This dissertation includes three chapters discussing the importance of bank heterogeneity in monetary policy implementation using tools such as changes in the interest on reserve and the discount window on bank lending. The first two chapters focus on the implications of differences in government regulation, while the third chapter focuses on market competition. The first chapter assesses the effects of a policy reform changing the relative return of holding reserves on the reserves held by U.S. branches of foreign banks compared to conventional domestic banks, using difference-in-differences regression analysis. The second chapter studies the implications of dispersion in the relative return of holding reserves using a liquidity mismatch banking model with different sectors that can trade reserves in an over-the-counter market for federal funds. The model is used to study the effects of changes to regulation, policy rates, and other market conditions on the distribution of reserves across sectors and the federal funds rate. The third chapter documents changes in competition in the loan and deposit market over the last two decades and considers the implications for monetary policy tools using regression analysis compared to simulations of a Dynamic Stochastic General Equilibrium model.

Chapter 1, titled DEPOSIT INSURANCE AND PORTFOLIO DESIGN OF BANKS, reviews the distinct response of U.S. branches of foreign banks to the monetary policy of interest on reserve balances following a policy reform in 2011. The Federal Deposit Insurance Corporation (FDIC) reform changed the relative return of holding reserves for U.S. branches of foreign banks (foreign banks for short) compared to conventional domestic banks (domestic banks for short). The data show higher excess reserves held by foreign banks following this policy change. A fixed-effects model is used to measure the effect of a change in the FDIC policy on excess reserves held by each
sector. A difference-in-difference comparison suggests a difference of 0.16 in reserves to assets of domestic banks compared to foreign banks following the policy change and a more considerable gap of around 0.25 for banks with average assets holdings in the top 15 percentile. Furthermore, the event study confirms that these larger banks widely capture the impact of policy.

The next chapter, Chapter 2, titled BANK PORTFOLIO CHOICE AND MONETARY POLICY TRANSMISSION IN THE FACE OF A NEW FEDERAL FUNDS MARKET, studies the implications of differences in regulation of banks for monetary policy. The chapter presents an equilibrium model in the framework of Bianchi and Bigio (2022) to include two types of bank branches instead of one; domestic banks must hold deposit insurance, while U.S. branches of foreign banks cannot. Deposit insurance allows for a more stable funding source but attaches a higher balance-sheet cost. Calibration finds consistent predictions that explain the higher excess reserves and the sequential credit supply of foreign branches. Moreover, findings suggest that foreign branches are more responsive to monetary policy tools, such as interest on reserves, because their funding source is associated with higher volatility in deposit withdrawals. The monetary policy of changes to the corridor rates in the model is the same across all banks. Still, because U.S. branches of foreign banks face different tradeoffs than U.S domestic banks, monetary policy affects each sector differently.

Chapter 3, titled CHANNELS OF MONETARY POLICY WITH IMPERFECT COMPETITION IN THE BANKING SECTOR, uses a relatively new measure of market power proposed by Boone (2008) to estimate the implications of market power on the pass-through of monetary policy for two monetary policy channels. The lending channel and the deposits channel. Data suggest that market power is high in the deposit market and somewhat high in the loan market, with an incline in competition in both sectors in the last two decades preceding 2001. The paper evaluates monetary policy pass-through to deposit and lending rates given the competition across banks
using a Dynamic Stochastic General Equilibrium (DSGE) model with sticky prices. The central assumption of the model is that the pass-through depends on competition across banks. It includes banks with imperfectly competitive markups for loans to firms, markdowns of deposit rates to consumers, and a monetary policy authority that can either change the federal funds rate or the spread between the federal funds rate and the rate paid on excess reserves. The model estimations align with the empirical evidence suggesting banks will compensate on loan spreads to avoid the contraction in lending caused by higher policy rates, while deposits will fluctuate less, and therefore spreads may increase when market rates increase.
To my parents, Ada Rafaeli & Peter Stanley Stern
&
my beloved family
Dvir, Danielle, Yuval, and Refael
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1.1 Introduction

Banks rely on either retail or wholesale deposits to fund their operations. The Federal Deposit Insurance Corporation (FDIC) often insured retail deposits, issued mostly from households, while wholesale funding is more volatile and subject to sudden withdrawals. As it happens, the initial negative wholesale funding shock during the onset of the 2008 financial crisis led to significant fire sales and the great recession that followed Diamond & Rajan (2009).

