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Financial Crisis as a Run on Profitable Banks

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I build a quantitative macro finance model, motivated by empirical findings in Kim (2023) that shows money market mutual funds withdraw from dealer banks with a high return on equity because safe assets issued by issuers with a higher ROE has lower moneyness. The model features a bank that borrows money by issuing a short-term money-like debt with time-varying moneyness. When lenders deem the bank asset too risky — using the bank's ROE as a proxy — the short-term debt no longer serves the role of money. An increase in the regulatory capital requirement affects the real economy through three different offsetting channels.

Key Words: Financial crisis; Safe asset; Private money; Moneyness, Capital requirement.
JEL Classification Numbers: E44, E61, G01, G18.

1. INTRODUCTION

A financial crisis is an event when lenders run on privately produced short-term safe asset because it loses its role as money (Gorton 2018). In that sense, the Global Financial Crisis of 2007-2008 was fundamentally similar to any other financial crises that we have experienced throughout history. During the National Banking Era from 1863 to 1914, for example, there was a frequent run on a bank's demand deposits when macroeconomic conditions signaled a recession Gonton 1988. The demand deposit was money-like in that it could almost always be valued at par with no questions asked. However, the holders of the demand deposit feared adverse selection as they did not have full information about the riskiness of the collateral that was backing the demand deposit. Therefore, when a negative shock hit, it incentivized them to conduct a costly due diligence on the collateral. When this happened, the demand deposit turned information sensitive and no longer served the role of money, leading to a run.

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The advent of the deposit insurance in 1934 rendered a run on retail banks obsolete. With this, the potential for a run on a money-like safe asset migrated from the retail banking sector to the wholesale banking sector[1] where there are a lot less regulations (Gertler, Kiyotaki, and Prestipino 2016, Begenau and Landvoigt 2021). This potential manifested itself as a run on securities such as repurchase agreement (repo) and asset backed commercial paper (ABCP) in the Global Financial Crisis of 2007-2008 (Gorton and Metrick 2012). The demand deposits of the National Banking Era in the 1800's or the repurchase agreement of the modern era were all privately-produced short-term safe asset created by financial intermediaries as relatively safe means to transfer wealth intertemporally and to facilitate transactions among market participants. Preventing financial crises caused by the time-varying moneyness of privately produced safe assets has been an unsolved challenge that the regulators have been facing for centuries, and as a result, there has been burgeoning interest in studying this market of privately produced money.[2]

The goal of this paper is to embed the notion that a financial crisis is a run on privately produce money-like short-term debt into a general macroeconomic framework with financial frictions. To this end, I build a quantitative macro-finance model that features a financial crisis instigated by the time-varying moneyness of a privately produced safe asset. Using this framework, I investigate one of the most contentious topics in the banking industry right now: the financial intermediaries' capital requirement.

This paper builds on the empirical result presented in a companion paper Kim (2023). Kim (2023) shows that a strong performance of a debtor (a dealer bank)—as measured by an increase in its return on equity (ROE)—leads to an *outflow* from that debtor. More specifically, a 1% increase in a dealer bank's ROE results in around 3% decrease in MMFs' holding of privately produced safe asset issued by that bank. Furthermore, Kim (2023) shows that the reason for the outflow is that the moneyness of the privately produced safe asset issued by a high-ROE bank is lower than that issued by a low-ROE bank where moneyness is measured by the asset's convenience yield.[3] Finally, Kim (2023) finds that the effect that the bank

[1]Anoether frequently used term to denote what I call a wholesale bank in my model is a shadow bank that exists outside the umbrella of existing banking regulation.

[2]Krishnamurthy and Vissing-Jorgensen (2012), Gorton, Lewellen, and Metrick (2012), Gorton and Metrick (2012), Sunderam (2014), Krishnamurthy and Vissing-Jorgensen (2015), Greenwood, Hanson, and Stein (2015), and Nagel (2016) to list a few.

[3]There are many synonyms to convenience yield used in the literature such as liquidity premium. This measure is usually calculated as a spread between the yield of the privately produced safe asset and the yield of a government-issued bond with similar risk and maturity such as Treasuries. Assuming that the two assets are equally safe, the difference in yield between the two accounts for how much more liquid the Treasuries are compared to the privately produced safe asset.

ROE had on the investment decision of a MMF was especially strong during the COVID-19 period, consistent with the nonlinear effect of a crisis.

In this paper, I build a quantitative macro-finance model that is disciplined by these empirical facts. There exist a bank and two types of investors. The first type of investors provides equity to the bank and incentivizes the bank to engage in a riskier and riskier investment. They are the equity investors in my model. The second type of investors are the depositors (the debt holders) who buy a short-term bond called the deposit that is issued by the bank. The depositors value the short-term bond as a transactional medium therefore pays a convenience yield to the bank.

The bank is funded by the equity investors and the depositors. It is subject to a capital requirement whether it be something required by the regulators or a haircut on the collateral that depositors demand due to agency friction. Consistent with the empirical findings, the depositors use the ROE of the bank to infer the riskiness of the bank thereby gauging the moneyness of the deposit. If the bank becomes too risky according to their assessments, the depositors have an incentive to produce private information about the collateral, which is the portfolio of the bank's asset. This makes the deposit to turn information sensitive and lose its moneyness. When this happens, the economy is in a financial crisis.

I use the simulated model as a laboratory to experiment what the effect of raising the regulatory capital requirement is on the real output. In the model, there are three channels through which a change in the capital requirement affects the ability of a bank to intermediate funds from the funding providers to the productive agents in the economy.

First is the *costly equity channel.* An increase in capital requirement increases a bank's cost of capital as it has to raise more equity, and equity is a more expensive form of financing than debt. This inhibits the bank's ability to lend, having a negative effect on the real economy.

Second is the *crisis potential channel.* An increase in capital requirement increases a bank's equity buffer. As the bank has more skin in the game, the depositors fear adverse selection less, lowering the frequency of financial crises; i.e. lowering the frequency that the privately produced safe asset turn information sensitive. This means a decrease in the potential for the bank's capital requirement constraint binding as the periods when the constraint binds usually coincide with the periods of financial crises. This incentivizes the bank to expand their balance sheet and lend more, thereby having a positive effect on the real economy.

The final channel is the *moneyness channel.* The costly equity channel had a negative effect on the real economy because a higher capital requirement made the bank to finance itself with equity that's more expensive than debt, thereby increasing the overall cost of capital. However, what the costly equity channel does not consider is the endogenous response of the cost of debt financing to an increase in the capital requirement. An increase in the capital requirement increases the moneyness of the bank-issued safe asset on average as there is more equity buffer for the depositors, which means the frequency of the safe asset turing information sensitive decreases. This means the average convenience yield that the bank enjoys increases, lowering its average debt financing cost and offsetting some of the negative effect that the costly equity channel had on its ability to intermediate fund to the real economy.

In the end, there are offsetting effects of the changes in the capital requirement on the real economy through these three channels. Which channel dominates will be investigated by carefully calibrating the quantitative model to the Argentinian economy. Argentina is a country that has been hit frequently by financial crises, making it a good economy to calibrate my model to as we can see numerous instances of a build-up towards and a recovery from financial crises.

For the counterfactual experiment, I start with a benchmark of 8% capital requirement, which is along the lines of what the Basel Accords stipulates. Then I observe the transitional dynamics of the model when I vary the capital requirement from 1% to 25%. I find that the optimal[4] level of the capital requirement is 18% when it comes to maximizing the real output of the economy. I find that the crisis potential channel and the moneyness channel dominates the costly equity channel by lowering the debt financing cost until 18% capital requirement level. Beyond 18% capital requirement level, the bank has to issue too much equity, making the equity too costly. This results in the costly equity channel dominating the crisis potential and the moneyness channel beyond the 18% capital requirement level.

Literature Review This paper is at the intersection of the literature on macroeconomics with financial friction and the literature on private safe asset production and how it relates to a financial crisis. Papers like Bernanke and Gertler (1989), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999) laid the groundwork for studying the macroeconomy when there are financial frictions such as credit market imperfections. Macroeconomic models with financial frictions gained a lot of attention after the Global Financial Crisis of 2007-2008 when the failure of financial intermediaries spilled over to the real economy and caused the Great Recession. Quantitative papers like Gertler and Kiyotaki (2010), Gertler and Karadi (2011), and Gertler and Kiyotaki (2015), and Gertler, Kiyotaki, and Prestipino (2016) as well as more theoretical papers like GennaioliI, Shleifer, and Vishny (2013), Plantin (2014), Farhi and Tirole (2020), Brunnermeier and Sannikov (2014), and He and Krishna- murthy (2013) studied roles that the financial intermediaries—especially those that were recently

[4]The word optimal does not refer to welfare optimality.

created called the wholesale or shadow banks that were outside the typical regulatory framework—played in building up the fragility in the financial market that ended up in a crisis.

In terms of policy interventions, my paper is related to the quantitative banking literature on the optimal bank capital requirement (Christiano and Ikeda 2016; Van den Heuvel 2008; Begenau 2020; Corbae and D'Erasmo 2021; Elenev, Landvoigt, and Van Nieuwerburgh 2021; Begenau and Landvoigt 2021). My paper focuses more on the specific financial instruments that these financial intermediaries were producing—namely money-like short-term asset—to investigate what kind of role of these instruments have played in financial crises, and what the optimal capital requirement is in this environment.

There is a line of literature starting from Diamond and Dybvig (1983) and Gorton and Pennacchi (1990) that justifies the role of financial intermediaries as producers of a money-like safe asset. Recent theoretical papers like Dang, Gorton, and Holmström (2012) and Dang et al. (2017) build on this idea to argue that short-term debt that are information insensitive serve the role of money and banks are optimally opaque to keep them from turning information sensitive. My paper embed this notion into a more general macroeconomic framework to study various poicy tools that can be used to prevent future crises.

2. SUMMARY OF THE EMPIRICAL RESULT IN KIM (2023)

In this section, I summarize the empirical result in the companion paper Kim (2023) that is used as a motivation for the model presented in this paper.

Kim (2023) first argues that the safe asset issuers' profitability is a significant metric when the safe asset holders determine the moneyness of their privately produced safe asset. Kim (2023) shows that an increase in ROE of a dealer bank makes a MMF to withdraw from the bank, and this is because the moneyness of the privately produced safe asset issued by that dealer bank decreases as its ROE increases. This effect is especially strong during a crisis period.

