\text{after-purchase investment}}\int_0^\infty M_{t,t+1}\left\{\chi.(1-\Phi(\lambda))+\Phi(\lambda)\right\}R_{p,t+1}dF$$

where the first term is less than one when purchasing bank equity incurs fee $1-\kappa$ leading to lower savings. When equity purchasing is costless $\kappa = 1$ and the first term has no interaction with $\overline{\eta}_{t+1}$. The second term on the right-hand-side shows the marginal effect of capital regulation on probability of solvency through $\Phi(\lambda)$ which increases as $\overline{\eta}_{t+1}$ increases. Let $\varpi(\chi) = \chi.(1-\Phi(\lambda))+\Phi(\lambda)$ denote the probability effect where χ shows the ex-post liquidation proceeds ($1-\chi$ is the proportional bankruptcy cost) that occurs over the default region. When $\chi = 1$ then $\varpi(\chi) = 1$ showing that probability factor $\varpi(\chi)$ is irrelevant to regulator's decision because there is no deadweight loss associated with defaults therefore the likelihood of default region $1-\Phi(\lambda)$ is immaterial to welfare. As χ decreases (proportional bankruptcy cost increases) $\varpi(\chi)$ becomes smaller showing the welfare loss in regulator's value function due to deadweight loss through probability channel. When $\chi \in (0,1)$ the regulator always is concerned with costly bankruptcies because increasing $\overline{\eta}_{t+1}$ amounts to increasing the probability of solvency that lowers its associated distortions. As $\overline{\eta}_{t+1}$ monotonically (weakly) increases $\varpi(\chi)$, the regulator recommends higher $\overline{\eta}_{t+1}$, and in an extreme case when equity purchase is costless ($\kappa = 1$), optimal capital requirement[38] is 100%. The optimal capital RW-capital requirement trades-off social costs of equity purchase fee against social benefits of less bank failure and its associated bankruptcy cost and is given by,

$$\overline{\eta}^*_{t+1} \;=\; 1+\frac{1-\omega_{t+1}}{Q_{X,t}}+\varphi_0(\mu_L,\sigma).B.\left(\varphi_1(\mu_L,\sigma)-\log\left(\frac{1-\kappa}{1-\chi}.B\right)\right)$$

where $B = \frac{Q_{D,t}\omega^{\alpha}_{t+1}}{A^{1-\alpha}}$, $\varphi_0(\mu_L,\sigma) < 0$ and $\varphi_1(\mu_L,\sigma) > \frac{1-\kappa}{1-\chi} > 0$. The solution specifies that when equity purchase fee increases (lower κ) then $\overline{\eta}^*_{t+1}$ decreases leading to lower deadweight loss. When bankruptcy cost increases (lower χ) then $\overline{\eta}^*_{t+1}$ increases to lower the probability of default where distortion lowers the welfare. When the price of deposits $Q_{D,t}$ increase $\overline{\eta}^*_{t+1}$ decreases because the bank needs to pay lower interest payments to depositors. When the balance sheet size increases the optimal capital requirement increases because of the decreasing return to scale on bank's loan section. When the price of reserves increase, the capital requirement increases because the bank is able to earn lower interest income from its reserve investment. This effect becomes smaller as

[37]See Appendix

[38]When $\overline{\eta}_{t+1} > \omega_{t+1}$ the bank is always solvent as it owns more equity than its loans therefore increasing the capital requirement beyond this limit leads to no further welfare gains as any optimal capital requirement is associate with $\Phi(\lambda) = 1$ and $\overline{\eta}^*_{t+1}$ has multiple solutions.

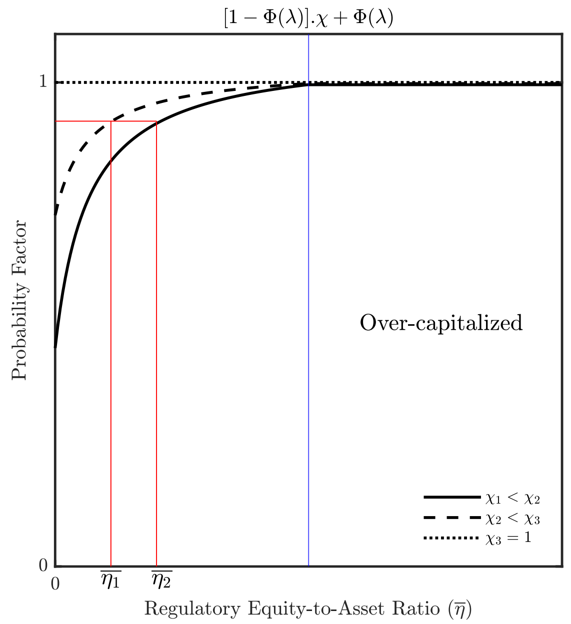


Figure 5: The probability factor $\varpi(\chi) = \chi.(1-\Phi(\lambda)) + \Phi(\lambda)$ increases when bank's capital structure includes more equity (ceteris paribus). As bankruptcy become more costly (lower $\chi 1$) then $\varpi(\chi)$ increases more sharply when capital structure includes more equity. When bankruptcy is costless ($\chi = 1$) then changes in capital structure leads to no welfare gain through probability factor $\varpi(\chi)$.

loan-to-asset ration increases which lowers bank's exposure to interest income from or expenses due to reserves.

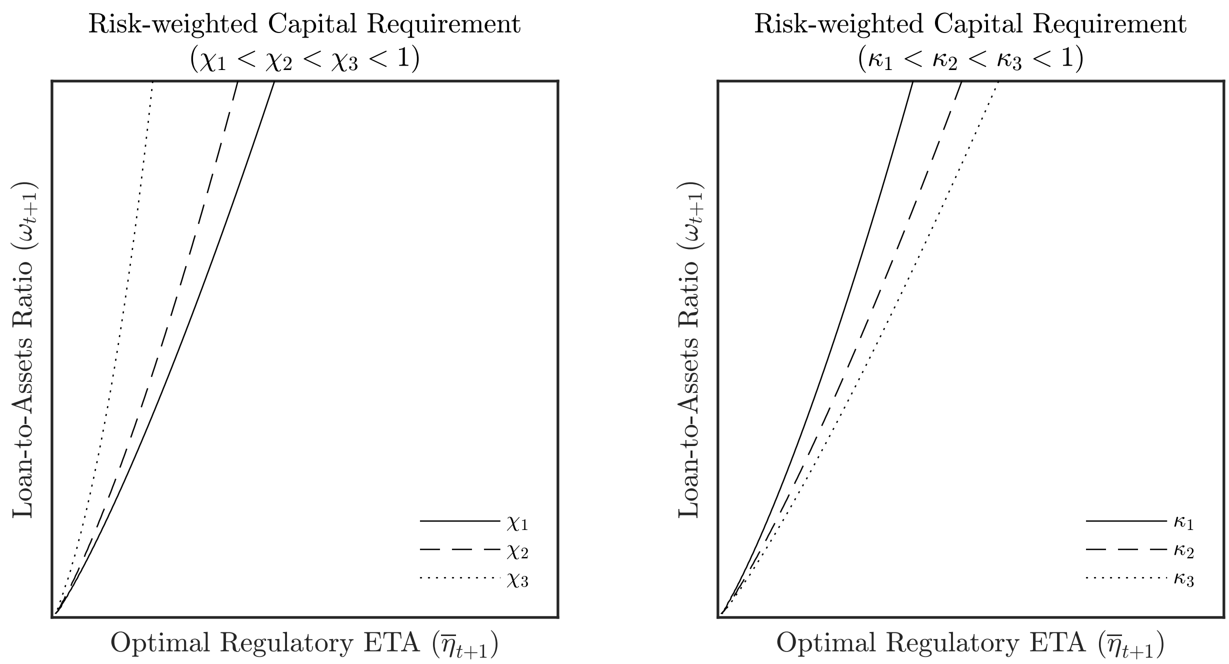
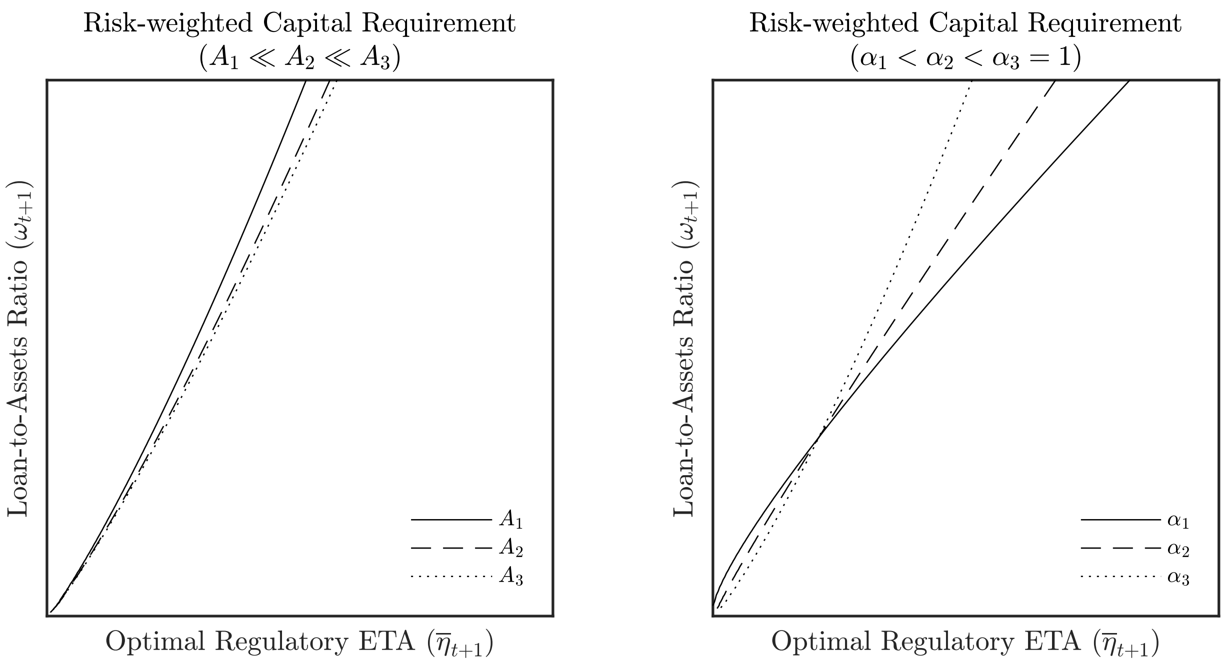


Figure 6: The slope of curves are RW-capital requirement in the space $(\overline{\eta}_{t+1}, \omega_{t+1})$. The graph illustrates changes in RW-capital requirement when bankruptcy cost parameter value changes (left) and when equity purchase fee changes (right).

Figure (6) illustrates changes in optimal capital requirement for given loan allocation by bank for three different bankruptcy cost parameter values ($\chi_1 < \chi_2 < \chi_3 < 1$) and equity purchase parameter values ($\kappa_1 < \kappa_2 < \kappa_3 < 1$). In particular, the slope of curves describe the ratio $\overline{\eta}_{t+1}/\omega_{t+1}$ which is the RW-capital requirement. As bankruptcy cost decreases, slope of curves in the left diagram become steeper which show lower lower equity requirement per unit of loan because the regulator is less concerned with costly defaults. As the fee associated with equity purchases decreases, the slopes of curves in the right diagram become flatter showing higher equity requirement per unit of loan because the regulator is less concerned with deadweight loss during equity purchases.

The price of equity is irrelevant to the optimal capital requirement because regulator's consideration is focused on distortions related to defaults that are determined by debtholder's contracts and not shareholders. The regulator is concerned with the welfare of the economy that includes both the debtholders and shareholders, however, the welfare improvement is achieved by reducing distortions so that households obtain higher consumption due to minimal deadweight losses.