In response to the extensive wholesale funding of banks prior to the financial crisis, one remedy was proposed as part of title II of the Dodd-Frank Act to change the assessment paid for deposit insurance. It changed from assessing total deposits to an asset-based assessment that increased the cost of overnight borrowing (Reform, 2010). Moreover, the Basel III committee required that banks hold more highly liquid assets pending both the banks' net cash flow and leverage ratios to shift the bank’s funding strategy to more stable deposits (Basel III, 2011). The implication is that need for precautionary reserves will decline with a shift from wholesale to retail deposits (Hein et al., 2012).

These policies applied only to FDIC-insured U.S. commercial banks, primarily domestic and some foreign branches. All domestic U.S. commercial banks hold a U.S. charter and are insured and regulated by the FDIC, while some U.S. branches of for-
eign banks are insured too. On the other hand, as of 2018, 197 branches and agencies of foreign banking organizations are not chartered, cannot hold retail deposits, and are therefore not affected by the new regulations. They hold over $2 trillion of domestic assets, accounting for around 15% of the U.S. total. However, new regulation may shift a foreign branch’s activity from a regulated subsidiary to a branch not under U.S. regulation because of lower funding costs so that the current number of branches may increase, as discussed by Fillat et al. (2018), DiSalvo (2019) and Berlin (2015).

This paper studies the effect of policy on bank portfolio choice of excess reserves using a differences-in-differences regression design that exploits the variation across the two banking sectors. Findings suggest that domestic banks decreased excess reserves to assets by as much as 0.16 following the reform compared to non-affected U.S. branches of foreign banks. With a more considerable impact on large banks holding an average portfolio exceeding $1 billion in assets.

The next part of the introduction includes a literature review, while the remainder of the chapter is organized as follows. Section 1.2 provides the data and empirical methodology, Section 1.3 presents the regression results, with Section 1.4 following an event-study of the regression equations. Section 1.5 concludes.

1.1.1 Previous Literature and the FDIC Reform

The new FDIC insurance assessment went into effect in April of 2011. It changed from assessing total deposits to assessing the average consolidated assets minus tangible equity (Tier 1 Capital). The purpose was to maintain a positive balance in funds even during a bank run and have a sustainable rate across credit cycles (Belton et al., 2020). The actual rate paid by a depository institution depends on the size and risk category of a bank. Whalen (2011) documents that the regulatory change shifted the assessment paid by large banks creating a more equitable fee across financial institutions. In practice, the new assessment may have or not have increased the
total amount of insurance banks paid. For example, Hein et al. (2012) found that the new policy increased insurance premiums to the large and complex structured banks that rely extensively on non-deposit (wholesale) funding sources. However, the total payment after policy reform depended on the level of substitution between wholesale to more stable retail deposits.

One of the first studies to document the implications of the new FDIC’s insurance policy on the portfolios of domestic and foreign banks was the paper by Kreicher et al. (2014). They find that the policy shifted funding of some domestic banks from abroad to more stable domestic deposits, while in contrast, foreign banks drew considerable net wholesale funding from abroad, which means that the net quantity effect of the policy is not apparent. Specifically, they estimate a 44-cent increase due to their own office for every dollar increase in reserves at non-chartered foreign banks following the central bank’s large asset purchases post the FDIC policy change. Hence, U.S. branches of foreign banks pull funds from abroad to increase their reserves account at the Fed.

Kotok (2011) estimates that the impact of the FDIC policy is equivalent to a 15-basis-point increase in rates by the Fed. His estimations imply that the reform results in a shock to markets of liquid funds, such as the federal funds market that support the fluctuations in wholesale deposits. To that end, I test the implications of the FDIC reform on the excess reserves held by banks, as the policy’s first channel would be to affect markets of liquid funds.