The empirical pattern that Kim (2023) establishes that a higher ROE of a safe asset issuer leads to a withdrawal from a safe asset holder is somewhat surprising and counterintuitive. Therefore, Kim (2023) also builds a model to rationalize these facts. The intuition for this result comes from the logic that the safe asset holders like MMFs care almost solely about the left tail of the distribution of the collateral value. The safe asset holders' upside is limited to the interest rate promised in the previous period while their downside is the complete insolvency of the safe asset issuer and the safe asset holders not being able to get any of their money back. When the safe asset issuers are enjoying a higher profit, the safe asset holders would be more worried than excited. While as debt holders they don't proportionally share the higher profit of the safe asset issuers, they are more exposed to the thicker left tail of the collateral value and a potential for bank insolvency as a higher expected return usually means a higher variance of the return.

3. MODEL

In this section, I present a model that features empirical patterns that I summarized in the previous section. Financial intermediaries issue privately produced safe assets that have time-varying moneyness. The moneyness varies according to a rule set by the safe asset holders, and it depends on the profitability of the financial intermediaries, as evidenced by the empirical results. The model takes this rule of the safe asset holders as given as it was empirically motivated by looking at the investment decision of the MMFs. Given the rule, I model the behavior of the safe asset holders and issuers and calibrate it to the Argentinian economy that have suffered from numerous instance of crises for the past 40 years. Finally, I use the calibrated model as a laboratory to conduct a policy experiment of changing the regulatory capital requirement.

The model references the wholesale banking sector such as the short-term lending market between dealer banks and MMFs. In the wholesale banking sector, the deposits are not protected by the deposit insurance, rendering the wholesale deposits susceptible to runs as opposed to retail deposits (Diamond and Dybvig 1983). Any safe and liquid form of investments in the wholesale banking sector such as repurchase agreements or commercial papers will holistically be referred to as "deposits" in the model as a safe asset holder's buying a privately produced safe asset from a safe asset issuer is equivalent to the safe asset holder depositing their money to the safe asset issuer.

There are three agents in the economy: depositors, equity investors, and a bank. We can think of depositors as institutional investors like the MMFs in the previous section or sovereign wealth funds that need safe and liquid form of investments. We can think of the bank as financial intermediaries that fund themselves using short-term debt and provide money-like asset to the depositors like the dealer banks in the previous section.

Depositors and equity investors fund the bank by holding the debt and the equity portion of the bank's liability, respectively. The depositors and the equity investors' goals are to maximize their respective expected lifetime utility. The bank whose incentives are perfectly aligned with the owners of the bank—the equity investors—manages the asset and the liability of the bank to maximize the expected discounted sum of dividend paid out to the equity investors.

The model is set in discrete time and runs for an infinite period of time $t = 0, 1, 2, \ldots$

3.1. Equity Investors

There is a continuum of identical equity investors. Equity investors provides funding to the bank by holding the equity portion of the bank's liabilities. The equity investors' problem is to maximize their lifetime utility subject to a budget constraint. They finance their consumption and investment in bank equity using the capital gains from holding the bank equity and dividend payout from the bank.

Formally, the equity investors' problem is as follows. Given the price of a share of equity p_t and the dividend paid out to them d_t, the equity investors choose consumption c_t^e and the number of bank shares s_{t+1} in order to maximize their lifetime utility:

$$\max_{\{c_t, s_{t+1}\}_{t=0}^{\infty}} \mathbb{E}_0 \Big[\sum_{t=0}^{\infty} \beta^t \frac{(c_t^e)^{1-\gamma_c}}{1-\gamma_c} \Big]$$
$$\text{subject to } c_t^e + p_t s_{t+1} = p_t s_t + d_t \ \forall t$$
$$s_0 \text{ given.}$$

As the equity investors are the owners of the bank, the bank uses the stochastic discount factor of the equity investors $\Lambda_t \equiv \beta^t (c_{t+1}^e / c_0^e)^{-\gamma_c}$ to discount its cash flows.

3.2. Depositors

There is a continuum of identical depositors. The depositors finance the bank by buying a one-period bond called the deposit that is issued by the bank. In every period, the depositors make a consumption-savings decision. There are two types of saving vehicles available to the depositors: cash and deposit. Just as we use both our physical currency and our checking account when buying goods and services, the cash and the deposit in this model are not only saving vehicles but also different types of money that are used in transactions. Let c^d denote the consumption of the depositors, and let m_d and m_c denote the deposit and cash holdings of the depositors, respectively.

3.2.1. Main Tradeoff of the Model

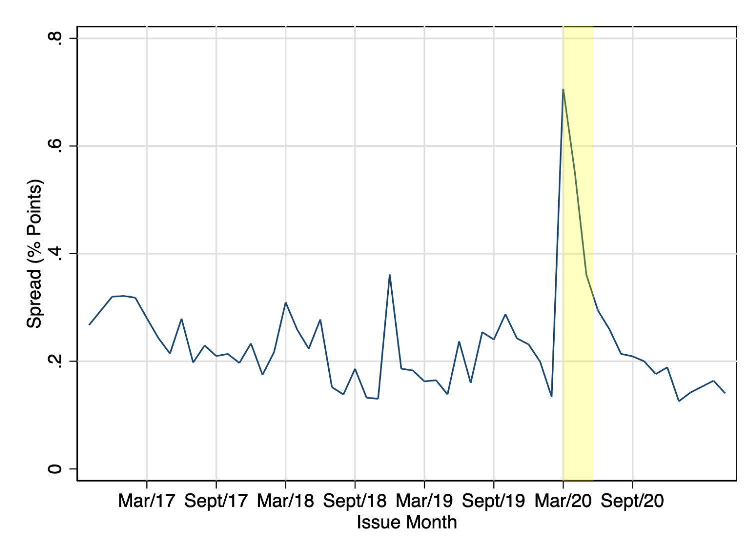
The tradeoff that the depositors face between holding cash versus deposit is the main source of friction that drives the mechanism of the model. If the depositors put their money in the bank as deposit, they earn an interest. However, if they hold their money as cash and put it under their mattress, they earn no interst. Therefore in a frictionless equilibrium, the depositors will choose to save their money entirely as deposit. The friction that breaks this equilibrium is characterized by cash and deposit offering different relative moneyness.

The relative moneyness of cash and deposit varies over time. The cash is always money while the deposit is not money when it turns information sensitive. Therefore, the cash provides a higher level of moneyness on average over time than the deposit, which is the reason why the depositors want to hold both cash and deposit in equilibrium even though the cash does not pay any interest.

3.2.2. Modeling the Time-varying Moneyness of the Deposit

In this subsection, I show how I model the time-varying moneyness of the deposit. There are two modeling assumptions I make that are motivated by the empirical findings in Kim (2023) that make the model much more tractable. The first assumption I make is that the depositors follow a given rule when determining the moneyness of the deposit at a given period: when the ROE of the bank goes up, the moneyness of the deposit goes down.

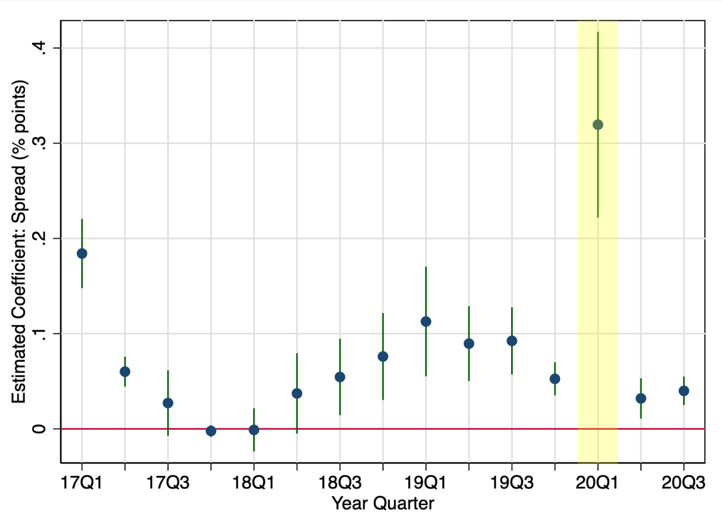
FIG. 1. Nonlinearity of Safe Asset Moneyness



Notes: This figure is reproduced from Kim (2023). It plots the *Spread* variable that proxies for moneyness of privately produced safe asset across time. Higher *Spread* corresponds to lower moneyness.

The second assumption I make is that there is a nonlinear relationship between the bank ROE and the moneyness of the deposit during a crisis period. Figure 1 shows that the constructed Spread variable that proxies for the moneyness of the privately produced safe asset shot up during the COVID-19 crisis period. In other words, the moneyness of the privately produced safe asset decreased dramatically during the COVID-19 crisis period. Furthermore, Figure 2 shows that the Spread variable was especially responsive to the dealer bank ROE during the COVID-19 crisis period. For tractability of the model, I take the two empirical results above as given and make the modeling assumptions accordingly.

FIG. 2. Nonlinearity of Safe Asset Moneyness



Notes: This figure is reproduced from Kim (2023). It plots the estimated β from the regression

$$Spread = \alpha + \beta ROE + Controls \& Fixed\ effects$$

quarter-by-quarter. Each estimate shows the elasticity of safe asset's moneyness to changes in ROE.

In order to conveniently model the idea of the depositors' demand for money-like assets, I follow the literature and assume that the depositors get an added utility from money holdings on top of the consumption utility.[5]

[5]This money-in-utility function formulation for modeling liquidity demand is widely used in the literature starting from Sidrauski (1967). The money holding is aggregated using the CES aggregator along the line of papers such as Barnett (1980).

More specifically, following Nagel (2016), I aggregate the deposit holding m_d and cash holding m_c by a CES aggregator as follows:

$$M_t = \left(\theta_t m_{c,t}^{\eta} + (1-\theta_t) m_{d,t}^{\eta}\right)^{\frac{1}{\eta}},$$

where M_t is defined as the aggregate money holding of the depositors. $\eta \in (-\infty, 1]$ controls the elasticity of substitution between cash and deposits where $1/(1-\eta)$ is the elasticity of subsitution. θ_t determines the relative moneyness of cash versus deposits.