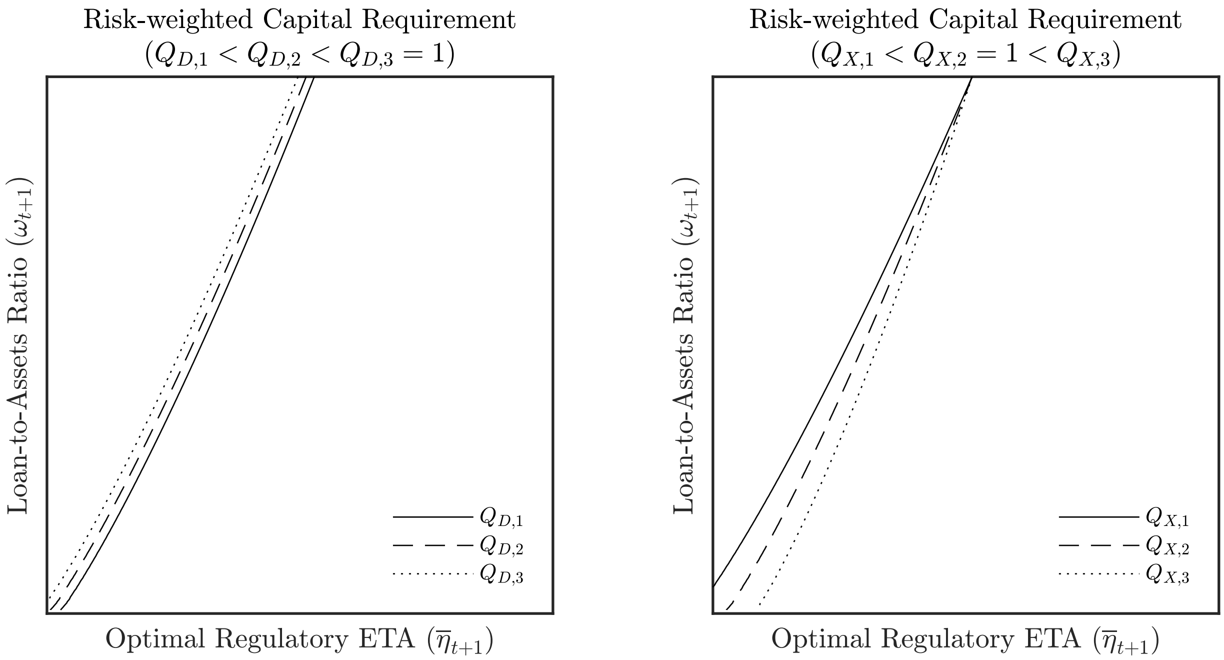


5.1 Demands for Financing under Capital Regulation

First-Order-Condition (Balance Sheet Size under Capital Regulation) Given the capital requirement, choosing the balance sheet size also determines the capital structure on funding side. Substituting $\overline{\eta}^*_{t+1}$ into the dividend function and probability of solvency gives the following first order condition:

$$\frac{d}{dA_{t+1}} \log \Phi\left(\lambda_{t+1}\right) \quad = \quad \frac{d}{dA_{t+1}} \log \mathbb{E}_t \left[M_{t,t+1} div_{t+1} \right] \tag{5.1}$$

the first order condition shows the trade offs between marginal gain in dividend against lowering probability of solvency due to lower marginal return from the loan section that is subject to



decreasing return to scale. This first order condition is the same as the case without capital regulation, however, the decision $\overline{\eta}^*_{t+1}$ is predetermined.

5.2 Equilibrium with Capital Regulation

Capital structure of the bank complies with RW-capital requirement for any balance sheet size. First, in order for the deposits and equity market to clear, the bank raises funds by choosing its balance sheet size considering the capital regulation $A^*_{t+1}(\overline{\eta}_{t+1})$ through total savings by the households S^*_{t+1}:

$$A^*_{t+1}(\overline{\eta}_{t+1}) \quad = \quad S^*_{t+1} \tag{5.2}$$

Second, in equilibrium, the portfolio choice of the households including deposits and equity must be equal to the capital structure of the bank that is predicated by RW-capital requirement,

$$\overline{\eta}_{t+1} \quad = \quad \theta^*_{t+1} \tag{5.3}$$

As a special case with logarithmic utility, the first market clearing condition simplifies to:

$$A^*_{t+1}(\overline{\eta}_{t+1}) \quad = \quad \underbrace{(1-\tau_{t+1}).(1-\theta^*_{t+1}+\kappa.\theta^*_{t+1}).(1-\beta).W_t}_{\text{supply of funds}} \tag{5.4}$$

where the first term on the right-hand-side shows the effect of equity purchase fee on lowering the total supply fund to the economy. When $\kappa = 1$ then equity purchase is costless and the supply of funds is fixed. The term $1-\tau_{t+1}$ show household's disposable income after paying proportional taxation to the regulator.

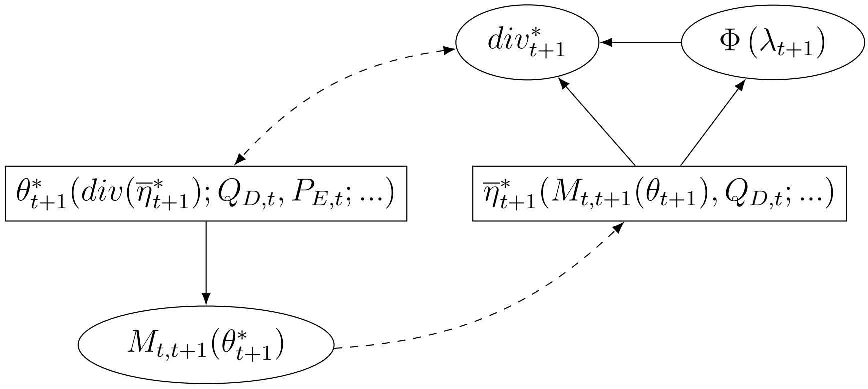


Figure 7: The diagram describes optimal schedules of the household and the bank under capital regulation where the regulator's decision to on minimum equity-to-assets ratio derives the default probability and dividend flow. Bank's decision on balance sheet size together with the regulatory ratio fully characterize bank's optimal behaviour.

A welfare analysis based on the laissez-faire allocations incorporates the optimal behaviour of counterparties under the following frictions: first, the deposit insurance guarantees bank debt, giving deposit investor the confidence that in any default state, they are able to consume out of their deposit investments. Second, the banking sector is subject to costly default. The profit-maximizing behaviour of the banking sector that fails to consider negative externalities associated with costly failure gives rise

6 Optimal Financial Regulation

The interaction between the capital constraint and IOER has important welfare implications. The policymaker considers the welfare gains, in terms of consumption units, associated with change of IOER over the default region, against gains over the solvency region. The first order condition with respect to this interest rate instrument is given by:

$$0 = \frac{\partial}{\partial r_{X,t+1}} \left\{ \int_0^{z_{b,t+1}} \underbrace{M_{t,t+1}\Big[r_{X,t+1}(1-\omega_{t+1}) - \Lambda_{t+1}\Big]}_{\substack{\text{discounted transfer value} \\ \text{in default}}} dF + \int_{z_{b,t+1}}^{\infty} \underbrace{M_{t,t+1}\Big[r_{X,t+1}(1-\omega_{t+1})\Big]}_{\substack{\text{discounted transfer value} \\ \text{in Solvency}}} dF \right\} \tag{6.1}$$

where the first term on the right-hand-side shows the (marginal) social value of a unit of transfer given changes in IOER in default. More precisely, the regulator considers the following trade off: in any default state, higher IOER increases ex-post liquidation proceeds within the banking sector which implies a lower deadweight loss in that state. However, IOER is financed from taxation indicating that transfer to households falls as IOER rate paid on excess reserves increases. The regulator considers the aforementioned opposable effects determine trade-offs over the default region. In solvency, the regulator is only concerned with lowering interest expenses associated with excess reserves because the banking sector is able to meet its deposit liabilities and losses are equal to zero. Re-writing the condition given in (6.1) using lemma (x) yields the following result:

$$0 = \frac{\partial}{\partial r_{X,t+1}}\left\{\mathbb{E}_t M_{t,t+1}\left[r_{X,t+1}(1-\omega_{t+1}) - \underbrace{(1-\Phi(z_{b,t+1}))}_{\substack{\text{endogenous}\\ \text{default probability}}} \Lambda_{t+1}\right]\right\} \tag{6.2}$$

where an explicit default probability term $1 - \Phi(z_{b,t+1})$ shows the impact of IOER decision on likelihood of default[39]. More precisely, this term captures a non-symmetric role of loss term Λ_{t+1} which arises only in default. As the regulator lowers IOER, defaults become more likely because equilibrium deposit rate decreases in IOER but at a diminishing rate leading to a growing net interest expenses in the banking sector.

6.1 Equilibrium Analysis

The optimal risk-weighted capital requirement determines the share of equity in banks capital structure which together with household's portfolio decision on risky asset pin down the following first equilibrium condition:

$$\overline{\eta}_{t+1} = \theta^*_{t+1} \tag{6.3}$$

Household's decision on aggregate saving together with bank's optimal decision on total balance sheet size, given the prie of equity and deposit rate, determine the second equilibrium condition given by:

$$A^*_{t+1}(\overline{\eta}_{t+1}) = S^*_{t+1} \tag{6.4}$$

In equilibrium, regulator's decision on optimal IOER considers the following channels: first, an optimal IOER trades off welfare gains of lower deadweight losses associated with costly bank failure, because in any default state, bank's higher revenues due to IOER increases ex-post liquidation proceeds. Second, regulators decision on optimal IOER equates marginal benefits of lower costly defaults against marginal benefits of higher transfers to households. Thirds, IOER interacts with banks asset allocation decision through its impact on solvency channel that is priced in bank's net worth. Specifically, an optimal IOER maximizes welfare gains associated with credit flow to the real economy against marginal cost of heightened default risk due to extended lending. Decision to lower IOER when the rate is above zero bound is negatively related to optimal capital regulation because lower net interest incomes increases bank's ability to meet debt liabilities and therefore increases probabilistic cost of default. Regulator's decision on optimal IOER incentivises banking sector to extend lending with an expansionary impact while tighter capital requirement

[39] Appendix D.

provides welfare gains by reducing (expected) bank failure cost.

7 Calibration

In the previous section, results relied on the assumption that investors have a unit coefficient of relative risk aversion and elasticity of intertemporal substitution (EIS). This section extends the implications of the model to more general cases when households are only assumed to have an early resolution of uncertainty with $\gamma > 1$ and $\gamma\psi > 1$.

As households become more risk-averse, their preference to hold a larger fraction of their wealth in deposits grows. Under equilibrium with binding capital regulation, the equity-to-asset ratio of the banking sector is equal to the household's portfolio share in risky asset which remains intact as households become more risk-averse leading to the following two effects. First, the equilibrium mechanism indicates in order to clear the markets deposit rate must fall leading to greater equity premium as a result of more risk-averse investors. Second, lower deposit rate is associated with lower interest expenses which incentivizes the bank to extend lending until the marginal reduction in its net worth due to added risk to its asset side wears off increased gain in its net worth due to enhanced solvency. However, higher lending requires the bank to support its riskier portfolio with additional equity by raising further capital from the equity market leading to equity prices to fall, further expanding the equity premium. This effect is partially dampened because as the bank becomes more capitalized, its exposure to default falls leading to lower compensation to its investors due to lower default risk.

This result describes that changes in household's risk-aversion has important implications for equilibrium prices, however, equilibrium allocations remain less affected due to frictions of capital constraints. Extended lending to the real sector is an expansionary effect, only when IOER remains above zero bound, which increases the total expected income to households. This wealth effect lowers asset prices because the stochastic discount factor of the households is negatively correlated with the aggregate wealth. Expectations of higher incomes (through their equity investment) lower the marginal utility of each unit of consumption at future dates and leads to lower valuations of bank net worth. The effect on bank asset prices reverses when IOER is below zero bound because the equilibrium deposit rate is very close to zero and any further increase in risk-aversion only leads to marginal fall in deposit rate. As a result, the bank's solvency due to higher next interest expenses is followed by lower credit flow to the real sector in order for the bank to maintain its net worth valuation. This contractionary effect amounts to lower expected wealth which indicates that the marginal utility of consumption at future dates increases leading to higher bank equity price today. This mechanism provides accounts to explain equity premium that is more consistent with empirical observations despite low degrees of risk aversion.