Concurrently with the FDIC’s new assessment base, large-scale asset purchases, coupled with interest on reserve balances, led to an abundance of reserves held by banks. Ennis & Wolman (2018) measure the aggregate liquidity in the banking system in response to monetary expansions of large-scale asset purchases following the financial crisis in 2008. They find that expansion efforts by the Fed in each of the three Quantitative Easing events correspond with indefinite higher liquidity so that,
in aggregate, the banking system as a whole did not substitute reserves for other forms of liquid assets. Moreover, DiSalvo (2019) documents that the share of assets held by foreign banks had not changed during this period, suggesting that cash assets substitute for other assets previously held by these institutions.\(^1\) The large increases of reserves at the time suggest that reserves serve as a good indicator of banks’ portfolio response to policy, as they are the major liquid asset on their portfolio.

Belton et al. (2020) investigate the impact of the FDIC policy, considering the policy act as a liquidity shock, as described by Kotok (2011), and results in an increase in the cost of wholesale funding for domestic banks with a corresponding decrease for foreign banks. So domestic banks face a negative liquidity shock while foreign banks face a positive liquidity shock. Using bank-specific data, they measure the policy impact on reserves and syndicated loans and find that U.S. branches of foreign banks reduced their participation in syndicated loans, even though the FDIC policy reform improved their access to wholesale funding. These banks reduced their lending in favor of “liquidity hoarding” (building up reserves), meaning that the differences in the increase in reserves during this period capture most of the effect of the FDIC reforms on banks.

This chapter revisits the question of the effect of the new policy on banks with excess reserves to assets as the outcome variable. Other studies, such as Belton et al. (2020) and Kreicher et al. (2014), fail to consider that U.S. branches of foreign banks are not required to hold reserves. So is true for smaller domestic banks. Excess reserves are not reported by banks adding a level of complicity to the analysis. However, its measure is adequate given that the required amount held by banks may depend on other factors such as the level of transaction accounts, current regulation, and reserve ratio policy. Because banks do not report excess reserves, I estimate

\(^1\)U.S. branches of foreign banks do not report all types of assets as domestic banks do. Therefore the portfolio asset composition of foreign banks reported in the next section includes other assets imputed by the data. The composition of assets over time supports the literature that suggests a substitution of reserves for other forms of non-liquid assets.
the required reserves of each bank and measure the difference across reserves and required reserves. With reserves documented to capture most of the liquidity shock of the policy, the current analysis contribution is to use a more comparable measure across banks by the change in the estimated excess reserves rather than total reserves. Estimations do not dispense with how the policy affected each sector; instead, they measure the differences in responses. Thus the policy could have affected one of the sectors and not the other, or it could have affected both simultaneously. Hence the outcome variable of excess reserves is used here to infer how policy impacts one sector compared to the other while controlling for the difference in the required ratios across banks.

1.2 Data and Empirical Methodology

1.2.1 Data

Figure 1.2.1 plots aggregate total assets and aggregate reserves to assets of insured and uninsured banks separately. The shaded areas in this figure are periods of Quantitative Easing using large-scaled asset purchases. Although we observe some differences across the two groups, it is evident that reserves increase following 2008 and continue to do so with each consecutive Quantitative-Easing event.

For this study, I use the quarterly Call Reports available from the Federal Reserve Bank of Chicago across the first quarter of 2005 through the first quarter of 2013, collected by the Federal Financial Institutions Examination Council (FFIEC), which is the interagency body responsible for examining financial institutions. FFIEC 031 is the Reports of Condition and Income for domestically chartered banks with foreign offices. FFIEC 041 is the equivalent form for domestically chartered banks without foreign offices. FFIEC 002 is the Report of Assets and Liabilities for branches and agencies of foreign banks that align with the other two forms.
Aggregate holdings of reserves of U.S. commercial banks insured by the FDIC (insured/domestic) and U.S. branches of foreign banks uninsured by the FDIC (uninsured/foreign): Totals on the left panel and percent of all assets on the right. Shaded bars mark the central bank’s Quantitative Easing with large-scale asset purchases.

Foreign banks are different from domestic banks since they are not required to hold any reserves. We are comparing the policy response on reserves of insured and uninsured banks. All uninsured banks in the data set are foreign banks and are not required to hold any reserves, so we need only to measure the change in excess reserves of domestic banks. Unfortunately, excess reserves are not reported in either of the two reports. In order to calculate the individual excess reserves of each bank, we compute the required reserves based on the banks’ net transaction accounts multiplied by a percentage required by the Fed, which is based on the size of the bank’s net transaction accounts.\(^2\)

Specifically, banks with net transaction accounts valued over $70 million will be required to hold 10% of these in reserves; banks with less than $12 million are exempt from any required reserves, while those with a value in between are required to hold 3% in reserves. All branches of foreign banks that the FDIC does not insure are exempt from required reserves, although such branch’s level of net transaction accounts.