θ_t is a crucial variable in the model that determines the relative contribution of cash and deposit to the depositors' overall utility. In other words, it determines the relative moneyness of cash and deposit. Since the bank is opaque (Dang et al. 2017), the depositors do not have an access to the information about the entire portfolio of the bank. Instead, they take publicly available signals to imperfectly assess the riskiness and the value of the collateral that is backing the deposit contract. Kim (2023) showed that one strong publicly available signal that the depositors use is the bank's profitability as measured by its ROE.

Using the first assumption, I formulate the variable θ_t as follows. I assume that a higher ROE leads to a higher θ according to a logistic function:

$$\theta_t = \frac{1}{1+\exp(-\kappa(ROE_t))},$$

where κ is a parameter that controls the responsiveness of the deposit's moneyness to the bank's ROE. When the ROE of the bank increases, θ_t increases, which makes the relative moneyness of deposit to decrease, consistent with the empirical result in Kim (2023).

A financial crisis is a sudden phenomenon. Relatedly, the information insensitivity of a privately produced safe asset is binary: the asset is either information sensitive or information insensitive. In order to capture the nonlinear nature of the time-varying moneyess of the privately produced safe assets that was present in the data, I use the second assumption and assume that there exists a threshold parameter $\bar{\theta}$ above which θ_t is equal to 1 so that

$$\theta_t = \begin{cases} \frac{1}{1+\exp(-\kappa(ROE_t))} & \text{if } \frac{1}{1+\exp(-\kappa(ROE_t))} < \bar{\theta} \\ 1 & \text{if } \frac{1}{1+\exp(-\kappa(ROE_t))} > \bar{\theta} \end{cases}.$$

We can see that when ROE of the bank goes above a certain threshold, θ_t turns 1, making the aggregate money function to be just equal to the depositors' cash holding; i.e. $M_t = m_{c,t}$. κ and $\bar{\theta}$ are parameters that I calibrate to crisis-related data moments in Argentina so that the model simulation can replicate and quantify realistic behaviors associated with financial crises.

As the depositors get direct utility from the aggregate money holdings, the depositors' period utility function can be written as follows

$$u(c_t, M_{t+1}) = u(c_t) + \psi v(M_{t+1}),$$

where ψ is a parameter that determines the relative utility contribution of the aggregate money holdings. The deposit's turning information sensitive is represented by the depositors not getting any extra utility from holding the deposit:

$$\begin{aligned} u(c_t, M_{t+1}) &= u(c_t) + \psi v(M_{t+1}) \\ &= u(c_t) + \psi v(m_{c,t+1}) \text{ when } \theta_t = 1. \end{aligned}$$

In the model, θ_t being equal to 1 corresponds to a financial crisis. In the case of the Global Financial Crisis for example, $\theta_t = 1$ represents a run on money market instruments such as repo or asset back commercial papers because buyers of these contracts got nervous about the the bank's investment in assets like mortgage backed securities.

Outside the model, the characterization of θ can be compared to the distinction between the slow run of 2007 versus the fast fun of 2008. In 2007, securitized safe assets especially the asset-backed commercial papers were becoming more and more illiquid as investors were slowly but steadily withdrawing from holding these assets (Covitz, Liang, and Suarez 2013). This is what some people call the slow run of 2007, and in my model, it corresponds to θ increasing without hitting the threshold $\bar{\theta}$. In 2008, investors withdrew completely from holding the securitized assets as they became completely illiquid. In my model, this fast run corresponds to θ hitting the threshold $\bar{\theta}$.

3.2.3. The Depositor's Problem

The depositors solve the following problem:

$$\max_{\{c_t, m_{d,t+1}, m_{c,t+1}\}_{t=0}^{\infty}} \mathbb{E}_0 \Big[\sum_{t=0}^{\infty} \beta^t \Big\{ u(c_t^d) + \psi v(M_{t+1}) \Big\} \Big]$$

$$\text{subject to } c_t^d + m_{c,t+1} + m_{d,t+1} = (1 + r_t) m_{d,t} + m_{c,t} \; \forall t$$

$$M_{t+1} = \Big(\theta_t m_{c,t+1}^{\eta} + (1 - \theta_t) m_{d,t+1}^{\eta} \Big)^{\frac{1}{\eta}}$$

$$\theta_t = \begin{cases} \frac{1}{1+\exp(-\kappa(ROE_t))} & \text{if } \frac{1}{1+\exp(-\kappa(ROE_t))} < \bar{\theta} \\ 1 & \text{if } \frac{1}{1+\exp(-\kappa(ROE_t))} > \bar{\theta} \end{cases}$$

$$m_{c,t+1}, m_{d,t+1} \geq 0$$

$$m_{c,0}, m_{d,0} \text{ given.}$$

I adopt a CRRA-type utility functions for the consumption utility as well as the utility from money so that $u(c_t^d) = \frac{(c_t^d)^{1-\gamma_c}}{1-\gamma_c}$ and $v(M_t) = \frac{M_t^{1-\gamma_m}}{1-\gamma_m}$. The depositors finance consumption and saving using returns from deposit with interest rate r and cash that they have saved. In each period, the depositors chooses consumption c_t^d, deposit holding $m_{d,t+1}$, and cash holding $m_{c,t+1}$ to maximize their lifetime utility.

3.3. Bank

The economy is populated by a continuum of identical banks. The objective of the bank is to maximize the shareholder value. They achieve this by maximizing the discounted sum of dividends paid out to the equity investors who are the owners of the bank.

The liability side of the bank balance sheet is made up of equity and deposit. As the names suggest, the equity investors provide equity financing to the bank therefore are the owners of the bank, and the depositors provide debt financing to the bank.

On the asset side of the bank balance sheet, the bank has two types of investment vehicles that they can invest in: risky assets a_t^r and safe assets a_t^s . Following the literature, the bank's risky asset investment represents their intermediating funding from the equity investors and the depositors to the real economy. Just as in papers like He and Krishnamurthy (2013) or Brunnermeier and Sannikov (2014), I am going to assume that the bank is both the owner and the manager of productive capital. I am modeling the relationship between nonfinancial firms and the bank in a reduced form way, assuming there is no agency friction between them. Therefore, the bank is the funding provider and the nonfinancial firms use all of the funding for production. Essentially, the risky asset variable a_t^r is comparable to a productive capital k in the business cycle literature. In this regard, the productivity of the risky asset a_t^r , denoted z_t, is going to follow a standard log AR(1) process as follows:

$$\log(z_{t+1}) = \rho \log(z_t) + \sigma \epsilon_{t+1},$$

where $\epsilon \sim N(0,1)$. ϵ is the only exogenous shock in the model. The safe asset a_t^s gets a constant marginal return of r^s. I assume that there is an abundant supply of this asset that the marginal return does not respond to the changes in the supply and demand of the safe asset investment.

The risky asset accumulates according to

$$a_{t+1}^r = (1-\delta)a_t^r + i_t,$$

where δ is the depreciation rate. As in the literature, the bank has to pay a quadratic capital adjustment cost for the amount of investment that exceeds the depreciated amount of the risky asset as follows:

$$\phi_1 \Big(\frac{i_t}{a_t^r} - \delta\Big)^2 a_t^r.$$

The output of the real economy denoted y_t for period t is as follows

$$y_t = z_t (a_t^r)^\alpha,$$

where $\alpha < 1$. The justification for the decreasing returns to scale production function for the risky asset is as follows.[6] As mentioned before, a_t^r is representing the amount of bank loan that the bank is providing to nonfinancial firms. Then the decreasing marginal revenue to a bank loan to captures the idea that there exists borrowers with heterogeneous level of profitability, and the first dollar of bank loan goes to the most profitable borrower, second to the next profitable one, and so on. As the bank is the sole owner of the firms in the real economy, it extracts all the surplus from firm production, which means the total revenue of the bank is equal to the output of the real economy plus the return from the safe asset investment $r^s a^s$.

Let $m_{d,t}$ be the amount of deposit issued to the depositors entering period t. The level of deposit issued determines the equilibrium interest rate paid

[6]This is a standard assumption in the quantitative banking literature. Ths justification is provided in papers such as Begenau (2020).

out to the depositors denoted r. The bank revenue combined with the interest payment to the depositors determines the bank's profit π. Profit at time t denoted π_t is equal to its total revenue less the interest expense paid out to the depositors:

$$\pi_t = z_t (a_t^r)^\alpha + r^s a_t^s - r_t m_{d,t}.$$

Let the net worth of the bank at the beginning of period t be denoted as n_t. When the production is complete and the bank pays its depositors their interest payment, the bank decides how much of the profit to retain for use in the following periods and how much to pay out to its equity investors as dividend d. The resources available to be paid out to equity investors is equal to $n_t + \pi_t - n_{t+1}$. To be consistent with the corporate finance literature (such as Hennesey and Whited 2007), I assume that issuing equity is a costly source of financing. The bank has to issue equity when $n_t + \pi_t - n_{t+1} < 0$. For each unit of equity raised, the bank has to pay a quadratic financing cost of $(\phi_2/2)(n_t + \pi_t - n_{t+1})^2$ where ϕ_2 is a parameter. Therefore, the bottom line amount of dividends paid to the equity investors is

$$d_t = n_t + \pi_t - n_{t+1} - \phi_1 \Big(\frac{i_t}{a_t^r} - \delta \Big)^2 a_t^r - \mathbb{1}_{\{n_t + \pi_t - n_{t+1} < 0\}} \frac{\phi_2}{2} (n_t + \pi_t - n_{t+1})^2,$$

where $d < 0$ corresponds to the bank issuing equity.

Finally, the bank faces a capital requirement constraint so that a certain proportion of the asset holding needs to be backed by its equity.

$$n_{t+1} \geq \xi a_{t+1}^r.$$

I also assume that the assets are risk-weighted when they go into the capital requirement constraint so that each type of asset will take up different amount of space in the constraint.[7] In particular, while the risky asset gets the full weight, the safe asset gets no weight when calculating the risk-adjusted asset. The capital requirement level parameter ξ in the model is a key policy variable. By varying the level of ξ, I can experiment what the effect of increasing regulatory capital requirement is on the real economy.

[7]Risk-based capital requirement is a standard feature in macroprudential policies. For example, according to Basel I Accord that was established in 1988, low-risk government debt got 0 percent weight while C&I loans got 100%. See for example Greenwood et al. (2017).