The framework in Section (2) shows the aggregate saving is driven by preferences towards substitution of consumption over time. More precisely, as the EIS approaches one, households become infinitely indifferent to transfer consumption across time and hence they consume a fixed fraction of their wealth equal to $1 - \beta$. When the policymaker lower IOER, the banking sector initially extends lending which leads to expansions of the real sector. Although the equilibrium deposit rate falls as IOER decreases, expansion in the real economy indicates that the expected wealth of the households grows because their financial income from investing in bank net worth grows. This mechanism increases return on wealth, however, overall savings by the households with unit EIS remain unchanged. This arises as a special case result because of the household's infinite reluctance to substitute intertemporally which leads them to consume the annuity of value of their wealth each period[40].

Conversely, when the household's preference to substitute consumption over time is characterized by an EIS other than unit, the total supply of saving in financial assets varies with return on wealth. When EIS is lower than the unit, households prefer to increase their consumption-wealth ratio because any additional increase in return on wealth leads to income effect to dominate the substitution effect. Subsequently, households increase their consumption today and save less which leads to the equilibrium size of the financial sector to shrink. In this context, the bank's balance sheet size is negatively affected because the overall funding through deposit and equity investments by their investors is reduced. Section (4.2) shows that lower balance sheet size is associated with a higher marginal return on lending to the real sector. Specifically, the decreasing return to scale assumption implies that the banking sector is able to generate a higher return on each unit of lending when the economy scales down.

Lowering IOER when supply of investment is driven by households who are reluctant to substitute consumption over time has the following implications. First, the equilibrium excess reserves unambiguously falls because the spread between IOER and the expected lending rate expands specifically due to the decreasing return to scale effect. This mechanism leads the banking sector to lower the share of its assets in excess reserves. On the aggregate level, the relative size of excess reserves is further reduced because of the overall lower savings in the financial sector. Second, the implications to the real sector is characterized by an expansion of extensive margin against shrinkage of the size of the financial sector. Bank's decision to increase lending trades off the loss of net worth valuation due to higher default risk against gain in valuation due to higher cashflow. However, on the margin the lending rate higher when the economy is scaled down, the default risk channel is dampened by the bank's ability to meet its debt liabilities as a result of a higher lending rate. The optimal capital requirement factors higher marginal productivity, associated with a lower size of the real sector, into account and prescribes a looser minimum equity-to-assets ratio. In equilibrium, this leads to a higher equilibrium deposit rate and lower risky asset price because bank's looser capital constraint drives the demand for debt financing upwards until the marginal gain from raising funds from deposits equates marginal loss of net worth valuation due to heightened default risk.

[40](needs citations from ICAPM-EZW literature e.g. Restoy, Merton, Campbell Viciera, 1999, 2002).

As households become more risk-averse, when their EIS is less than unit, their preference to hold a larger share of their financial investment in deposits grows. However, capital requirement constraint indicates that increased aversion towards risk leads to a lower equilibrium deposit rate. Higher coefficient of risk aversion, keeping EIS below one, implies that bank's cost of debt falls and lending grows because the bank is able to afford further risk on its asset side. This result contrasts the finding of theoretical models based on partial equilibrium. More precisely, in a partial equilibrium model, higher risk aversion leads to lowera return on wealth because the household's portfolio includes a larger share of risk-free asset. However, in general equilibrium, higher risk-averse investors accept a lower equilibrium deposit rate which together with capital constraints, lower the cost of debt for the bank and lead to higher return on wealth as a result of extended lending to the real sector. This indicates that although consumption-wealth ratio increases in return on wealth, increasing the attitude towards risk is associated with higher return on wealth and subsequently, aggregate saving falls when EIS is lower than unity. Before

Structural Parameterization		
Description	Notation	Value
Household Subjective Discount Factor	β	0.99
Household Coefficient of Relative Risk-aversion	γ	1.00
Household Elasticity of Intertemporal Substitution	ψ	1.00
Bankruptcy Cost Parameter (proportional cost: $1-\chi$)	χ	70.00%
Intermediation Cost Parameter (proportional cost: $1-\kappa$)	κ	98.50%
Lending Decreasing Return to Scale	α	0.95
Aggregate Shock (Lending) Mean Parameter	μ_L	0.085
Aggregate Shock (Lending) S.D. Parameter	σ_L	11.75%
Aggregate Shock (Lending) Expectation	$e^{\mu_L+\frac{1}{2}\sigma_L^2}$	0.0963
Aggregate Shock (Lending) Variance	$e^{2\mu_L+\sigma_L^2}(e^{\sigma_L^2}-1)$	0.017

Table 3: Calibration Parameterization

proceeding to the numerical illustration, it is worth mentioning that when EIS is above one, the aggregate saving is driven by the substitution effect that exceeds the income effect. Particularly, in this case, higher return on wealth is followed by higher saving which expands the size of the financial sector. This result indicates that when households are willing to substitute consumption over time, higher return on wealth increases the marginal utility of consumption today as consumption becomes more expensive relative to future dates. Subsequently, aggregate saving increases and in equilibrium, bank's balance sheet expands leading to the following two implications: first, the extensive margin on excess reserves grows because the marginal loan rate falls when the financial sector expands. This result leads to extenuating implications for over-reliance on excess reserves. Alternatively, the decreasing return to scale implies that the bank is concerned with its solvency channel because, on the margin, it is less able to meet its liabilities at the end of the period and rebalances its portfolio away from lending to the real sector. Second, the extended size of the financial sector prompts the regulator to tighten the capital regulation leading to a lower equilibrium deposit rate and lower risky asset price. The social welfare func-

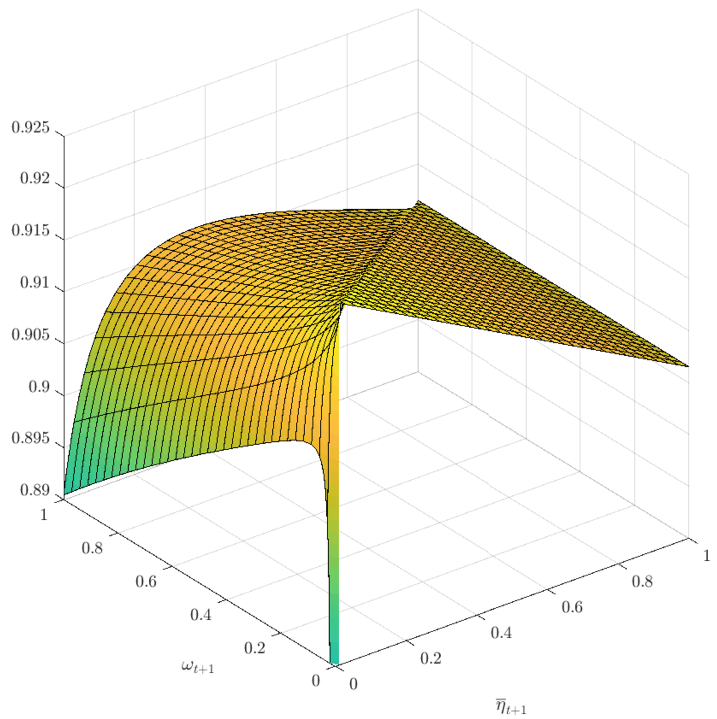


Figure 8: The surface illustrates the social welfare value over capital regulation ($\overline{\eta}_{t+1}$) and asset allocation (ω_{t+1}) space. A kind along the diagonal is generated by the solvency condition at which the bank's net worth remains at zero regardless of severity of a default. The surface is linear in capital regulation decision and asset allocation when $\overline{\eta}_{t+1} \geq \omega_{t+1}$ because when bank's exposure to risk is fully coverable by its equity then higher capital structure provides no further welfare gain and the variations in welfare is driven by equity intermediation cost.

tion is increasing in capital regulation decision ($\overline{\eta}_{t+1}$) when the marginal social gains in higher bank capitalization exceeds marginal costs of equity intermediation. Particularly, the proportional cost associated with raising capital through equity market due to costly intermediation increases in size when the regulator sets a higher capital constraint. Given each choice of asset allocation by the bank ω_{t+1}, regulator's optimal capital regulation maximizes the social welfare $\overline{\eta}^*_{t+1}(\omega_{t+1})$. Figure (8) illustrate the social welfare function with the following parameterization [41], $\{\beta, \gamma, \psi, \kappa, \chi, \alpha, \mu_L, \sigma_L\} = \{0.99, 1, 1, 0.70, 0.985, 0.95, 0.085, 0.1175\}$. The social welfare surface exhibits a linear characterization over ($\overline{\eta}_{t+1}, \omega_{t+1}$) when $\overline{\eta}_{t+1} \geq \omega_{t+1}$ because the banking sector is able to cover any adverse negative outcome to its borrowers and remain solvent as it is overcapitalized. As a result, the regulator's ability to requirement higher equity-to-assets ratio on the liabilities of the banking sector is inconsequential to welfare as it provides no further gain. Any higher capital requirement constraint, however, incurs equity intermediation cost which leads to a proportional cost that lower social welfare along $\overline{\eta}_{t+1}$ for any given asset allocation decision. The

[41] Parameters refer to, subjective discount factor, coefficient of relative risk aversion, elasticity of intertemporal substitution, after-purchase equity intermediation (cost: $1-\kappa$), ex-post liquidation proceeds (bankruptcy cost: $1-\chi$), and the degree of decreasing return to scale, respectively. The last two parameters μ_l and σ_L described the log-normal distribution of the loan sector, with expected mean and variance equal to $e^{\mu_L + \frac{1}{2}\sigma_L^2}$ and $e^{2\mu_L + \sigma_L^2} \times (e^{\sigma_L^2} - 1)$, respectively.

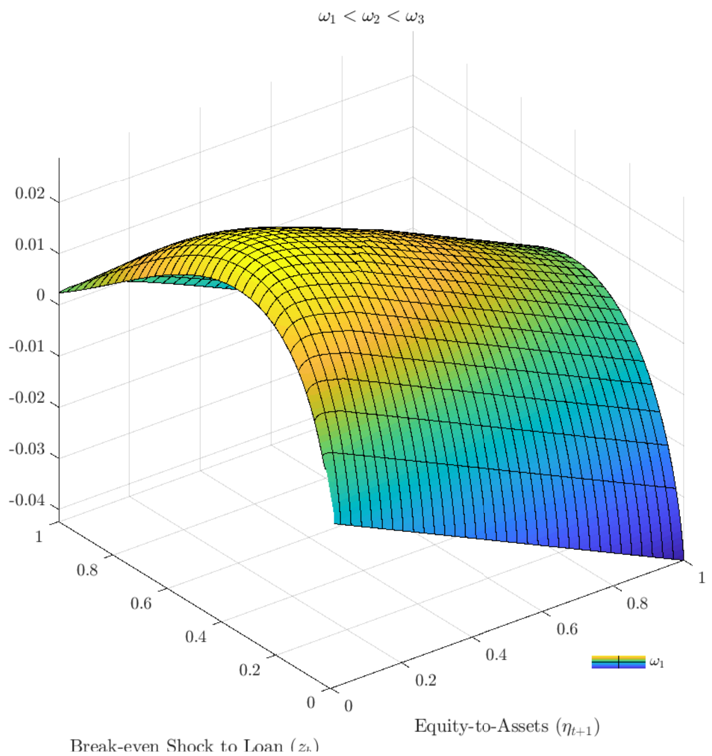


Figure 9: The surface shows bank net worth valuation over ($\eta_{t+1}\omega_{t+1}$) space. Over the capital structure choice, the bank faces trade-off between cost of equity against gains in valuation due to more capitalization. Over the portfolio choice dimension, the bank faces trade-offs between higher return from lending against exposure to higher risk which negatively affects its net worth by its risk-averse shareholders.

risk-neutral bank maximized the present value of expected future cashflow by financing its operations through deposits and equity. Bank's decision on raising funding considers the implications of capital structure on its net worth valuation by its risk-averse investors who simultaneously considers cash flow and solvency. Because equity contributes to reduce bank default risk and enhance its valuation, the objective function of the bank over capital structure exhibits a concave characteristic. Specifically, the trade-off between the cost of equity against gains in valuation comprises two opposing considerations that the bank balances in order to determine its optimal capital structure. The present value problem of the bank also considers the benefits of investing a higher share of funds in loans. However, because the stochastic discount factor is negatively correlated with the variance of bank portfolio, overinvestment in loan leads to lower bank valuations through the shareholder's valuation that arises endogenously. As a result, bank decision on optimal portfolio considers the trade-offs between higher lending return against volatility of asset side that is ultimately characterized by a concave value function over portfolio choice decision. The optimal risk-weighted capital regulation evaluates social costs associated with bank failure which are not internalized by the bank. This schedule serves as a constraint that conditions the bank's lending to its capital structure.