---

\(^2\)The amount for each bracket has changed over the study period. We use the most recent bracket of the period in question, which was changed in December 2012. Using the upper bound of the bracket ensures that the required reserves are not underestimated.
accounts might be high.

Because many branches have reserves held by a parent bank, individual observations are aggregated to the level of the top-tier holding company, with a regression of the unconsolidated data available in the appendix. After aggregation, the data has quite a few branches that do not hold reserves at all. The reason might be that smaller branches may still depend on larger banks to hold their reserves for ease of operations. Therefore, any bank with a zero-sum measure of total reserves through the panel (no reserves over the entire panel) is dropped. The consolidated data set yields roughly 34 thousand observations of 32 quarterly periods with around 41 uninsured and 1028 insured banks.

Table 1.1: Summary Statistics Consolidated

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Uninsured (N=1,312)</th>
<th>Insured (N= 32,896)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. Dev.</td>
</tr>
<tr>
<td>Assets ($Billion)</td>
<td>6.116</td>
<td>14.753</td>
</tr>
<tr>
<td>Excess Reserves ($Billion)</td>
<td>1.108</td>
<td>4.872</td>
</tr>
<tr>
<td>Cash ($Billion)</td>
<td>1.379</td>
<td>4.935</td>
</tr>
<tr>
<td>Cash (% of Assets)</td>
<td>0.222</td>
<td>0.288</td>
</tr>
<tr>
<td>Deposits ($Billion)</td>
<td>2.595</td>
<td>6.381</td>
</tr>
<tr>
<td>Deposits (% of Liabilities)</td>
<td>0.254</td>
<td>0.311</td>
</tr>
<tr>
<td>Loans ($Billion)</td>
<td>0.736</td>
<td>1.567</td>
</tr>
<tr>
<td>Loans (% of Assets)</td>
<td>0.358</td>
<td>0.321</td>
</tr>
<tr>
<td>Securities ($Billion)</td>
<td>0.558</td>
<td>0.943</td>
</tr>
<tr>
<td>Securities (% of Assets)</td>
<td>0.161</td>
<td>0.233</td>
</tr>
</tbody>
</table>

Table 1.1 reports some of the bank characteristics. The left panel specifies the summary statistics of uninsured banks (the U.S. branches of foreign banks uninsured by the FDIC), and the right panel the insured banks. In addition, Tables A.1 and A.2 in the appendix report the summary statistics of the unconsolidated data before dropping observations and aggregating the data. Comparing Tables A.1 and A.2, we see large dispersion across banks.

Previous literature argues that the FDIC reform had more significant implications on the largest insured institutions because they faced significantly higher funding

---

3This drop results in a loss of about two-thirds of the domestic branches.
costs after the reform (for example, see Hein et al. (2012), Whalen (2011)). For this reason, the regression controls for a bank’s size with an indicator of the average total assets of a bank to be higher than $1 billion in total assets, and an additional regression of the two samples is provided for comparison.

In Table 1.1, we see that the mean of securities to assets, loans to assets, and deposits to liabilities are larger for insured banks than uninsured banks. On the other hand, the average share of cash to assets is higher for uninsured banks. Reserves are the dominant component of total cash assets, although not the only one. Cash assets include reserves, currency and coins, balances due from unrelated depository institutions, and other cash items in the collection process. We see that the mean of excess reserves of uninsured banks is over three times larger than insured banks.