The bank solves the following problem.

$$\max_{\{a^r_{t+1},a^s_{t+1},n_{t+1},m_{d,t+1},d_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_t d_t$$

$$\begin{aligned}
\text{subject to } d_t + n_{t+1} = & \underbrace{(1-\delta)a^r_t + z^r_t (a^r_t)^\alpha}_{\text{return on risky asset}} + \underbrace{(1+r^s)a^s_t}_{\text{return on safe asset}} \\
& \underbrace{-(1+r_t)m_{d,t}}_{\text{interest payout}} \underbrace{-\phi_1 \left(\frac{a^r_{t+1} - (1-\delta)a^r_t}{a^r_{t+1}} - \delta \right)^2 a^r_t}_{\text{capital adjustment cost}} \\
& \underbrace{-\mathbb{1}_{\{n_t+\pi_t-n_{t+1}<0\}} \frac{\phi_2}{2} (n_t + \pi_t - n_{t+1})^2}_{\text{equity financing cost}} \\
& a^r_{t+1} + a^s_{t+1} = n_{t+1} + m_{d,t+1} \\
& n_{t+1} \geq \xi a^r_{t+1} \\
& \Lambda_t = \beta^t \left(\frac{c^e_t}{c_0} \right)^{-\gamma_c} \\
& a^r_{t+1}, a^s_{t+1}, n_{t+1}, m_{d,t+1} \geq 0 \\
& a^r_0, a^s_0, m_{d,0}, d_0 \text{ given.}
\end{aligned}$$

The bank chooses their asset portfolio a^r_{t+1} and a^s_{t+1} , the financing method n_{t+1} and $m_{d,t+1}$, and the dividend payout d_t in order to maximize the present value of the dividend stream. As the equity investors are the owners of the bank, the bank discounts its dividend stream using the equity investors' intertemporal marginal rate of substitution as its stochasitic discount factor. The first line of the constraint is the budget constraint of the bank. The bank finances dividend payout d_t and the stock of net worth n_{t+1} using the returns from risky and safe asset investment minus deposit interest payout, the capital adjustment cost and the equity financing cost. The second constraint makes sure that the asset side of the balance sheet equal the liability side. Finally, the third constraint is the capital requirement constraint that is occasionally binding.

3.4. Definition of the equilibrium

A competitive equilbrium is a set of prices $\{p_t, r_t\}_{t=1}^{\infty}$ and allocations $\{c^e_t, s_{t+1}\}_{t=0}^{\infty}$, $\{c^d_t, m_{d,t+1}, m_{c,t+1}\}_{t=0}^{\infty}$, and $\{d_t, a^r_{t+1}, a^s_{t+1}, n_{t+1}, m_{d,t+1}\}_{t=0}^{\infty}$ such that

- Given prices $\{p_t, r_t\}_{t=1}^{\infty}$ and dividend $\{d_t\}_{t=1}^{\infty}$, the allocation $\{c^e_t, s_{t+1}\}_{t=0}^{\infty}$ maximizes the equity investors' lifetime utility.

- Given prices $\{r_t\}_{t=1}^{\infty}$, the allocation $\{c_t^d, m_{d,t+1}, m_{c,t+1}\}_{t=0}^{\infty}$ maximizes the depositors' lifetime utility.
- Given prices $\{r_t\}_{t=1}^{\infty}$ and the initial capital structure $\{a_0^r, a_0^s, m_{d,0}, n_0\}$, $\{a_t^r, a_t^s, n_t, m_{d,t}\}_{t=1}^{\infty}$ maximizes the sum of present discounted dividends.
- Consumption goods market clears.
- Bank equity market clears.
- Deposit market clears.

3.5. How the Model Relates to the Empirical Findings

In this subsection, I analytically show how the model embeds the essence of findings from the empirical result in Kim (2023). In order to make the model simpler for analytical results, I focus on the nonstochastic steady state equilibrium of the economy.

The first order conditions of the depositors' problem with respect to the deposit in the non stochastic steady state is as follows:

$$\text{FOC w.r.t. deposit holding: } 1-\beta(1+r)-\psi_m c^{\gamma_c}(1-\theta)M^{-\gamma_m}\left(\frac{M}{m_d}\right)^{1-\eta}=0$$

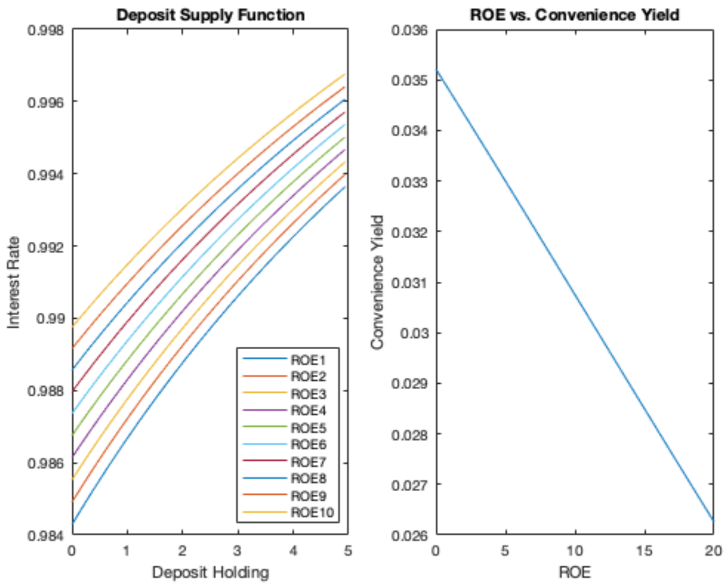
$$\Leftrightarrow 1+r=\frac{1}{\beta}-\underbrace{\frac{\psi_m c^{\gamma_c}(1-\theta)M^{-\gamma_m}\left(\frac{M}{m_d}\right)^{1-\eta}}{\beta}}_{\text{convenience yield}>0}. \tag{1}$$

Looking at Equation (1), if the convenience yield term is not there, we have a standard theoretically implied interest rate where the rate is equal to the inverse of the depositors' time discount factor. If the depositors get direct utility from holding the deposit, we can see that all else equal, the interest rate r is lower than when the depositors do not. The depositors are willing to give up some interest income for the deposit's use as money in transactions. However, when the deposit is information sensitive; i.e. $\theta = 1$, the convenience yield term disappears and the depositors require a higher interest rate as the deposit has no use as money in transactions.

Let's further simplify the Equation (1) by assuming that $\eta = 1$ so that cash and deposit are perfect subsitutes, $\gamma_c = 0$ so that depositors are risk neutral, and $\gamma_m = 1$. Then we have a simplified depositors' supply function for deposit as follows:

$$1+r=\frac{1}{\beta}-\frac{\psi_m\left(1-\frac{1}{1+\exp(-\kappa ROE)}\right)}{\beta\left(m_c+\left[1-\frac{1}{1+\exp(-\kappa ROE)}\right]m_d\right)}. \tag{2}$$

FIG. 3. Deposit Supply Function and Convenience Yield



The Equation (2) shows that the ROE of the bank controls the supply elasticity of the deposit. As the ROE of the bank goes up, the depositors' supply of deposit becomes more and more elastic until when the deposit turns information sensitive; i.e. $\theta = 1$, and the supply for the deposit becomes perfectly elastic.

The left panel of Figure 3 plots the depositors' supply function for deposit for each level of ROE. We can see that as ROE increases, the supply function shifts in as it becomes more elastic. For the same level of interst rate offered, if ROE of the bank goes up, the depositors are willing to supply less deposit to the bank. This characteristic of the depositors' supply function of deposit is consistent with what we found in data: we saw that an increase in ROE of dealer banks led to a lower supply of deposits from the MMFs.

In order to incentivize the depositors to keep holding the same level of deposits at a higher level of ROE, the bank has to offer a higher interest rate. This means at a higher level of ROE, the convenience yield that the the bank enjoys decreases as the right panel of Figure 3 suggests. From the model's perspective, an increase in ROE increases θ, which decreases the level of utility that the depositors get from holding the deposit as we can see from the period utility function of the depositors:

$$u(c_t^d, m_{c,t+1}, m_{d,t+1}) = u(c_t^d) + \psi v\left(\left[m_{c,t+1}^{\eta} + \underbrace{\left\{1 - \frac{1}{1+\exp(-\kappa ROE)}\right\}}_{\text{This term is decreasing in ROE}} m_{d,t+1}^{\eta}\right]^{\frac{1}{\eta}}\right).$$

We saw that an increase in ROE of the dealer banks led to a increase in the spread between the privately produced safe asset yield and the Treasury yield, which meant that the convenience yield that the dealer banks enjoyed decreased.

4. CALIBRATION

TABLE 1.

Parameters

	Description	Value	Source
β	Subjective discount factor	0.98	Risk-free rate of 2%
γ_c	Risk aversion	2	Standard
ξ	Capital requirement	0.08	Basel II standard
ρ	TFP autocorrelation	0.93	Argentinian data
σ	TFP volatility	0.06	Argentinian data
η	Elasticity of substitution deposit/cash	0.875	Wang (2022)
δ	Depreciation rate	0.1	Standard
ϕ_2	Cost of equity issuance	0.1	Standard
r_s	Safe asset return	0.02	Standard
α	Decreasing returns to scale on production	0.33	Internal calibration
ϕ_1	Capital adjustment cost	0.21	Internal calibration
κ	Responsiveness of θ to ROE	0.06	Internal calibration
$\bar{\theta}$	θ threshold for a crisis	0.55	Internal calibration
ψ	Utility weight on money	0.33	Internal calibration
γ_m	Curvature of the money utility function	2.15	Internal calibration

I calibrate the model to the Argentinian economy, an emerging economy that has been subject to numerous financial crises over the last few decades. According to the systemetic banking crises database published in Laevan and Valencia (2012), in the span of about 20 years from 1980 to 2001, Argentina experienced four banking crises. With this timeframe in mind, I calibrate the model to target the Argentinian economy between the years 1970 and 2018 so that the calibrated model can fully contain the build-up towards and the recovery from Argentinian financial crises.

Overall, there are 15 parameters in the model. I divide the parameters into two sets. The first set contains conventional parameters that either has direct counterparts in the literature or can be directly pinned down from the data. I fix these parameters to appropriate values. The second set contains parameters that are either unique to the model or are related to various aspects of a crisis in the model. I calibrate these parameters to match relevant data moments.