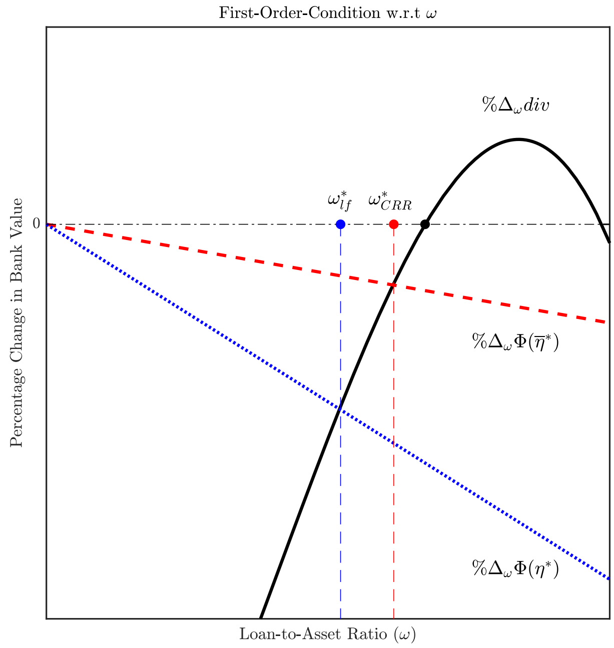


Figure 10: The figure illustrates bank's ability to extend loans when capital regulation requires the bank to hold additional equity per unit of loan. The solid line shows percentage change in bank's value function given a unit change in allocation to loan, the dotted line shows percentage change in bank's solvency when its portfolio holding of loan increases, and dashed line shows percentage change in solvency when bank complies with capital regulation.

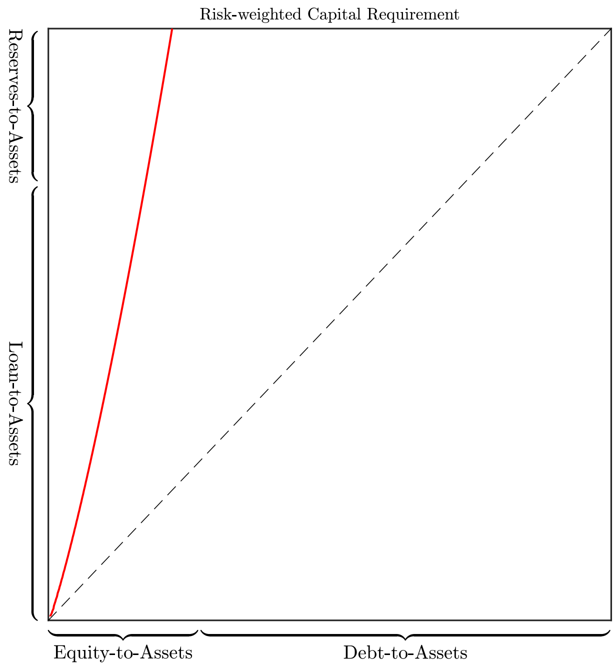


Figure 11: The figure illustrate equilibrium deposit rate in response to given interest-on-reserves rate. Variations within higher interest-on-reserves rate is associated with changes in equilibrium deposit rate in the same direction and comparable magnitude, however, as interest-on-reserves fall, equilibrium deposit rate becomes less responsive to changes in interest-on-reserves and remains strictly positive.

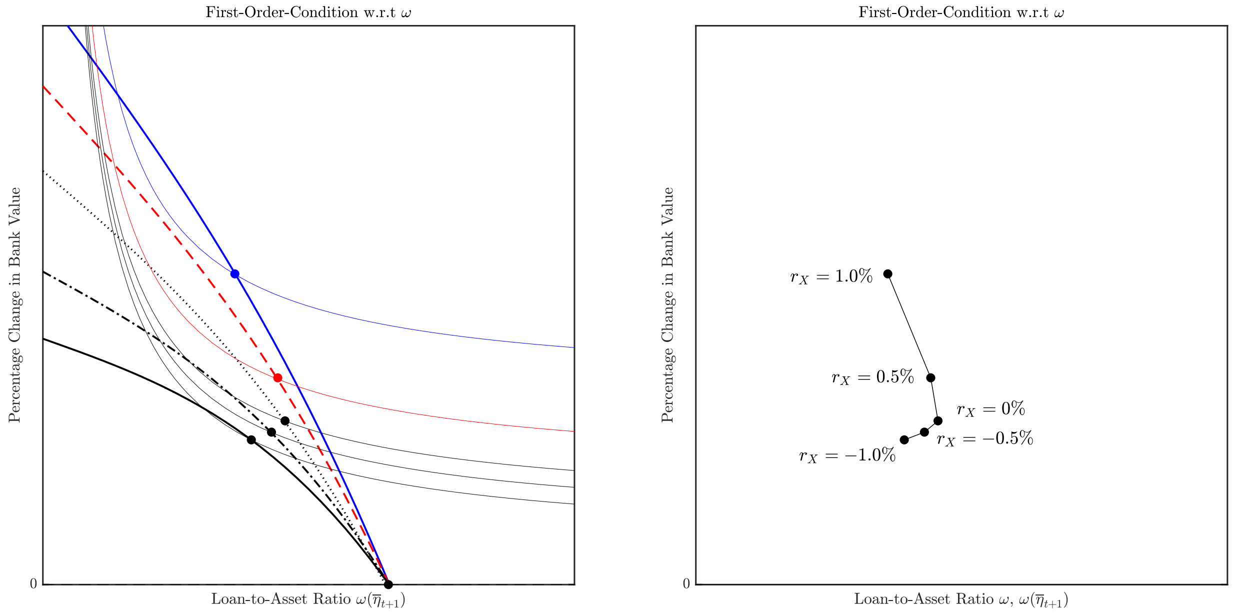


Figure 12: Optimal asset allocation under capital requirement

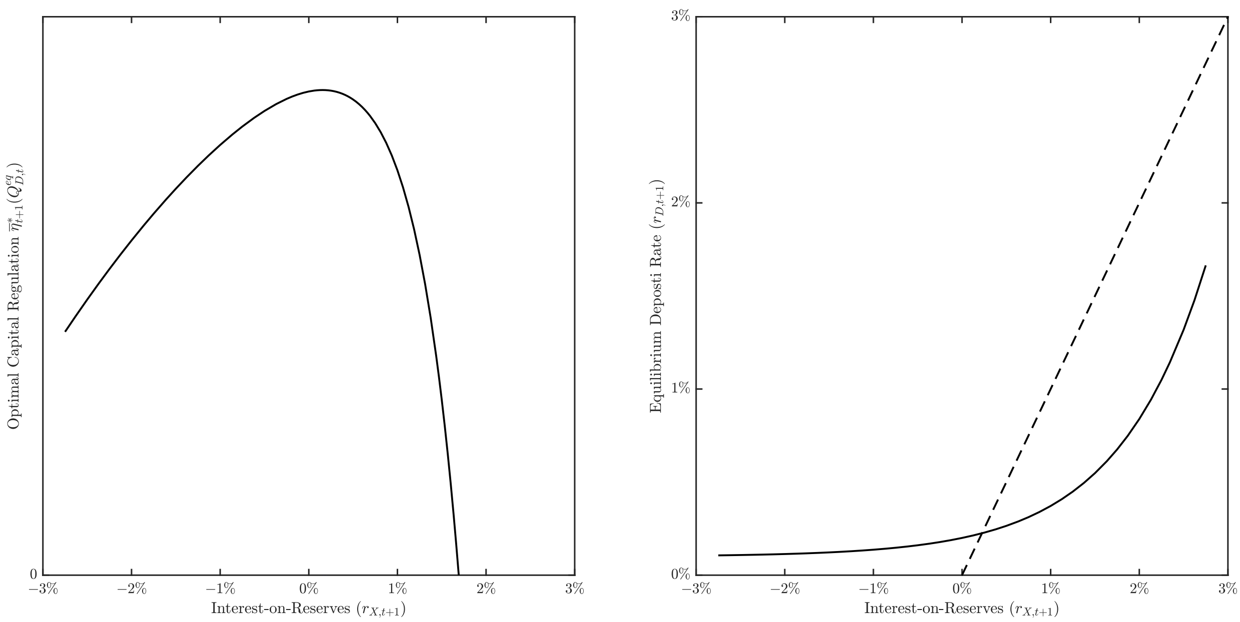


Figure 13: The figure illustrates that for a given interest-on-reserves rate, optimal capital regulation falls when bank interest expenses fall faster than the reduction in interest incomes from reserves. Conversely, the relationship between optimal capital regulation and interest-on-reserves reverses when bank's default risk increases as a results of loss of interest income from reserves and nonresponsive changes in deposit rate. The figure illustrates bank's ability to extend loans when capital regulation requires the bank to hold additional equity per unit of loan. The solid line shows percentage change in bank's value function given a unit change in allocation to loan, the dotted line shows percentage change in bank's solvency when its portfolio holding of loan increases, and dashed line shows percentage change in solvency when bank complies with capital regulation.

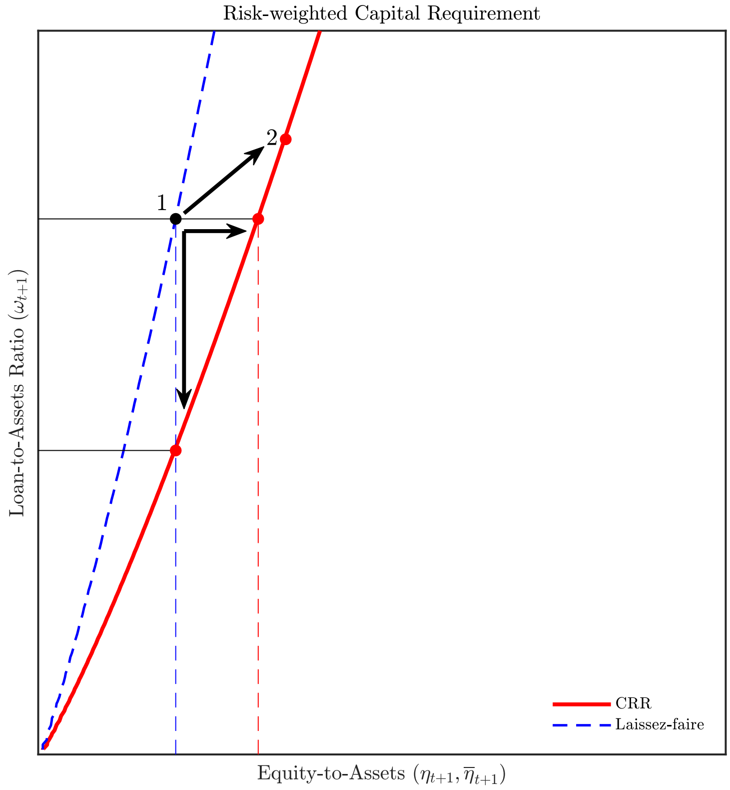


Figure 14: The figure illustrates bank's portfolio rebalancing when RW-capital regulation requires the bank to hold higher equity per loans. The solid dashed line described bank's laissez-faire loan-to-equity schedule and the solid line describes regulated loan-to-assets schedule which is always toward the outer right side of unregulated schedule.