1.2.2 Empirical Methodology

The empirical methodology is a difference-in-difference approach to measure the change in excess reserves after the policy reform of insured banks compared to uninsured banks. The unit of observation is the top-tier branch $i$ at time $t$, with the equation following

$$Y_{i,t} = \alpha_1FDIC_{i,t} + \alpha_2FDIC_{i,t} \times S_{i,t} + X_{i,t} \alpha_3 + \sum_{j=1}^{q} \gamma_j D_{j,t} + \theta_i + \tau_t + \varepsilon_{i,t}. \quad (1.2-1)$$

As in Kreicher et al. (2014), the timing of the policy is set to the second quarter of 2011. Kreicher et al. (2014) discuss that even though the proposal for a new assessment was known even six months before the policy reform went into effect, it was not thought that reserves would be included, thereby coming as a surprise to banks. Hence we should not expect a response prior to the second quarter of 2011. The indicator $FDIC_{i,t}$ will be equal to one if a bank is a domestically chartered bank and the period is after the first quarter of 2011.
$X_{i,t}$ is the vector of controls. It includes the log of liabilities, securities, loans, deposits, employees, type of insurance indicator (FDIC insured or not), and an indicator for if a bank’s average quarterly assets exceed $1$ billion during the study. $D_{j,t}$ is an indicator for the quarterly time trends, and $FDIC_{i,t} \times S_{i,t}$ is the size interaction term for a treated bank with average assets exceeding $1$ billion. The outcome variable $Y_{i,t}$ equals the excess reserves to the total assets of bank $i$ in time $t$, while $\theta_i$, and $\tau_t$ are the bank-specific and time-specific fixed-effects.

The methodology of employing excess reserves rather than total reserves is justified because the bank’s choice of total reserves will depend on the required reserve balances regardless of policy. Non-insured banks are not required to hold reserves, and measuring total reserves rather than the reserves in excess violates the parallel trend assumption necessary for a differences-in-differences analysis. The required amount is measured as a function of the net transaction accounts pending at the bank, multiplied by the respective reserve requirement ratio. The excess reserves are simply the reported total reserves less required at each quarter. All reserves of uninsured banks are recorded as excess reserves.

1.3 Regression Results

Tables 1.2 and 1.3 summarize the regression results for changes in excess reserves to assets in response to a change in the FDIC policy. In Table 1.2, the results are for the entire sample of consolidated banks, while Table 1.3 reports the coefficients for two samples partitioned by size. Bank size is measured by the average amount of assets it holds across the span of the panel. This split results in large banks capturing about 15% of the observations. Table A.3, Appendix A.1, provides results for the same model with unconsolidated banks and is consistent with the main result. In all tables, standard errors are clustered by the entity type of the top-tier holding company, with p-values reported in parenthesis. This clustering is ideal as the types
Table 1.2: Regression Results

<table>
<thead>
<tr>
<th>Dependent variable: Ratio of Excess Reserves to Assets</th>
<th>Full Sample 2009-2013</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>FDIC</td>
<td>0.026**</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td>log(Liabilities)</td>
<td>0.056**</td>
</tr>
<tr>
<td></td>
<td>(0.0011)</td>
</tr>
<tr>
<td>log(Securities )</td>
<td>-0.010**</td>
</tr>
<tr>
<td></td>
<td>(0.0014)</td>
</tr>
<tr>
<td>log(Loans)</td>
<td>-0.033*</td>
</tr>
<tr>
<td></td>
<td>(0.0108)</td>
</tr>
<tr>
<td>log(Deposits)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.6344)</td>
</tr>
<tr>
<td># of Employees</td>
<td>-0.004***</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td># of Employees</td>
<td>-0.004***</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td>FDIC : Size</td>
<td>(0.2023)</td>
</tr>
<tr>
<td>Bank-Specific</td>
<td>✓</td>
</tr>
<tr>
<td>Time</td>
<td>✓</td>
</tr>
<tr>
<td>Observations</td>
<td>33,152</td>
</tr>
<tr>
<td>R^2</td>
<td>0.133</td>
</tr>
<tr>
<td>Adjusted R^2</td>
<td>0.105</td>
</tr>
</tbody>
</table>

Note: p<0.1; *p<0.05; **p<0.01; ***p<0.001

Standard errors clustered at the top-tier holding company level

Classifying insured or uninsured banks are mutually exclusive, which means that the categories of U.S. branches of foreign banks entity types are different from those of insured commercial banks.