4.1. Externally Calibrated Parameters

The first panel of Table 1 shows the set of parameters that I set to fixed values. I assign fixed values to nine parameters. First, for preference parameters, I use standard values in the macro literature. The subjective discount factor for the equity invesotrs and the depositors, β, is set to 0.98, which implies an annual risk-free rate of roughly 2%. I set the coefficient of relative risk aversion, γ_c, to be 2, which makes the equity investors and the depositors be averse to consumption fluctuation. I follow the literature and set the initial capital requirement parameter, ξ, to 8%.

The productivity process of the bank's risky asset follows an AR(1) process as indicated before. There are two parameters associated with this productivity process, ρ and σ, that correspond to the autocorrelation and the volatility of the process, respectively. I estimate ρ and σ using the Argentinian TFP process data provided in the Penn World Table. The estimation results in $\rho = 0.93$ and $\sigma = 0.07$.

The parameter η determines the elasticity of subsitution between cash and deposit. I set η to 0.875, which is the that Wang (2022) calculated in his paper, targeting 12% money (called cash in my model)-deposit ratio and 70% deposit pass-through rate. Wang (2022) estimates this value using the US data. Ideally, there would be Argentinian data available for me to estimate η for the Argentinian household. However, in this paper, due to the data availability, I directly use the value estimated in Wang (2022). Therefore, an implicit assumption that I am making is that the US households and Argentinian households share the same elasticity of subsitution between cash and deposit. η value of 0.875 makes the cash and deposit imperfect substitutes. Finally, for the rate of return on the safe asset in the model, I set it to equal the risk-free rate of 2%.

4.2. Internally Calibrated Parameters

I internally calibrate the remaining six parameters of the model to match data moments that are related to 1) the macroeconomy of Argentina, 2) the demand for money in Argentina, and 3) the crises in Argentina using simulated methods of moments. The second panel of Table 1 shows the calibrated parameter values, and Table 2 shows the five data moments of interest that I am targeting.

TABLE 2.

Targeted Moments

Parameter	Target Description	Model	Data
ψ	Mean proportion of convenience yield in deposit rate	0.324	0.365
γ_m	Vol(proportion of convenience yield in deposit rate)	0.152	0.176
$\bar{\theta}$	Crisis frequency	0.095	0.082
κ	Average θ over time in Krisnamurthy and Li (2021)	0.561	0.570
α	Capital-output	4.613	4.419
ϕ_1	Corr(inv growth, output growth)	0.18	0.28

The parameter α determines the decreasing returns to scale of the production function. I calibrate α to match the average capital to output ratio of Argentina during the relevant period that I obtain from the Penn World Table. The parameter ϕ_1 controls the cost that the bank has to pay in order to adjust the level of the risky asset. As the risky asset in my model is analogous to a productive capital in the macro literature, I calibrate ϕ_1 to match the correlation between the investment growth and the output growth in Argentina that I obtain from the Penn World Table.

Parameters κ that determines the responsiveness of θ to ROE and $\bar{\theta}$ that determines the threshold for the θ variable jointly determine the frequency of a crisis. I calibrate κ and $\bar{\theta}$ to match the frequency of a financial crisis in Argentina and the measure of average liquidity provision provided by private money that is estimated in Krishnamurthy and Li (2021).

According to Laevan and Valencia (2012), there have been four crises between the years of 1970 and 2018: March 1980, December 1989, January 1995, and November 2001. I calculate the crisis frequency to be 8.2% of the available months.

Using the historical data, Krishnamurthy and Li (2021) directly estimate what the historical average value of θ is. They estimate the relative quantity of liquidity service provided between government bonds is about 1.5 times bigger than that provided by privately produced debt excluding traditional bank deposits. I think of cash in my model to be the most liquid form of money thus think of it as the most comparable to the government bonds. If this is the case, the result in Krishnamurthy and Li (2021) indicates that θ has to be roughly 0.57. I calibrate $\bar{\theta}$ and κ to match the crisis frequency as well as the estimate given in Krishnamurthy and Li (2021).

Parameters ψ and γ_m determines the convenience yield that the deposit earns for providing liquidity services to the depositors. Convenience yield is the spread between a yield of an asset that gives a liquidity benefit and an asset that does not. In order to calculate the convenience yield in the model, I assume that there exists an alternative deposit that does not provide any liquidity benefit. Suppose that the alternative deposit pays an interest rate of $\tilde{r}_t$. Then the first order condition of the depositors' problem with respect to deposit holding yields the following equation:

$$1 - \beta \mathbb{E}_t \Big[\Big(\frac{c^d_{t+1}}{c^d_t} \Big)^{-\gamma_c} (1 + \tilde{r}_{t+1}) \Big] = 0,$$

as opposed to the equation from the first order condition of the depositors' problem with respect to deposit holding when the deposit does provide liquidity benefit:

$$1 - \beta \mathbb{E}_t \Big[\Big(\frac{c^d_{t+1}}{c^d_t} \Big)^{-\gamma_c} (1 + r_{t+1}) \Big] - \psi (c^d_t)^{\gamma_c} (1 - \theta_t) M_{t+1}^{-\gamma_m} \Big(\frac{M_{t+1}}{m_{d,t+1}} \Big)^{\frac{1}{\eta}} = 0.$$

I calculate the spread between r and $\tilde{r}$ to calculate the model-implied convenience yield.

Calculating the convenience yield for Argentina is a difficult task in and of itself. Krishnamurthy and Vissing-Jorgensen (2012) calculates the convenience yield as the spread between the yield on long-maturity Treasury bonds and Moody's Aaa rated long-maturity corporate bond yield. The underlying assumption is that the highly-rated corporate bonds and the Treasury bonds are both very unlikely to default. With the same level of safety between the two, the only difference between the two assets is that the Treasury bonds are more liquid than the highly-rated corporate bonds. The difference in yields between the two is therefore the convenience yield that the Treasuries command for exhibiting a more money-like characteristic. Krishnamurthy and Vissing-Jorgensen (2012) calculates the convinence yield to be 0.68%.

As there are no readily available aggregate measures of Argentinian corporate bonds as those provided by Moody's, calculating the convenience yield using exactly the same method that Krishnamurthy and Vissing-Jorgensen (2012) used in their paper is not feasible. However, I follow as closely as possible the method that Krishnamurthy and Vissing-Jorgensen (2012) used to come up with the Argentinian counterpart of the convenience yield.

Calculating the convenience yield boils down to calculating the spread between two assets that are similar in terms of safety and maturity but are different in terms of liquidity. The two Argentinian assets that I choose to calculate the spread of are the Argentinian soverign bond and the corporate bond of a state-owned oil company called YPF. [8]

These two bonds satisfy the two important criteria that were needed for a sound calculation of a convenience yield. First, the Argentinian sovereign bond and the YPF corporate bond share similar safety attributes. Just as the Treasuries and the Aaa bonds were equally unlikely to default, the Argentinian sovereign bond and the YPF corporate bond share similarly high likelihood of default. This is true especially because YPF is a state-owned company whose majority owner is the Argentinian government. Second, the Argentinian sovereign bond is more liquid than the YPF corporate bond.

I calculate the spread between the Argentinian sovereign bond and the YPF corporate bond with the same maturity that have been issued since 2012 when the renationalization happened. Both the time series of the Argentinian sovereign bond yield and the YPF corporate bond yield are obatined from Bloomberg. The mean of the convenience yield in Argentina is estimated to be 5.18% and the standard deviation is estimated to be 1.61%. Although at the first glance the magnitude of the convenience yield level seems high, considering that the average Argentinina soverign yield itself was around 15% in this time period as opposed to the Treasury yields in the single digit, I argue that 5.18% is about the right magnitude. The estimated first and second moments of the convenience yield of Argentina are used to calibrate liquidity related parameters γ_m that determines the curvature of the money utility function, and ψ that determines relative utility weight of the money utility function.

4.3. Model Validation

I test the performance of the model in different dimensions. First, I show if my model is able to reproduce various data moments that are related to Argentinian business cycle and crises that were not targeted during the calibration. Then I plot the simulated dynamics of the model in the window around the crisis period when θ equals 1 against the dynamics shown in the actual Argentinian data. Finally, I re-calibrate the model to

[8]YPF is Argentina's largest oil company. Argentina renationalized YPF by buying 51% of the company in 2012. See new articles such as https://www.nytimes.com/2012/04/17/business/global/argentine-president-to-nationalize-oil-company.html

Norwegian data and show that the re-calibrated model exhibits significantly less frequency of crises compared to the model calibrated to the Argentinian economy.

4.3.1. Targeted and Untargeted Moments

Table 2 shows that the model is sucessful in matching the targeted moments. Numbers produced by the model simulation that is on the model column of the table and numbers produced by the Argentinian data that is on the data column of the table coincide very well with each other.

TABLE 3.

Untargeted Moments

	Model Counterpart	Data	Model
Consumption to Output	$\mathbb{E}\left[\frac{c_t}{y_t}\right]$	0.753	0.823
Net Interest Margin	$\mathbb{E}[\alpha z a_r^{\alpha-1} - r]$	0.040	0.083
Investment to Capital	$\mathbb{E}\left[\frac{a_{t+1}^r-(1-\delta)a_t^r}{y_t}\right]$	0.024	0.100
M1 to M2	$\mathbb{E}\left[\frac{m_{c,t}}{m_{d,t}}\right]$	0.668	0.626
Vol(Y Growth)	$\text{Vol}(\Delta y_t)$	0.052	0.071
Vol(C Growth)	$\text{Vol}(\Delta c_t)$	0.061	0.012
Vol(I Growth)	$\text{Vol}(\Delta(a_{t+1}^r - (1-\delta)a_t^r))$	1.373	0.379
Corr(C Growth, Y Growth)	$\text{Corr}(\Delta c_t, \Delta y_t)$	0.928	0.692
Corr(I Growth, Y Growth)	$\text{Corr}(\Delta(a_{t+1}^r - (1-\delta)a_t^r), \Delta y_t)$	0.094	0.065
Corr(Crisis, Y Growth)	$\text{Corr}(\theta_t = 1, \Delta y_t)$	-0.304	-0.137
Corr(Crisis, C Growth)	$\text{Corr}(\theta_t = 1, \Delta c_t)$	-0.246	-0.714
Corr(Crisis, C Growth)	$\text{Corr}(\theta_t = 1, \Delta c_t)$	-0.196	-0.527

Notes: business cycle statistics are calculated using the Argentinian data on Penn World Table. Argentinian M1 and M2 data are from IMF's International Financial Statistics. Net interest margin data is from the World Bank's Global Financial Development Dataset.