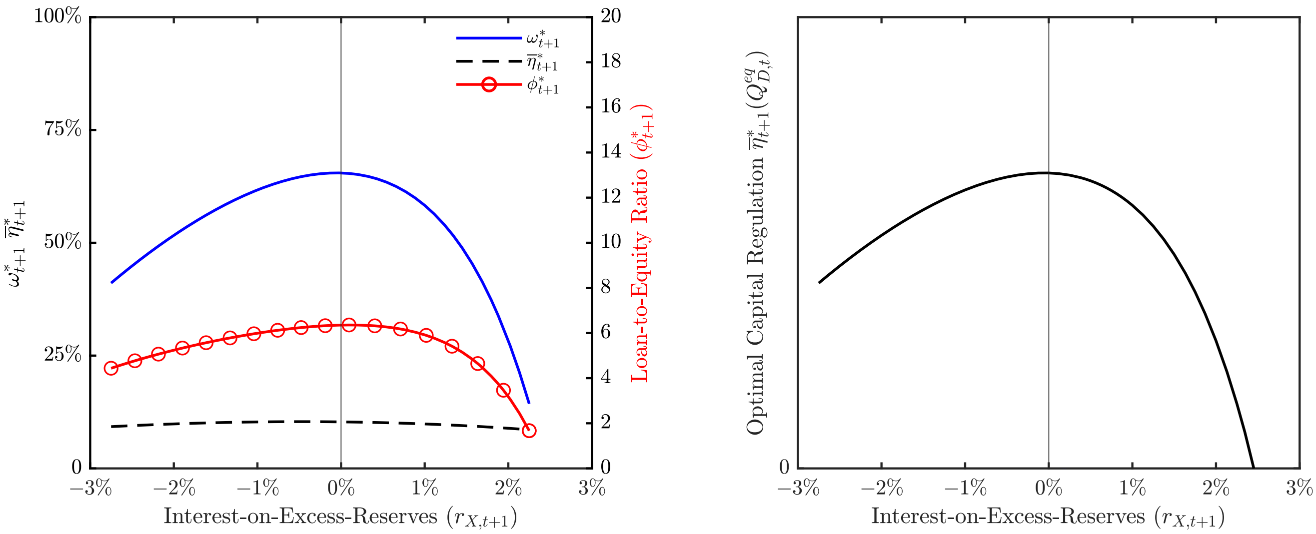


Figure 15: The figure illustrates bank's portfolio rebalancing when RW-capital regulation requires the bank to hold higher equity per loans. The solid dashed line described bank's laissez-faire loan-to-equity schedule and the solid line describes regulated loan-to-assets schedule which is always toward the outer right side of unregulated schedule.

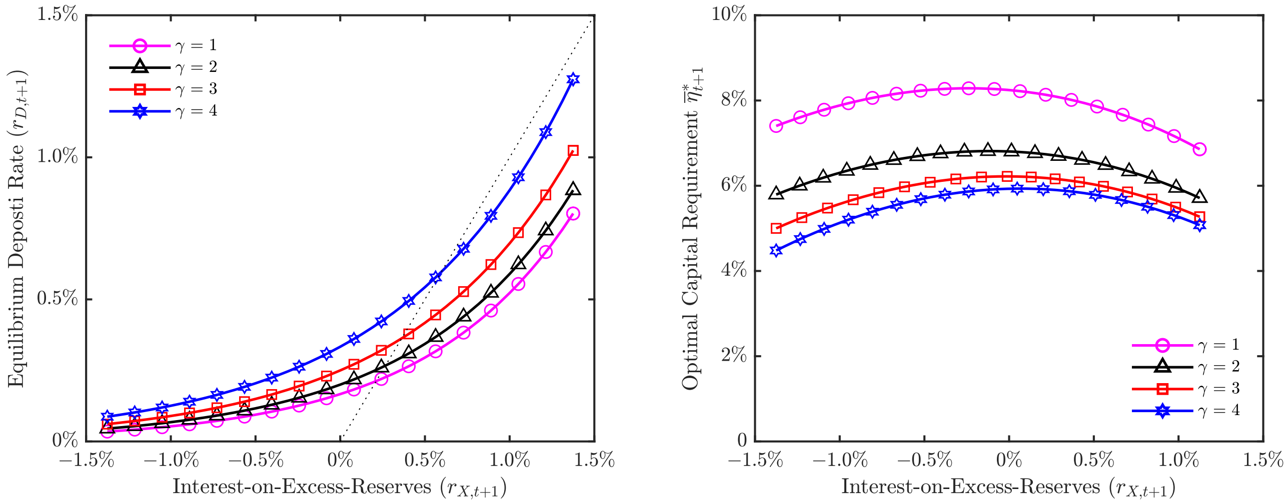


Figure 16: The figure on the left depicts equilibrium deposit rate variations given exogenous changes in IOER. When household's risk-aversion increases, for any given value of IOER, equilibrium deposit rate falls particularly when IOER is above the zero bound. The figure on the right shows optimal capital regulation in response to equilibrium deposit rate.

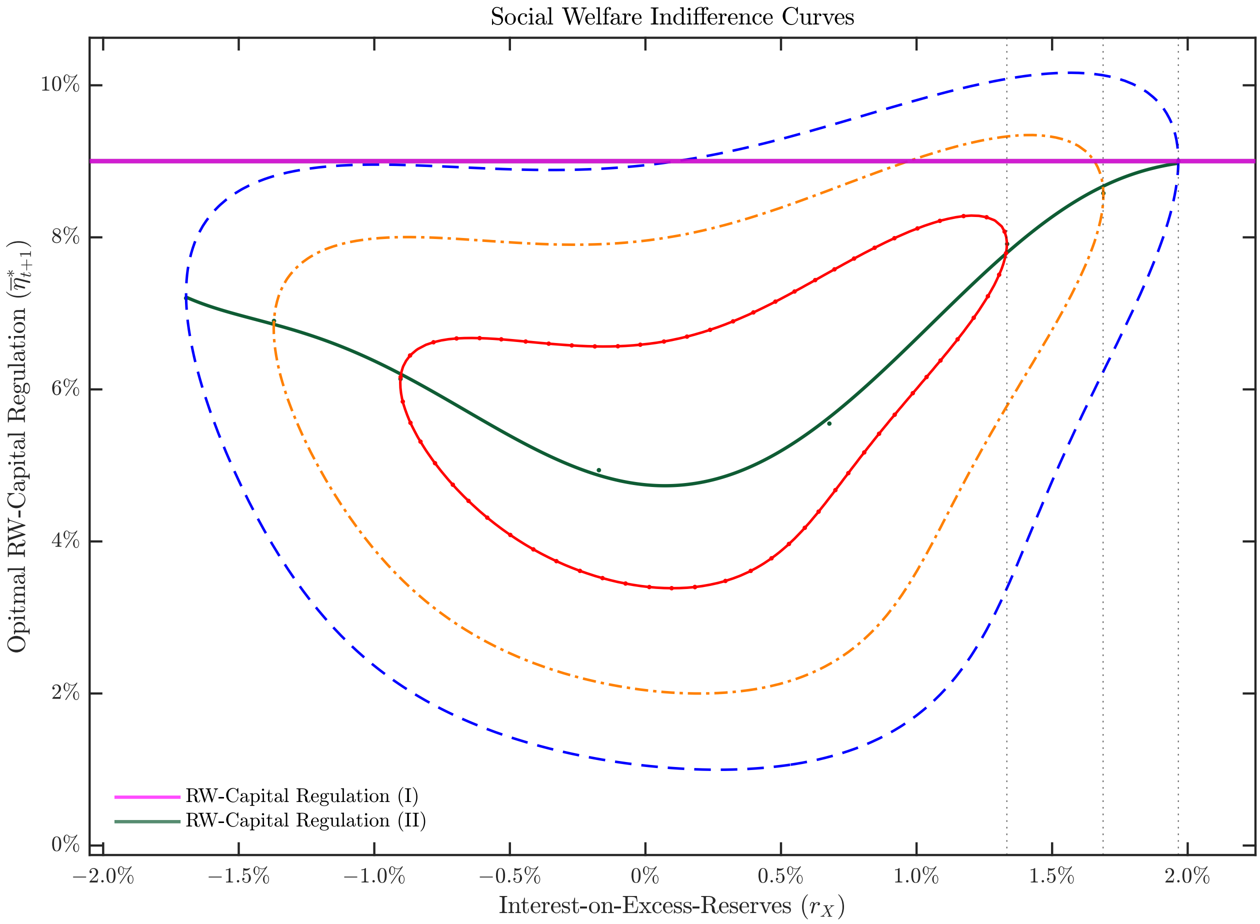


Figure 17: The figure illustrates the social welfare function level curves. The social welfare increases towards the inner contour curves depicted by dashed (blue), dashed-dotted (orange) and solid (red) contours. The horizontal solid line describes the RW-capital regulation (I) that is decided in isolation of interest rate policy which is always associated with a lower welfare, relative to RW-capital regulation (II). Regulatory schedule (II) considers the welfare implications of lower IOER and is less strict than (I) and is able to achieve higher welfare relative to (I).

Optimal Risk-weighted Capital Requirement (% of total assets)

Panel A: Low Loss Given Default ($1-\chi = 10\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.32	2.13	1.95	1.76	1.57	1.39	1.20	1.01	1.19	1.37	1.57
25%	4.64	4.26	3.89	3.52	3.14	2.77	2.40	2.02	2.38	2.74	3.14
50%	6.96	6.40	5.84	5.28	4.72	4.16	3.60	3.04	3.57	4.11	4.72
75%	9.27	8.53	7.78	7.03	6.29	5.54	4.79	4.05	4.76	5.47	6.29
90%	11.59	10.66	9.73	8.79	7.86	6.93	5.99	5.06	5.95	6.84	7.86
100%	13.91	12.79	11.67	10.55	9.43	8.31	7.19	6.07	7.14	8.21	9.43

Panel A: Low Loss Given Default ($1-\chi = 20\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.51	2.33	2.15	1.97	1.79	1.61	1.44	1.26	1.46	1.65	1.83
25%	5.01	4.65	4.30	3.94	3.58	3.23	2.87	2.51	2.93	3.30	3.66
50%	7.52	6.98	6.45	5.91	5.38	4.84	4.31	3.77	4.39	4.95	5.49
75%	10.02	9.31	8.59	7.88	7.17	6.45	5.74	5.03	5.85	6.59	7.31
90%	12.53	11.63	10.74	9.85	8.96	8.07	7.18	6.28	7.32	8.24	9.14
100%	15.03	13.96	12.89	11.82	10.75	9.68	8.61	7.54	8.78	9.89	10.97

Panel A: Low Loss Given Default ($1-\chi = 30\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.80	2.61	2.43	2.24	2.06	1.87	1.69	1.51	1.69	1.88	2.07
25%	5.59	5.22	4.85	4.48	4.11	3.74	3.37	3.01	3.39	3.76	4.14
50%	8.39	7.83	7.28	6.72	6.17	5.61	5.06	4.52	5.08	5.65	6.21
75%	11.18	10.44	9.70	8.96	8.22	7.48	6.74	6.02	6.77	7.53	8.28
90%	13.98	13.05	12.13	11.20	10.28	9.35	8.43	7.53	8.47	9.41	10.35
100%	16.77	15.66	14.55	13.44	12.33	11.22	10.11	9.03	10.16	11.29	12.42

Table 4: The table illustrates the optimal risk-weighted capital regulation set by the policymaker on the banking sector to condition its asset allocation to its capital structure. Panel (A) shows the required capital as a percentage of total assets and various IOER where the required capital ubiquitously increases when share of total asset invested in lending (ω_{t+1}) increases. As IOER is lowered, the corresponding required capital decreases for any given level of asset allocation when IOER is above zero. As IOER reaches zero and marginally negative, the policymaker requires the liabilities to includes lower capital per unit of loan. Panels (B) and (C) replicate the same quantities when the bankruptcy cost and its associated deadweight losses increases leading to higher minimum capital requirement given IOER and share of funds invested in risky asset.

8 Discussion

The 2007-2008 financial crisis and its aftermath prompted policymakers to re-evaluate regulatory instruments that were intended to address banking system's negative externalities to society. The model in this paper considered a financial regulatory policy together with a monetary policy tool that are available to policymaker to address distortions in banking system generated by costly bankruptcies and overreliance on interest-bearing reserves as safe assets that strain credit flow to the real economy.

Section (x) shows that when interest-on-reserves is taken as given, capital regulation is able to lower the likelihood of bank failure by requiring the bank to maintain a higher equity per loan ratio. From bank's perspective, this implies that in order to comply with the regulation, further capital per unit of loan must be raised through the equity market which is more expensive, in terms of price per each unit of fund, relative to debt. The general equilibrium implication of section (x) indicates that as the bank seeks to raise financing from the equity market, the price of equity falls which further increases the cost of meeting the capital regulation. The model in section (x) sheds light on three channels that entail important implications when considering costly equity financing.

First, raising funds through the equity market comes at a more expensive price at purchase which ultimately narrows cashflow generated by the difference between bank's revenues less its costs, but on the margin, each additional unit of equity also increases the likelihood of bank solvency which is priced by bank investors. The decomposition in section (x) shows bank's expected profit is determined by the product of cashflow component and solvency component indicating that although bank's equity return falls due to higher cost of funding, the fall is partly offset by marginal contribution of each additional unit of equity to solvency and therefore bank value. Results in solution methodology show that the contribution of the solvency component to increase expected profit is substantial when equity is scarce and fades as bank's equity-to- assets increases because it becomes less likely for the bank to declare bankruptcy due to delinquencies among borrower. Although the bank is risk-neutral, it is still concerned about pecuniary implications of holding equity for (expected) profitability and therefore never chooses to finance all of its funds from debt. This is because marginal contribution of equity to expected profit is higher than that of the cashflow when bank's capital structure includes limited equity. In laissez-faire equilibrium, marginal contribution of equity to solvency and cashflow are equal, but in equilibrium with capital regulation, bank equity has a lower marginal contribution to solvency channel than it has to cashflow channel which indicates capital regulation is always binding.

The third channel furthers this equilibrium analysis and shows that higher bank capital leads to lower riskiness of bank equity and lowers the risk compensation that bank has to pay to raise funds from risk-averse households. When capital regulation is levied, the bank considers that its market share price is bound to fall because of increased demand for capital but as each equity unit is added to its capital structure, lower risk compensation bids up the share price which dampens the increasing cost of capital as further equity is raised to comply with capital regulation[42].

Household's are internalize higher non-financial income through the transfers that they receive from the regulator when defaults are less likely. However, the household's financial income comprises the present value of deposit income in default and the present value of excess return in solvency which increases when solvency becomes more likely. This effect lowers the stochastic discount factor which has two effects. First, this implies that the deposit rate increases because the household marginal utility of consumption becomes flatter with added income and requires higher risk-free[43] compensation to invest in the deposits, and second, higher stochastic discount factor is associated with lower bank valuation which subsequently lower's households demand for bank equity. As a result, the equity premium narrows under equilibrium with capital regulation. However, this effect is dampened because, on the margin, the bank holds more debt which bids down its share price due to higher required compensation for additional default risk.

When the regulator exogenously lowers interest-on-reserves, the equilibrium deposit rate falls. First, lower interest-on-reserves implies that, because the spread between the expected loan and reserves widens, the bank substitutes reserves with loans on its asset side. This re-allocation must be accompanied by higher equity on the liabilities side to satisfy regulator's risk-weighted capital requirement which is ensued by a lower equity price, and accordingly, a lower deposit rate because the bank demand for debt financing is reduced. This transmission mechanism across bank assets-liabilities implies that exogenous changes in interest-on-reserves moves the equilibrium deposit rate in the same direction, however, as falling interest-on-reserves nears zero, or possibly below zero, the equilibrium deposit rate become less responsive. This is because households are endogenously forming their valuations about investments and as long as they require a minimal compensation for time preference, they always require a strictly positive deposit rate and subsequently, falling interest-on-reserves is associated with an increasingly flatter response by equilibrium deposit rate particularly when interest-on-reserves is very low or negative.

When considering extensive margins, the bank's funding from deposits is always larger than bank's investment in reserves. As equilibrium deposit rate falls, bank's interest expenses on deposits fall faster than reduced interest incomes from reserves due to higher relative extensive margins in deposits than reserves. This mechanism indicates that bank's default risk falls thereby, first extending its ability to meet debt liabilities at the end of the period and, second, the bank is able to increase lending to its borrowers until the marginal gain from loan revenues become equal

[42] Transitioning from laissez-faire to equilibrium with capital regulation.

[43] Although section (x) takes the choice of taxation as given, the level of taxation is still an important decision for the equilibrium asset prices. First, it is important for the regulator to raise an adequate level of taxation to be able to provide guarantees on deposits so that deposit insurance eliminates the possibility of bank runs. Any value of taxation higher than the difference between outstanding loans plus interest less the reserves plus interest is irrelevant to bank runs specifically because deposits are always guaranteed in real terms. However, as taxation falls below this certain limit, there exists some states of the world in which extremely adverse negative shock to bank borrowers can bankrupt the bank such that the deposit insurance fund becomes unable to cover the depositors in full. This study does not examine the welfare implications of taxation and assumes that the deposit insurance is provided in real terms by taxing the economy in anticipation of worst-case scenario shock outcome.

to increased default risk due to increased loans.

However, flattening response of deposit rate to falling interest-on-reserves narrows the difference between interest expenses and interest incomes that allows the bank to extend its lending. When interest-on-excess-reserves is close to zero, falling deposit rate offers limited reduction in bank interest expenses which together with sharper drop in interest income from reserves, amounts to a net decrease in interest incomes that leads to higher bank default risk. The bank optimally reacts to added default risk by lowering its lending which then lowers the real output. The underlying hump-shaped relationship between interest-on-reserves specifies that RW-capital regulation needs to tighten as interest-on-reserves falls from a positive level to close to zero and the needs to loosen if interest-on-reserves falls further to zero or below zero. Optimal capital regulation in response to any interest-on-reserves value considers welfare benefits of higher equity per loan, relative to laissez-faire allocation.

Section (y) shows capital regulation addresses distortions associated with costly bankruptcy at the expense of strains on credit flow to the real sector when interest-on-reserves is very low. The regulator considers the non-monotonic interaction between two policies to choose an optimal interest-on-reserves rate that provides social value by expanding credit while capital regulation is at its optimum. First, high interest-on-reserves, given an optimal capital regulation, is associated with high remuneration of reserves that has to be paid from regulator's resources to the banking sector. Regulator's resources are financed from taxation of the economy to cover interest expenses but also are intended to compensate depositors in any default state as a part of government guarantee provided by the deposit insurance service. The equilibrium analysis in this section shows that overreliance on excess reserves together with high interest burdens the regulator's resources and therefore taxes must increase to maintain guarantees in real term, otherwise, depositors' loss of confidence in given guarantees, even if not originally justified by fundamentals, will tend to be self-confirming.

Second, an optimal interest-on-reserves policy considers credit flow to output sector against added default risk due to exposure of the banking sector to extended lending when interest-on-reserves is above zero. Conversely, very low or negative interest-on-excess-reserves trades off social costs of lower lending against lower default risk within the banking sector.

9 Conclusion

Over the past decade, oversized excess reserves consistently comprised nearly half of the total assets of central banks in charge of 40% of world economy and policymakers used IOER as a lever (inter alia) to address banks' overreliance on excess reserves. The transmission mechanism between IOER policy rate and capital requirement regulation is an important consideration with welfare implications because conflicting policies may effectively lead to under-regulation of the banking sector and therefore re-exposure to default risk, or over-regulation that disrupts credit flow to the real economy.

First, this paper provides a foundation to understand this interaction and show that policymaker's decision to lower IOER provides social benefits only when this policy rate is above zero. In general equilibrium, falling IOER is followed by an almost proportional fall in the equilibrium deposit rate when IOER is above zero but as this rate becomes very low or possibly negative, the equilibrium deposit rate remains positive and nonresponsive to further changes in IOER. Because the banking sector has only a fraction of deposits invested in reserves, a proportional decrease in equilibrium deposit rate in response to falling IOER leads to a faster drop in interest expenses on deposits than loss of interest incomes from reserves. The banking sector extends lending to the real economy as a result of lower default risk when IOER falls and subsequently, the optimal capital regulation tightens to adjust for the added risk to banks' assets.

However, when IOER becomes very low, or possibly negative, the equilibrium deposit rate exhibits an increasingly flatter response to further changes in IOER because deposit investors require a marginally positive compensation for time preference to forego consumption. When equilibrium deposit rate is increasingly nonresponsive to any further reduction in IOER, loss of interest incomes from reserves exceeds lowered interest expenses on deposits. Bank's optimally responds to increased default risk due to higher net interest expenses by lowering lending in order to maintain its shareholder value and subsequently optimal capital regulation loosen. The analysis in Section (4) shows that lower IOER dissuades the banking sector from over-relying on idle excess reserves which has an expansionary effect of real output only when lower rates lead to lower default risk, otherwise lowering IOER generates counterproductive results by worsening this overreliance problem and becomes contractionary.

Second, the analysis in Section (6) shows that for any given IOER rate, optimal capital regulation constantly addresses distortions associated with costly bank failure by requiring the banking sector to hold higher equity per unit of loan. Particularly, as IOER falls within positive territory, optimal capital regulation responds negatively, and positively when IOER becomes very low or below zero. The social value provided by the capital regulation, however, is able to address one distortion at a time at the expense of disruptions of credit flow to the real sector. An optimal IOER policy, when considered in conjunction with the optimal capital regulation, is able to provide further social value by maximizing gains from boosting the real economy while addressing costly bank failure distortions.

An optimal joint financial regulation that considers this non-monotonic relationship between two levers provides support for an integration between the monetary authority in charge of reserves management and the financial regulatory body in charge of capital regulation. The analysis in Section (6) also sheds light on the interconnectedness of IOER to government guarantees that protect deposits held in the banking sector. The results show that a positive IOER when combined with oversized excess reserves leads to large interest expenses and strains government resources that are intended to compensate depositors in any default state, whereas low or below zero IOER can relax government funds, raised from the households or the banking sector, and provide social benefits by increasing the size of the financial sector and ultimately credit flow to the real economy.

Finally, this paper shows a motivation for the monetary and financial regulatory policymakers to act jointly to provide further welfare gains to the society. Nonetheless, future work on joint financial regulation of banking system confronted with aggregate uncertainty needs to consider the welfare implications of deposit insurance funding regimes, an aspect that remains an open question in this paper. Under-funded deposit insurance system provides partial insurance to depositors leading to higher equilibrium cost of debt for the banking system because rational investors price potential bank defaults as well as sovereign defaults. Although sovereign default is unlikely to occur when government guarantees are met in nominal terms, nominal implications become an important consideration that extends the scope of this study to models beyond the real economy. Alternatively, a government guarantee is met by borrowing against the future which raises fiscal implications, or by borrowing from foreign with potentially a downward pressure on exchange rates and international finance considerations.

10 Appendix

A. Cashflow and Solvency Channels

Let $g(k)$ denote expectations function over a subset of x support:

$$g(k) = \int_{k}^{\infty} x f(x) dx \tag{10.1}$$

where $f(x)$ is the lognormal distribution, therefore:

$$g(k) = \int_{k}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln x - \mu)^2}{2\sigma^2}\right) dx \tag{10.2}$$

Using a change of variables $y = \frac{\ln x - \mu}{\sigma}$, $dx = \sigma \exp(\sigma y + \mu) dy$ gives:

$$\int_{y=(\ln k-\mu)/\sigma}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{1}{2}y^2) \sigma \exp(\sigma y + \mu) dy \tag{10.3}$$

Completing the square

$$\begin{aligned}
&= \int \frac{1}{\sqrt{2\pi}} \exp(-\frac{1}{2}y^2 + \sigma y + \mu) dy && (10.4)\\
&= \int \frac{1}{\sqrt{2\pi}} \exp[-\frac{1}{2}(y-\sigma)^2 + (\mu + \frac{1}{2}\sigma^2)] dy && (10.5)\\
&= = \exp(\mu + \frac{\sigma^2}{2}) \frac{1}{\sqrt{2\pi}} \int_{y=(\ln K-\mu)/\sigma}^{\infty} \exp(-\frac{1}{2}(y-\sigma)^2) dy && (10.6)
\end{aligned}$$

Apply the change of variable $v = y - \sigma$ and $dy = dv$ to re-write the original expectation as:

$$\begin{aligned}
g(k) &= \exp(\mu + \frac{\sigma^2}{2}) \frac{1}{\sqrt{2\pi}} \int_{v=(\ln k-\mu)/\sigma-\sigma}^{\infty} \exp(-\frac{1}{2}v^2) dv && (10.7)\\
&= \exp\left(\mu + \frac{\sigma^2}{2}\right) \left[1 - \Phi(\frac{\ln k - \mu - \sigma^2}{\sigma})\right] && (10.8)\\
&= \exp\left(\mu + \frac{\sigma^2}{2}\right) \Phi\left(\frac{-\ln k + \mu + \sigma^2}{\sigma}\right) && (10.9)
\end{aligned}$$

where $1 - \Phi(x) = \Phi(-x)$.