For a model that features only one shock, the TFP shock, Table 3 shows that the calibrated model is able to produce simulated moments that are consistent with key untargeted moments related to Argentinian banking system, business cycle, and crises. We can first see in the first panel that the model can reproduce first moments of the Argentinian economy in relation to its business cycle and monetary base. In the following panels, we can see that the model can also reproduce second moments of the Argentinian economy very well in terms of its business cycles and its relation to crisis frequency.

4.3.2. Data vs. Model Dynamics

To validate that the model can replicate the dynamics of a real crisis, I plot the simulated dynamics of the model in the window around the crisis period when θ equals 1 against an actual Argentinian data in Figure 4. I identify crisis periods in the model simulations and compute the average of the variables across simulations. The solid blud line shows the average value of the variables and the red dashed lines above and below the blue line show the 95% confidence interval. The solid orange line shows the actual Argentinian data. The crisis year is set as year zero.

Figure 4 shows that the model reproduces the dynamics of a financial crisis in a reasonable way. In the first panel for example, we can see that from the peak of the output to the trough, the output decreases by about 22% in the simulation, which is close to the observed fall of about 23% in the data and is also consistent with findings from existing quantitative models calibrated to Argentinian data in papers like Perez (2018). The rest of the panels in Figure 4 consistently show that the dynamics as well as the magnitudes of the movements in key variables of the simulated model are consistent with the actual dynamics in data.

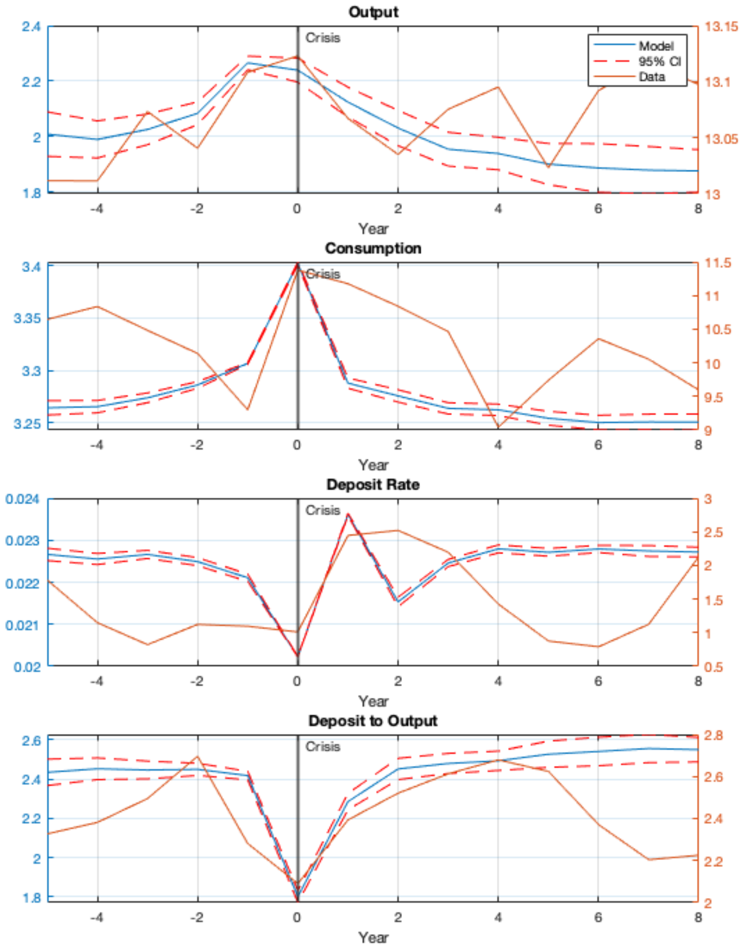
4.3.3. Alternative Calibration to the Norwegian Economy

For the final model validation, I re-calibrate the model to the Norwegian economy. According to Laevan and Valencia (2012), there was one banking crisis in Norway in 1991 during the time period of 1970 to 2018. For model validation, I internally calibrate four parameters: macro-related parameters α and ϕ_1 as well as liquidity-related parameters ψ_m and γ_m, to relevant Norwegian data moments while fixing crisis-related parameters κ and $\bar{\theta}$ to the ones calibrated to the Argentinian economy.

The reasoning for this calibration exercise is as follows. As I mentioned, parameters κ and $\bar{\theta}$ jointly determines the frequency of a crisis. I argue that with everything else in the model calibrated to the Norwegian economy except for crisis-related parameters, the frequency of a crisis in the re-calibrated model model should be a lot less than the model calibrated solely to the Argentinian economy. Essentially, the crisis frequency is an additional untargeted moment that the model is going to try to replicate.

Details of the calibration to the Norwegian economy is relegated to Appendix A.1, but the crisis frequency of the re-calibrated model is 0.87%. This frequency is a lot less than 8.2%, which is what I targeted as the crisis frequency of Argentina.

FIG. 4. Model vs. Data Dynamics Around a Crisis



Notes: This figure plots the dynamics of different variables around the crisis episodes in the simulated model and the actual data. For the model dynamics, I identify crisis periods as when $\theta = 1$ and compute the average of the variables across simulations. The solid blue line shows the average values of the variables and the red dashed lines show the 95% confidence interval. The simulated variables as well as the variables from the data are all logged.

5. EFFECT OF A CAPITAL REQUIREMENT INCREASE ON THE REAL OUTPUT

Academic research that explores the market for privately produced money existing outside the retail banking system has been active ever since the collapse of this market was the central contributor to the Global Financial Crisis of 2007 and 2008. The contribution of this paper's quantiative model is to embed the research that has been done in this area as well as the empirical facts that I uncovered in Kim (2023) into a standard macro-finance model so that we can have a laboratory on which we can conduct various policy experiments.

With the calibrated model, I run the policy experiment of changing the regulatory capital requirement. Changes in the capital requirement affects the bank through its capial requirement constraint

$$n \geq \xi a^r,$$

where a certain proportion of the bank's risky asset holding needs to be backed by the bank's equity. For the experiment, I re-solve the model changing ξ from 1% to 25%. Then I investigate the effect of an increase in regulatory capital requirement on the real economy, namely how it affect the bank's ability to intermediate funds from the funding providers to the productive agents in the economy.

5.1. Three Channels Through Which Changes in the Capital Requirement Affect the Real Economy

In my model, there are three channels through which the changes in the regulatory capital requirement affects a bank's ability to intermediate funds to the real economy.

First, an increase in capital requirement decreases the real output through what I call the *costly equity channel.* An increase in capital requirement makes the bank to reshuffle the liability side of its balance sheet where they substitute debt financing with equity financing. There exists a concensus in the corporate finance literature that equity financing is a more costly form of financing than debt.[9] This means that an increase in capital requirement increases the cost of capital of the bank. This deteriorates the bank balance sheet leading to a decrease in lending to the real economy and the real output.

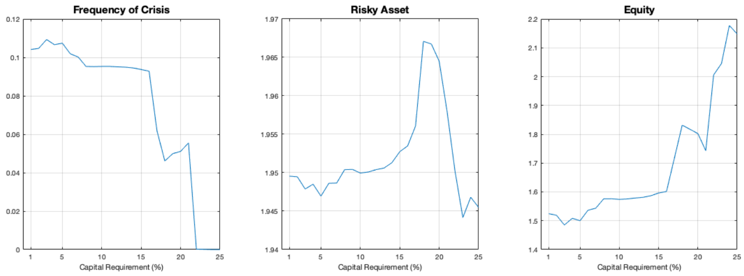
[9]There are various reasons given why equity is a more costly form of financing than debt. One significant reason given for example in papers like Hanson, Stein, and Kashyap (2010) is the tax benefit that the financial sector especially enjoys when it finance itself with debt over equity.

On the other hand, an increase in capital requirement increases the real output through what I call the *crisis potential channel*. An increase in capital requirement increases the equity buffer of the bank, which means the debt holders fear adverse selection less as the bank has more skin in the game. This means the frequency of the bank debt turning information sensitive decreases which means the frequency of a crisis decreases. With the potential for the capital requirement constraint binding decreasing as crisis periods are almost always the periods when the constraint binds, the bank increases lending to the real economy which increases output of the economy.

Finally, the third channel through which an increase in capital requirement affects the real output is what I call the *moneyness channel*. If we look back at the first costly equity channel, an increase in capital requirement increases the cost of capital because equity is a more expensive form of financing than debt. However, this is true only under the assumption that the endogenous response of the cost of debt financing to an increase in capital requirement is minimal. However, as we have seen in many of the financial crises, this is not the case. For example, we saw the short-term financing rate such as the repo rate skyrocketing during the 2008 financial crisis when the demand for these assets was suddenly nonexistent due to it turning information sensitive and its convenience yield being close to zero. An increase in the capital requirement decreases crisis frequency and increases the number of period when the deposit retains its moneyness. This means it increases the average convenience yield over time, which means on average, the short-term financing cost decreases. This dampens the increase in the cost of capital due to the costly equity channel leading to a higher lending to the real economy and a higher real output.

An increase in the regulatory capital requirement affects the real economy through these three offsetting channels. If the costly equity channel dominates, an increase in the capital requirement decreases the real output while if the crisis potential channel and the moneyness channel combined dominate, an increase in the capital requirement increases the real output. With the model calibrated to real Argentinian data, I can investigate which channel dominates for each level of the capital requirment, which means I can figure out what the optimal level of capital requirement is in terms of maximizing the real output of the economy.

FIG. 5. Effect of a Change in the Capital Requirement on the Crisis Frequency



Notes: This figure shows the simulated first moments of different variables when the model at a different level of capital requirements from a 1% capital requirement to a 25% capital requirement. All variables are logged.

5.2. Counterfactual Experiment: Changing the Capital Requirement

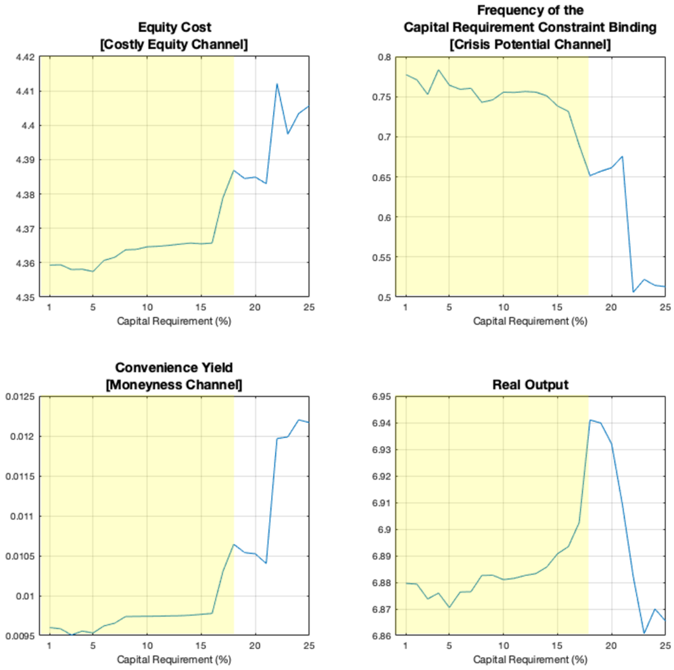
Figures 5 and 6 plot the simulated first moments of different variables of the model when the model is solved for different levels of capital requirements from a 1% capital requirement to a 25% capital requirement.

5.2.1. How an Increase in the Capital Requirement Affects the Crisis Frequency

Figure 5 plots variables that are related to the crisis frequency and the direct determinants of a crisis which are the bank's risky asset and equity holdings. In the first panel of Figure 5, the crisis frequency almost monotonically decreases as the capital requirment is increased. We can see that the crisis frequency decreases even though the bank is getting riskier on the left hand side of its balance sheet.

The lower crisis frequency and a larger holding of the risky asset can be reconciled by the bank having to hold a higher level of equity as shown in the third panel of Figure 5. A higher profitability of the bank due to a larger holding of the risky asset is counteracted by a larger holding of equity. This means the effect that the higher capital requirment has on the bank's ROE is minimal as both the denominator and the numerator of ROE increase. Comparing this result to results in the banking theory literature, as an increase in the capital requirement increases the bank's skin in the game, the depositors fear the adverse selection less, making the deposit information insensitive for a longer periods of time.

FIG. 6. Effect of a Change in the Capital Requirement the Real Output Through Different Channels



Notes: This figure shows the simulated first moments of different variables when the model at a different level of capital requirements from a 1% capital requirement to a 25% capital requirement. The first three panels shows the simulated moments for the variables that proxies for the three channels that the changes in the capital requirement has on the real output that I explained in Section 5.1. The yellow-shaded region is where the crisis potential channel and the moneyness channel dominate the costly equity channel. The non-shaded region is where the costly equity channel dominates the crisis potential channel and the moneyness channel. The optimal level of capital requirement is therefore 18% when it comes to maximizing the rel output of the economy. All variables are logged.

5.2.2. How an Increase in the Capital Requirement Affects the Real Economy Through Three Channels

In Figure 6, I plot three variables that proxy for the three different channels that the changes in the capital requirement has on the real output that I explained in Section 5.1.

In the first panel of Figure 6, we can see that the equity financing cost increases as the capital requirement increases. In order to satisfy a higher capital requirement level, the bank has to issue more equity especially following crises as equity gets wiped out when the depositors run from the bank. The bank pays a quadratic equity issuance cost when it is issuing equity, so the more it has to issue, the more resources it has to expend, which deteriorates its balance sheet. This first panel of Figure 6 represents the costly equity channel of the effect of the increase in the capital requirement. It puts a downward pressure on the real output as the bank has a lower amount of resources available to fund the real economy.

In the second panel of Figure 6, we can see that the frequency of the capital requirement constraint binding decreases as the capital requirement level increases. This is natural as the capital requirement constraint binds during the crisis, and the crisis frequency decreases as the capital requirement increases as we saw in Figure 5. Therefore, the second panel of Figure 6 represents the crisis potential channel of the increase in the capital requirement as it enables the bank's ability to intermediate resources to the real economy with the capital requirement constraint non-binding.

In the third panel of Figure 6, we can see that the convenience yield that the bank enjoys increases as the capital requirement level increases. In other words, the debt financing cost of the bank decreases as the capital requirement level increases. As we saw in Figure 5, an increase in the capital requirement decreases the frequency of a crisis, which means the number of periods that the deposit carries a positive convenience yield increases. This benefits the bank by lowering its debt financing cost. Therefore, the third panel of Figure 6 represents the moneyness channel of the increase in the capital requirement as it enables the bank's ability to intermediate resources to the real economy.

Finally, in the fourth panel of Figure 6, we can see that the real output is maximized at the 18% capital requirement level. This means the crisis potential channel and the moneyness channel dominates the costly equity channel by lowering the debt financing cost until 18% capital requirement level. Beyond 18% capital requirement level, the bank has to issue too much equity, making the equity too costly. This results in the costly equity channel dominating the crisis potential and the moneyness channel beyond the 18% capital requirement level.

6. CONCLUSION

This paper seeks to understand the financial crisis from a perspective that it is an event when people run from privately produced safe asset that loses the role of money. I contribute to the discussion of how to regulate the market of privately produced safe assets and the financial intermediaries that produce them. Motivated by this empirical finding in Kim (2023), I built a quantitative macro-finance model where a lender's investment decision is affected by the profitability of the borrowers through its effect on an asset's moneyness. Using this model as a laboratory, I find that the optimal capital requirment that optimizes a bank's ability to intermediate fund to the real economy is around 18%.

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APPENDIX A

A.1. NORWAY CALIBRATION

As there are no readily available aggregate measures of Norwegian corporate bonds, I follow the same method that I used to calculate the convenience yield in Argentina to calculate the convenience yield in Norway.

Calculating the convenience yield boils down to calculating the spread between two assets that are similar in terms of safety and maturity but are different in terms of liquidity. Following the method for calculating the Argentinian convenience yield, the two Norwegian assets that I choose to calculate the spread of are the Norwegian soverign bond and the corporate bond of a state-owned oil company called Equinor.

I calculate the spread between the Norwegian sovereign bond and the Equinor corporate bond with the same maturity. Both the time series of the Norwegian sovereign bond yield and the Equinor corporate bond yield are obatined from Bloomberg. The mean of the convenience yield in Argentina is estimated to be 0.88% and the standard deviation is estimated to be 0.51%. The magnitude of the convenience yield in Norway looks to be a lot more aligned with the magnitude of the convenience yield for developed countries as opposed to what we saw for Argentina. The estimated first and second moments of the convenience yield of Norway are used to recalibrate liquidity related parameters γ_m that determines the curvature of the money utility function, and ψ that determines relative utility weight of the money utility function.

The parameters related to Norway's macroeconomy are calibrated to their Norwegian counterparts. The crisis-related parameters, κ and $\bar{\theta}$, are explicitly set to the value calibrated for Argentina. We see in the Laevan and Valencia (2012) dataset that there was only one banking crisis in Norway during the same time span as opposed to Argentina that had four. I use the frequency of a crisis as another untargeted moment and argue that if the model simulation with only the crisis-related parameters set to the Argentinian value results in less frequency of a crisis, the model passes the bar in terms of validation.

Table 2 shows the calculated untargeted moments. We can see in the first line that the model is in a crisis state in only 0.87% of time periods, which is far less than 8.4% for Argentina. I argue that this result provides another validation that the model provides an appropriate laboratory to study various policy implications of financial crises.

TABLE 1.

Targeted Moments

Parameter	Target Description	Model	Data
ψ	Mean proportion of convenience yield in deposit rate	0.324	0.365
γ_m	Vol(proportion of convenience yield in deposit rate)	0.152	0.176
κ	Average θ over time in Krisnamurthy and Li (2021)	0.561	0.570
α	Capital-output	4.613	4.419
ϕ_1	Corr(inv growth, output growth)	0.18	0.28

A.2. MODEL SOLUTION

The depositors' problem is as follows:

$$\max_{\{c_t, m_{d,t+1}, m_{c,t+1}\}_{t=0}^{\infty}} \mathbb{E}_0\Big[\sum_{t=0}^{\infty}\beta^t\Big\{u(c_t^d)+\psi v(M_{t+1})\Big\}\Big]$$

$$\text{such that } c_t^d + m_{c,t+1} + m_{d,t+1} = (1+r_t)m_{d,t} + m_{c,t}\ \forall t$$

$$M_{t+1} = \Big(\theta_t m_{c,t+1}^{\eta} + (1-\theta_t) m_{d,t+1}^{\eta}\Big)^{\frac{1}{\eta}}$$

$$\theta_t = \begin{cases} \frac{1}{1+\exp(-\kappa(ROE_t))} & \text{if } \frac{1}{1+\exp(-\kappa(ROE_t))} < \bar{\theta} \\ 1 & \text{if } \frac{1}{1+\exp(-\kappa(ROE_t))} > \bar{\theta} \end{cases}$$

$$m_{c,t+1}, m_{d,t+1} \geq 0$$

$$m_{c,0}, m_{d,0} \text{ given}$$

TABLE 2.

Norway Untargeted Moments

	Model Counterpart	Data	Model
Crisis Frequency	$\Pr(Crisis)$		0.87%
Consumption to Output	$\mathbb{E}\left[\frac{c_t}{y_t}\right]$	0.516	0.460
Net Interest Margin	$\mathbb{E}\left[\alpha z_t (a_t^r)^{\alpha-1} - r_t\right]$	0.022	0.047
Investment to Capital	$\mathbb{E}\left[\frac{a_{t+1}^r-(1-\delta)a_t^r}{a_t^r}\right]$	0.028	0.101
Vol(Output Growth)	$\text{Vol}(\Delta y_t)$	0.018	0.072
Vol(Consumption Growth)	$\text{Vol}(\Delta c_t)$	0.016	0.008
Vol(Investment Growth)	$\text{Vol}(\Delta(a_{t+1}^r - (1-\delta)a_t^r))$	0.177	0.557
Corr(Consumption, Output)	$\text{Corr}(c_t, y_t)$	0.983	0.469
Corr(Investment, Output)	$\text{Corr}((a_{t+1}^r - (1-\delta)a_t^r), y_t)$	0.492	0.228
Corr(Crisis, Output Growth)	$\text{Corr}(\mathbb{1}\{\theta \geq \bar{\theta}\}, \Delta y_t)$	0.016	-0.04
Corr(Crisis, Consumption Growth)	$\text{Corr}(\mathbb{1}\{\theta \geq \bar{\theta}\}, \Delta y_t)$	0.015	0.239
Corr(Crisis, Investment Growth)	$\text{Corr}(\mathbb{1}\{\theta \geq \bar{\theta}\}, \Delta y_t)$	-0.074	-0.111

Notes: business cycle statistics are calculated using the Norwegian data on Penn World Table. Net interest margin data is from the World Bank's Global Financial Development Dataset.