B. Stochastic Discount Factor and the Equity Premium

The stochastic discount factor is (when $\psi = 1$ and i.i.d. return):

$$\begin{aligned}
M_{t,t+1} &= \frac{R_{h,t+1}^{-\gamma}}{\mathbb{E}_t[R_{h,t+1}^{1-\gamma}]} && (10.10)\\
\log M_{t,t+1} &= -\gamma \log R_{h,t+1} - \log \mathbb{E}_t[R_{h,t+1}^{1-\gamma}] && (10.11)\\
&= -\gamma \log R_{h,t+1} - \mathbb{E}_t \log R_{h,t+1}^{1-\gamma} - \frac{1}{2}\mathbb{V}_t \log R_{h,t+1}^{1-\gamma} && (10.12)\\
&= -\gamma \log R_{h,t+1} - (1-\gamma)\mathbb{E}_t \log R_{h,t+1} - \frac{(1-\gamma)^2}{2}\mathbb{V}_t \log R_{h,t+1} && (10.13)
\end{aligned}$$

the (logarithmic) moments are:

$$\begin{aligned}
\mathbb{E}_t \log M_{t,t+1} &= -\mathbb{E}_t \log R_{h,t+1} - \frac{(1-\gamma)^2}{2}\mathbb{V}_t \log R_{h,t+1} && (10.14)\\
\mathbb{V}_t \log M_{t,t+1} &= \gamma^2 \mathbb{V}_t \log R_{h,t+1} && (10.15)
\end{aligned}$$

using the Euler equation with respect to deposit investment, $1 = R_{D,t+1}\mathbb{E}_t M_{t,t+1}$, the deposit rate (household's risk-free rate) is:

$$\begin{aligned}
0 &= \log R_{D,t+1} + \log \mathbb{E}_t M_{t,t+1} && (10.16)\\
&= \log R_{D,t+1} + \mathbb{E}_t \log M_{t,t+1} + \frac{1}{2}\mathbb{V}_t \log M_{t,t+1} && (10.17)\\
&= \log R_{D,t+1} - \mathbb{E}_t \log R_{h,t+1} - \frac{(1-\gamma)^2}{2}\mathbb{V}_t \log R_{h,t+1} + \frac{\gamma^2}{2}\mathbb{V}_t \log R_{h,t+1} && (10.18)\\
&= r_{D,t+1} - \mathbb{E}_t r_{h,t+1} + \frac{2\gamma-1}{2}\mathbb{V}_t r_{h,t+1} && (10.19)\\
&= r_{D,t+1} - (1-\pi_{t+1})r_{D,t+1} - \pi_{t+1}\mathbb{E}_t r_{E,t+1} + \frac{2\gamma-1}{2}\mathbb{V}_t r_{h,t+1} && (10.20)\\
&= -\pi_{t+1}(\mathbb{E}_t r_{E,t+1} - r_{D,t+1}) + \frac{2\gamma-1}{2}\mathbb{V}_t r_{h,t+1} && (10.21)
\end{aligned}$$

The equity premium is:

$$\mathbb{E}_t r_{E,t+1} - r_{D,t+1} = \left(\gamma - \frac{1}{2}\right)\mathbb{V}_t r_{E,t+1} \qquad (10.22)$$

C. Present Value of Equity Return

Monotonicity of the following present value problem yields ($\mathbb{E}_t M_{t,t+1}R_{E,t+1} = \int_\Delta M_{t,t+1}R_{E,t+1}dF$):

$$\arg\max\ \mathbb{E}_t M_{t,t+1}R_{E,t+1} = \arg\max\ \log \mathbb{E}_t M_{t,t+1}R_{E,t+1} \qquad (10.23)$$

then,

$$\log \mathbb{E}_t M_{t,t+1}R_{E,t+1} = \mathbb{E}_t \log(M_{t,t+1}R_{E,t+1}) + \frac{1}{2}\mathbb{V}_t \log(M_{t,t+1}R_{E,t+1}) \qquad (10.24)$$

the first term on the RHS of equation (10.24) is:

$$\begin{aligned}
\mathbb{E}_t \log(M_{t,t+1}R_{E,t+1}) &= \mathbb{E}_t \log R_{E,t+1} + \mathbb{E}_t \log M_{t,t+1}\\
&= \mathbb{E}_t \log R_{E,t+1} - \mathbb{E}_t \log R_{h,t+1} - \frac{(1-\gamma)^2}{2}\mathbb{V}_t \log R_{h,t+1} && (10.25)
\end{aligned}$$

the second term (without 1/2) on the RHS of equation (10.24) is:

$$\begin{aligned}
\mathbb{V}_t \log(M_{t,t+1}R_{E,t+1}) &= \mathbb{V}_t \log R_{E,t+1} + \mathbb{V}_t \log M_{t,t+1} + 2\mathrm{Cov}_t(\log M_{t,t+1}, \log R_{E,t+1})\\
&= \mathbb{V}_t \log R_{E,t+1} + \gamma^2\mathbb{V}_t \log R_{h,t+1} + 2\mathrm{Cov}_t(\log M_{t,t+1}, \log R_{E,t+1})\\
&= (1-\gamma\pi_{t+1})^2\mathbb{V}_t \log R_{E,t+1} && (10.26)
\end{aligned}$$

Re-writing equation (10.24) using (10.25) and (10.26):

$$
\begin{aligned}
&= \log \mathbb{E}_t M_{t,t+1} R_{E,t+1} \\
&= \mathbb{E}_t \log R_{E,t+1} - \mathbb{E}_t \log R_{h,t+1} - \frac{(1-\gamma)^2}{2} \mathbb{V}_t \log R_{h,t+1} + \frac{(1-\gamma\pi_{t+1})^2}{2} \mathbb{V}_t \log R_{E,t+1} \\
&= \mathbb{E}_t \log R_{E,t+1} - \mathbb{E}_t \log R_{h,t+1} - \frac{1}{2} \left[(1-\gamma)^2 \pi_{t+1}^2 - (1-\gamma\pi_{t+1})^2 \right] \mathbb{V}_t \log R_{E,t+1} \\
&= (1-\pi_{t+1})(\mathbb{E}_t r_{E,t+1} - r_{D,t+1}) - \frac{1}{2}(1-\pi_{t+1}) \left[(2\gamma-1)\pi_{t+1} - 1 \right] \mathbb{V}_t \log R_{E,t+1} \qquad (10.27)
\end{aligned}
$$

D. Deposit Insurance Premium

First-Order Condition (5) w.r.t. to deposit insurance taxations:

$$
0 = \mathbb{E}_t \left\{ M_{t,t+1} \left(\underbrace{-\left[(1-\theta_{t+1}) R_{D,t+1} + \theta_{t+1} R_{E,t+1} \right]}_{\text{loss of credit to output market}} \underbrace{+\frac{d\mathrm{Tr}_{t+1}}{d\tau_{t+1}}}_{\text{gain from lower bankruptcy cost}} \right) \right\}
$$

$$
\begin{aligned}
0 = &\int_0^\delta \left\{ M_{t,t+1} \left(-\left[(1-\theta_{t+1}) R_{D,t+1} \right] + \frac{d\mathrm{Tr}_{t+1}}{d\tau_{t+1}} \right) \right\} dF + \\
&\int_\delta^\infty \left\{ M_{t,t+1} \left(-\left[(1-\theta_{t+1}) R_{D,t+1} + \theta_{t+1} R_{E,t+1} \right] + 1 \right) \right\} dF
\end{aligned}
$$

E. Optimal Capital Regulation

The social welfare function is evaluated by household's utility function given regulator's resources,

$$
g = \begin{cases} (1-\tau).\left[\frac{1-\overline{\eta}}{Q_{D,t}} + (1-\kappa).\overline{\eta}.R_{E,t+1} \right] + \left[\tau - (1-\tau).(1-\omega_{t+1}).r_x \right] & \text{in solvency} \\ (1-\tau).\frac{1-\overline{\eta}}{Q_{D,t}} + \left[\tau - (1-\tau).\left[\left(\frac{1-\overline{\eta}}{Q_{D,t}} - \chi.R_{p,t+1} \right) - (1-\omega_{t+1}).r_x \right] \right] & \text{in default} \end{cases}
$$

The first derivative of w.r.t. capital regulation choice $\overline{\eta}_{t+1}$ is

$$
0 = \frac{\chi + \Phi(\lambda_{t+1}).(1-\chi)}{1-\chi} - \frac{1-\overline{\eta}_{t+1}(1-\kappa)}{1-\kappa} \left(-\frac{1}{\sigma} \frac{\partial \Phi(\lambda_{t+1})}{\partial \tau_{t+1}} \frac{\partial \lambda_{t+1}}{\partial z_{b,t+1}} \right) \frac{\partial z_{b,t+1}}{\partial \overline{\eta}_{t+1}}
$$

Approximating the term $-\frac{1}{\sigma} \frac{\partial \Phi(\lambda_{t+1})}{\partial \tau_{t+1}} \frac{\partial \lambda_{t+1}}{\partial z_{b,t+1}}$ with the following exponential affine function, $e^{a_0 + a_1 z_b}$ where a_0 and a_1 are functions of μ and σ.

F. Price Functional Equation

Given strictly increasing and concave preferences in argument C_t and intertemporal budget constraint constraint. The first order conditions for the Lagrangian problem of the household gives:

$$\begin{aligned}
\lambda_t C_t^{-\frac{1}{\psi}} &= \delta(\mu_t(U_{t+1})_{t+1})^{-\frac{1}{\psi}} \Big[\mathbb{E}_t\Big[U(W_{t+1})^{1-\gamma}\Big]\Big]^{\frac{1}{1-\gamma}-1} \mathbb{E}_t\Big[U(W_{t+1})^{-\gamma}U'(W_{t+1})R_{c,t+1}\Big] \\
&= \delta(\mu_t(U_{t+1}))^{-\frac{1}{\psi}} \Big[\mathbb{E}_t\Big[U(W_{t+1})^{1-\gamma}\Big]\Big]^{\frac{1}{1-\gamma}-1} \mathbb{E}_t\Big[U(W_{t+1})^{-\gamma}\lambda_{t+1}C_{t+1}^{-\frac{1}{\psi}}R_{c,t+1}\Big] \qquad (10.28)
\end{aligned}$$

the recursive structure is required to have closed-form solution. The stochastic discount factor M_{t+1} is:

$$M_{t+1} = \delta\frac{\lambda_{t+1}}{\lambda_t}\frac{U(W_{t+1})^{\frac{1}{\psi}-\gamma}}{(\mu_t(U_{t+1}))^{\frac{1}{\psi}-\gamma}}\frac{C_{t+1}^{-\frac{1}{\psi}}}{C_t^{-\frac{1}{\psi}}} \qquad (10.29)$$

rewrite the SDF in logarithms:

$$\begin{aligned}
m_{t+1} &= \log(\delta) + \log(\frac{\lambda_{t+1}}{\lambda_t}) - \frac{1}{\psi}\Delta C_{t+1} + (\frac{1}{\psi}-\gamma)\log(\frac{U_{t+1}}{\mu_t(U_{t+1})}) \\
&= \theta\log(\delta_t) + \theta\log\Big(\frac{\lambda_{t+1}}{\lambda_t}\Big) - \frac{\theta}{\psi}\Delta c_{t+1} + (\theta-1)r_{c,t+1} \qquad (10.30)
\end{aligned}$$

conditional expected return to equity and to risk-free bond are:

$$\begin{aligned}
r_{f,t+1} &= \frac{\mu}{\psi} - \log(\delta) - \log\left(\frac{\lambda_{t+1}}{\lambda_t}\right) + \left[\frac{1-\theta}{\theta}(1-\gamma)^2 - \gamma^2)\right]\frac{\sigma_c^2}{2} \\
&+ \left[(1-\theta)(\kappa_{c,1}A_{c,1})^2\right]\frac{\sigma_\lambda^2}{2} \qquad (10.31)
\end{aligned}$$