Plugging in the budget constraint to the objective function and writing the Lagrangian, the problem becomes

$$\mathcal{L} = \max_{\{m_{c,t+1}, m_{d,t+1}\}_{t=0}^{\infty}} \mathbb{E}_0\Big[\sum_{t=0}^{\infty} \beta^t \Big(\frac{[(1+r_t)m_{d,t} + m_{c,t} - m_{c,t+1} - m_{d,t+1} - p_t s_{t+1}]^{1-\gamma_c}}{1-\gamma_c}$$

$$+ \psi_m \frac{M_{t+1}^{1-\gamma_m}}{1-\gamma_m} + \lambda_{c,t} m_{c,t+1} + \lambda_{d,t} m_{d,t+1}\Big)\Big]$$

First order conditions with respect to deposit and cash holdings are as follows:

$$[m_{c,t+1}]\ \beta^t\Big[-c_t^{-\gamma_c} + \psi_m M_{t+1}^{-\gamma_m}\theta_t\Big(\frac{M_{t+1}}{m_{c,t+1}}\Big)^{1-\eta} + \lambda_{c,t}\Big] + \mathbb{E}_t\beta^{t+1}\Big[c_{t+1}^{-\gamma_c}\Big] = 0$$

$$[m_{d,t+1}]\ \beta^t\Big[-c_t^{-\gamma_c} + \psi_m(1-\theta_t) M_{t+1}^{-\gamma_m}\Big(\frac{M_t}{m_{d,t}}\Big)^{1-\eta} + \lambda_{d,t}\Big] + \mathbb{E}_t\beta^{t+1}\Big[c_{t+1}^{-\gamma_c}(1+r_{t+1})\Big] = 0$$

Rearranging, we have the following two Euler equations:

$$1 = \beta\mathbb{E}_t\Big[\Big(\frac{c_{t+1}}{c_t}\Big)^{-\gamma_c}\Big] + \psi_m c_t^{\gamma_c} M_{t+1}^{-\gamma_m}\theta_t\Big(\frac{M_{t+1}}{m_{c,t+1}}\Big)^{1-\eta} + \lambda_{c,t}c_t^{\gamma_c}$$

$$1 = \beta\mathbb{E}_t\Big[\Big(\frac{c_{t+1}}{c_t}\Big)^{-\gamma_c}(1+r_{t+1})\Big] + \psi_m c_t^{\gamma_c} M_{t+1}^{-\gamma_m}(1-\theta_t)\Big(\frac{M_{t+1}}{\theta_t m_{d,t+1}}\Big)^{1-\eta} + \lambda_{d,t}c_t^{\gamma_c}$$

The bank's problem is as follows:

$$\begin{aligned}
&\max_{\{l_{t+1},s_{t+1},n_{t+1},m_{d,t+1},d_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_t d_t \\
&\text{such that } d_t + n_{t+1} = (1-\delta)a_t^r + z_t^r(a_t^r)^\alpha + (1+r^s)a_t^s \\
&\qquad - (1+r_t)m_{d,t} - \phi_1\Big(\frac{a_{t+1}^r - (1-\delta)a_t^r}{a_{t+1}^r} - \delta\Big)^2 a_t^r \\
&\qquad - \mathbb{1}_{\{n_t+\pi_t-n_{t+1}<0\}}\frac{\phi_2}{2}(n_t+\pi_t-n_{t+1})^2 \\
&a_{t+1}^r + a_{t+1}^s = n_{t+1} + m_{d,t+1} \\
&n_{t+1} \geq \xi a_{t+1}^r \\
&\Lambda_t = \beta^t\Big(\frac{c_t^e}{c_0^e}\Big)^{-\gamma_c} \\
&a_{t+1}^r, a_{t+1}^s, n_{t+1}, m_{d,t+1} \geq 0 \\
&a_0^r, a_0^s, m_{d,0}, d_0 \text{ given}
\end{aligned}$$

Plugging in the first and the second constraints into the objective function and writing down the Lagrangian, we have

$$\begin{aligned}
\mathcal{L} = \max \beta^t\Big(\frac{c_t}{c_0}\Big)^{-\gamma_c}\Big[&(1-\delta)a_t^r + z_t(a_t^r)^\alpha + (1+r^s)a_t^s \\
&- (1+r_t)m_{d,t} - a_{t+1}^r - a_{t+1}^s + m_{d,t+1} - \phi_1\Big(\frac{a_{t+1}^r-(1-\delta)a_t^r}{a_{t+1}^r} - \delta\Big)^2 a_{t+1}^r \\
&- \frac{\phi}{2}(n_t + \pi_t - a_{t+1}^r - a_{t+1}^s + m_{d,t+1})^2\Big] \\
&+ \mathbb{E}_t\beta^{t+1}\Big(\frac{c_{t+1}}{c_0}\Big)^{-\gamma_c}\Big[(1-\delta)a_{t+1}^r + z_{t+1}(a_{t+1}^r)^\alpha + (1+r^s)a_{t+1}^s \\
&- (1+r_{t+1})m_{d,t+1} - n_{t+2} - \phi_1\Big(\frac{a_{t+2}^r-(1-\delta)a_{t+1}^r}{a_{t+2}^r} - \delta\Big)^2 a_{t+2}^r \\
&- \frac{\phi}{2}(a_{t+1}^r + a_{t+1}^s - m_{d,t+1} + \pi_{t+1} - n_{t+2})^2\Big] \\
&+ \mu_t(a_{t+1}^r + a_{t+1}^s - m_{d,t+1} - \xi a_{t+1}^r) \\
&+ \lambda_{l,t}a_{t+1}^r + \lambda_{s,t}a_{t+1}^s + \lambda_{d,t}m_{d,t+1} + \lambda_{n,t}(a_{t+1}^r + a_{t+1}^s - m_{d,t+1})\Big]
\end{aligned}$$

First order conditions with respect to three variables are as follows:

$$
\begin{aligned}
[a^r_{t+1}]\ & \beta^t\Big(\frac{c_t}{c_0}\Big)^{-\gamma_c}\Big[-1-2\phi_1\Big(\frac{a^r_{t+1}-(1-\delta)a^r_t}{a^r_{t+1}}-\delta\Big)\frac{(1-\delta)a^r_t}{a^r_{t+1}} \\
& -\phi_1\Big(\frac{a^r_{t+1}-(1-\delta)l_t}{a^r_{t+1}}-\delta\Big)^2+\phi_2(n_t+\pi_t-n_{t+1})+\mu_t(1-\xi)+\lambda_{l,t}+\lambda_{n,t}\Big] \\
& +\mathbb{E}_t\Big[\beta^{t+1}\Big(\frac{c_{t+1}}{c_0}\Big)^{-\gamma_c}\Big(1-\delta+\alpha z_{t+1}(a^r_{t+1})^{\alpha-1} \\
& -2\phi_1\Big(\frac{a^r_{t+2}-(1-\delta)a^r_{t+1}}{a^r_{t+2}}-\delta\Big)a^r_{t+2}(1-\delta) \\
& -\phi(n_{t+1}+\pi_{t+1}-n_{t+2})(1+\alpha z_{t+1}(a^r_{t+1})^{\alpha-1})\Big]=0 \\
[a^s_{t+1}]\ & \beta^t\Big(\frac{c_t}{c_0}\Big)^{-\gamma_c}(-1+\phi(n_t+\pi_t-n_{t+1})+\mu_t+\lambda_{a^s,t}+\lambda_{n,t}) \\
& +\mathbb{E}_t\Big[\beta^{t+1}\Big(\frac{c_{t+1}}{c_t}\Big)^{-\gamma_c}\Big(1+r^s-\phi(n_{t+1}+\pi_{t+1}-n_{t+2})(1+r^s)\Big)\Big]=0 \\
[m_{d,t+1}]\ & \beta^t\Big(\frac{c_t}{c_0}\Big)^{-\gamma_c}(1-\phi(n_t+\pi_t-n_{t+1})-\mu_t+\lambda_{m_d,t}-\lambda_{n,t}) \\
& +\mathbb{E}_t\Big[\beta^{t+1}\Big(\frac{c_{t+1}}{c_t}\Big)^{-\gamma_c}\Big(-(1+r_{t+1})-\phi(n_{t+1}+\pi_{t+1}-n_{t+2})(-1-r_{t+1})\Big)\Big]=0
\end{aligned}
$$

Rearranging, we have Euler equations for the bank's problem:

Risky asset:

$$
\begin{aligned}
& -1+\phi(n_t+\pi_t-n_{t+1}) \\
& +\beta\mathbb{E}_t\Big[\Big(1-\delta+\alpha z^r_{t+1}(a^r_{t+1})^{\alpha-1}\Big)\Big(1-\phi(n_{t+1}+\pi_{t+1}-n_{t+2})\Big)\Big] \\
& +\mu_t(1-\xi)+\lambda_{l,t}+\lambda_{n,t}=0
\end{aligned}
$$

Safe asset:

$$
\begin{aligned}
& -1+\phi(n_t+\pi_t-n_{t+1}) \\
& +\beta\mathbb{E}_t\Big[(1+r^s)\Big(1-\phi(n_{t+1}+\pi_{t+1}-n_{t+2})\Big)\Big] \\
& +\mu_t+\lambda_{s,t}+\lambda_{n,t}=0
\end{aligned}
$$

Deposit:

$$
\begin{aligned}
&1-\phi(n_t+\pi_t-n_{t+1})\\
&-\beta\mathbb{E}_t\Big[(1+r_{t+1})\Big(1-\phi(n_{t+1}+\pi_{t+1}-n_{t+2})\Big)\Big]\\
&-\mu_t+\lambda_{m_d,t}-\lambda_{n,t}=0
\end{aligned}
$$

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