Conjecture the following affine functional equality

$$\begin{aligned}
P_t(\theta_{t+1}, R_{D,t+1};\gamma) &= \vartheta(P_{t+1} + div_{t+1}) \qquad (10.32) \\
&= \frac{\vartheta}{1-\vartheta}\mathbb{E}_t[div_{t+1}] \qquad (10.33)
\end{aligned}$$

where

$$\begin{aligned}
1 &= R_{D,t+1}\mathbb{E}_t\left[\frac{1}{((1-\theta)R_{D,t+1} + \theta R_{E,t+1})^\gamma}\right] \\
&= R_{D,t+1}\mathbb{E}_t\left[\frac{1}{\left((1-\theta)R_{D,t+1} + \theta\frac{P_{t+1}+div_{t+1}}{P_t}\right)^\gamma}\right]
\end{aligned}$$

$$\vartheta = \left\{ 1 - \frac{\frac{1}{1-\Phi(\delta)} \cdot \frac{1}{R_{D,t+1}} - \frac{\Phi(\delta)}{1-\Phi(\delta)} \frac{1}{\left[\frac{1}{(1-\theta_{t+1})R_{D,t+1}}\right]^{\gamma}} - \gamma(1-\theta_{t+1})R_{D,t+1} - \frac{\gamma^2}{2}\theta_{t+1}^2}{\gamma\theta_{t+1}} \right\}^{-1}$$

G. Optimal Capital Regulation

H. Solvency Condition

$$R_{b,t+1}(\eta_{t+1}, \omega_{t+1}; R_{X,t+1}, R_{D,t+1}) = \max\left\{ \frac{1-\eta_{t+1}}{\omega_{t+1}} R_{D,t+1} - \frac{1-\omega_{t+1}}{\omega_{t+1}} R_{X,t+1}, 0 \right\} \quad (10.34)$$

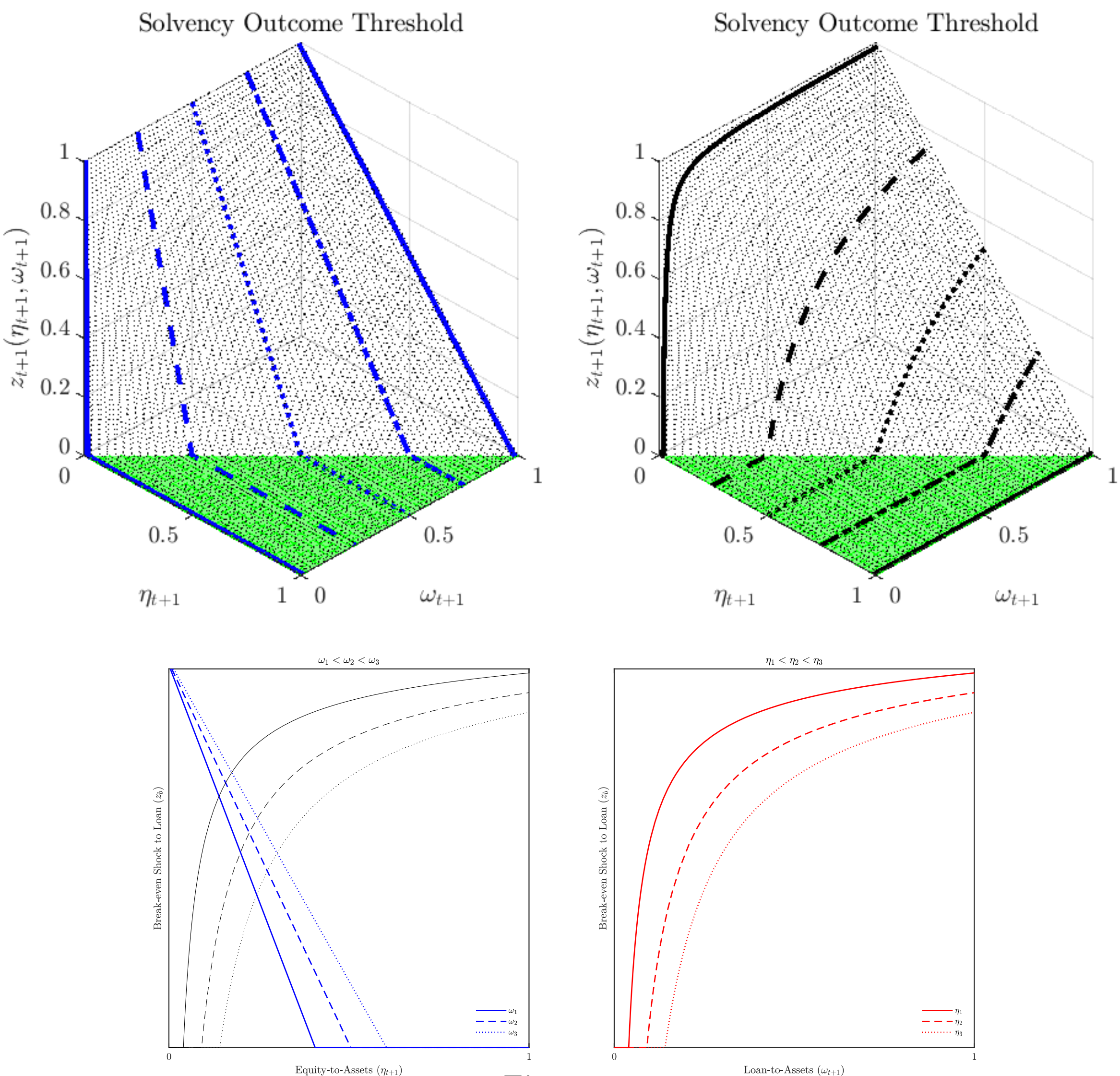


Figure 18

Optimal Risk-weighted Capital Requirement (% of total assets)

Panel A: Low Loss Given Default ($1-\chi = 10\%, \kappa = 99\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.36	2.22	2.09	1.95	1.81	1.67	1.53	1.39	1.55	1.69	1.84
25%	4.72	4.44	4.17	3.89	3.61	3.34	3.06	2.78	3.10	3.38	3.67
50%	7.08	6.67	6.26	5.84	5.42	5.01	4.59	4.18	4.65	5.07	5.51
75%	9.44	8.89	8.34	7.78	7.23	6.67	6.12	5.57	6.19	6.76	7.35
90%	11.80	11.11	10.43	9.73	9.03	8.34	7.65	6.96	7.74	8.45	9.18
100%	14.16	13.33	12.51	11.67	10.84	10.01	9.18	8.35	9.29	10.14	11.02

Panel A: Low Loss Given Default ($1-\chi = 20\%, \kappa = 99\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.51	2.38	2.26	2.14	2.01	1.89	1.77	1.64	1.77	1.88	2.00
25%	5.01	4.76	4.52	4.27	4.02	3.78	3.53	3.28	3.54	3.76	4.01
50%	7.52	7.15	6.78	6.41	6.04	5.67	5.30	4.93	5.32	5.65	6.01
75%	10.02	9.53	9.03	8.54	8.05	7.55	7.06	6.57	7.09	7.53	8.01
90%	12.53	11.91	11.29	10.68	10.06	9.44	8.83	8.21	8.86	9.41	10.02
100%	15.03	14.29	13.55	12.81	12.07	11.33	10.59	9.85	10.63	11.29	12.02

Panel A: Low Loss Given Default ($1-\chi = 30\%, \kappa = 99\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.88	2.73	2.58	2.42	2.27	2.12	1.96	1.81	1.95	2.09	2.26
25%	5.76	5.46	5.15	4.84	4.54	4.23	3.92	3.62	3.89	4.17	4.52
50%	8.65	8.19	7.73	7.27	6.81	6.35	5.89	5.43	5.84	6.26	6.79
75%	11.53	10.91	10.30	9.69	9.07	8.46	7.85	7.23	7.79	8.34	9.05
90%	14.41	13.64	12.88	12.11	11.34	10.58	9.81	9.04	9.73	10.43	11.31
100%	17.29	16.37	15.45	14.53	13.61	12.69	11.77	10.85	11.68	12.51	13.57

Table 5: The table illustrates the optimal risk-weighted capital regulation set by the policymaker on the banking sector to condition its asset allocation to its capital structure. Panel (A) shows the required capital as a percentage of total assets and various IOER where the required capital ubiquitously increases when share of total asset invested in lending (ω_{t+1}) increases. As IOER is lowered, the corresponding required capital decreases for any given level of asset allocation when IOER is above zero. As IOER reaches zero and marginally negative, the policymaker requires the liabilities to includes lower capital per unit of loan. Panels (B) and (C) replicate the same quantities when the bankruptcy cost and its associated deadweight losses increases leading to higher minimum capital requirement given IOER and share of funds invested in risky asset.

Optimal Risk-weighted Capital Requirement (% of total assets)

Panel A: Low Loss Given Default ($1-\chi = 10\%, \kappa = 99.5\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.43	2.30	2.17	2.04	1.91	1.78	1.65	1.52	1.65	1.79	1.92
25%	4.86	4.60	4.34	4.08	3.82	3.56	3.30	3.04	3.30	3.57	3.85
50%	7.29	6.90	6.51	6.12	5.73	5.34	4.95	4.56	4.96	5.36	5.77
75%	9.71	9.19	8.67	8.15	7.63	7.11	6.59	6.08	6.61	7.14	7.69
90%	12.14	11.49	10.84	10.19	9.54	8.89	8.24	7.60	8.26	8.93	9.62
100%	14.57	13.79	13.01	12.23	11.45	10.67	9.89	9.12	9.91	10.71	11.54

Panel A: Low Loss Given Default ($1-\chi = 20\%, \kappa = 99.5\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.57	2.45	2.33	2.21	2.09	1.97	1.85	1.73	1.85	1.97	2.06
25%	5.13	4.89	4.65	4.41	4.17	3.93	3.69	3.45	3.71	3.94	4.11
50%	7.70	7.34	6.98	6.62	6.26	5.90	5.54	5.18	5.56	5.92	6.17
75%	10.26	9.78	9.30	8.82	8.34	7.86	7.38	6.90	7.41	7.89	8.23
90%	12.83	12.23	11.63	11.03	10.43	9.83	9.23	8.63	9.27	9.86	10.28
100%	15.39	14.67	13.95	13.23	12.51	11.79	11.07	10.35	11.12	11.83	12.34

Panel A: Low Loss Given Default ($1-\chi = 30\%, \kappa = 99.5\%$)

ω_{t+1}	Interest-on-Excess-Reserves ($r_{X,t+1}$) in percentage points										
	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.00	−0.25	−0.50	−0.75
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10%	2.97	2.86	2.76	2.66	2.55	2.45	2.35	2.24	2.36	2.46	2.55
25%	5.93	5.72	5.52	5.31	5.10	4.90	4.69	4.48	4.72	4.91	5.10
50%	8.90	8.59	8.28	7.97	7.66	7.35	7.04	6.73	7.09	7.37	7.65
75%	11.86	11.45	11.03	10.62	10.21	9.79	9.38	8.97	9.45	9.82	10.19
90%	14.83	14.31	13.79	13.28	12.76	12.24	11.73	11.21	11.81	12.28	12.74
100%	17.79	17.17	16.55	15.93	15.31	14.69	14.07	13.45	14.17	14.73	15.29

Table 6: The table illustrates the optimal risk-weighted capital regulation set by the policymaker on the banking sector to condition its asset allocation to its capital structure. Panel (A) shows the required capital as a percentage of total assets and various IOER where the required capital ubiquitously increases when share of total asset invested in lending (ω_{t+1}) increases. As IOER is lowered, the corresponding required capital decreases for any given level of asset allocation when IOER is above zero. As IOER reaches zero and marginally negative, the policymaker requires the liabilities to includes lower capital per unit of loan. Panels (B) and (C) replicate the same quantities when the bankruptcy cost and its associated deadweight losses increases leading to higher minimum capital requirement given IOER and share of funds invested in risky asset.

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