As in Belton et al. (2020), the main regression results in Table 1.2 include two samples. The first for the entire period from 2005 to 2013 and the second for the period between 2009 to 2013. I do this to control for any implications from the financial crisis across this timespan that could influence the results. Models (1) and (3) include individual fixed-effects, while (2) and (4) control for both time and individual fixed-effects for each respective model. The FDIC policy has a negative and significant coefficient when controlling for bank and time fixed effects, although it is positive and significant without controlling for time trends. The positive coefficient is expected because large-scaled asset purchases at the time resulted in higher reserves to assets across both insured and uninsured banks, as is seen in Figure 1.2.1. Hence, failure to control for time trends will bias the regression estimations.
Estimations of negative coefficients for the FDIC policy indicator indicate that insured banks were less likely to increase reserves following policy change despite increasing reserves due to monetary policy. The interaction term of size and the policy reform is not significant with the restrictive clustered-standard-errors but is otherwise. We measure a difference of $-0.166$ in reserves to assets of insured banks compared to uninsured banks. The estimated coefficient is still significant, although more minor at $-0.07$ following a subsample from 2009 on. Moreover, when dividing the data into large and small banks, large banks are more heavily affected by the policy reform, with an estimated coefficient of $-0.248$. In contrast, the sample of the smaller banks implies a reduction of 0.11 for the ratio compared to uninsured banks following the policy reform.

The implication is that large insured banks with average assets above $1$ billion are more likely to increase reserves than smaller banks. The logic holds because the FDIC policy reform increased the assessment of larger banks by more. Banks’ response to policy by a change in excess reserves may indicate the presence of substitution across retail and wholesale deposits of banks to lower the higher balance-sheet costs incurred
with the policy reform. However, an important note is that the current analysis is silent about whether uninsured banks increase reserves by more after policy reform or if insured banks increase reserves by less. Rather the coefficient indicates the difference across the two, where the assumption here is that the policy reform could influence both the control and the treated groups.

1.4 Event Study

The following section conducts an event study by generating dynamic policy effects and regressing them on banks’ excess reserves. The event study regression provides an extension to Equation 1.2-1 by adding a set of policy leads and lags as follows

$$Y_{i,t} = \sum_{j=1}^{4} \delta_j DIC_{i,t-j} + \sum_{j=1}^{3} \rho_j DIC_{i,t+j} + \alpha_1 DIC_{i,t} + \theta_i + \tau_t + \epsilon_{i,t}. \quad (1.4-2)$$

Table 1.4 displays the coefficient estimates for Equation 1.4-2, and Figures 1.2, 1.3, and 1.4 provide the event study plots with the dynamic effects coefficients normalized to the exposure time. Figure 1.2 is the event study for the entire sample, while Figures 1.3 and 1.4 plot the event study for small and large banks, respectively. All three
event-study plots confirm a policy response of a decline in banks’ excess reserves to assets with a more pronounced response for larger banks than smaller banks.

Table 1.4: Event Study Regression

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable: Ratio of Excess Reserves to Assets</th>
<th>(Full Sample)</th>
<th>(Small Banks)</th>
<th>(Large Banks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Full Sample)</td>
<td>(Small Banks)</td>
<td>(Large Banks)</td>
</tr>
<tr>
<td>$D_{t_{min}4}$</td>
<td>$-0.100^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t_{min}3}$</td>
<td>$-0.097^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t_{min}2}$</td>
<td>$-0.109^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t_{min}1}$</td>
<td>$-0.064^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t0}$</td>
<td>$-0.152^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t1}$</td>
<td>$-0.164^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t2}$</td>
<td>$-0.198^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>$D_{t3}$</td>
<td>$-0.168^{***}$</td>
<td>$(0.008)$</td>
<td>$(0.009)$</td>
<td>$(0.020)$</td>
</tr>
<tr>
<td>Observations</td>
<td>33,152</td>
<td>27,872</td>
<td>5,280</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.055</td>
<td>0.038</td>
<td>0.095</td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.024</td>
<td>0.006</td>
<td>0.058</td>
<td></td>
</tr>
</tbody>
</table>

Note: *p<0.1; **p<0.05; ***p<0.01

The first column of Table 1.4 corresponds with the event study of the entire (full) sample. Four periods before the FDIC policy change, denoted by $D_{t_{min}4}$, we see that the ratio of excess reserves to assets is negative and statistically significant, with domestic banks’ ratios estimated to be 0.1 lower than foreign banks. $D_{t0}$ is the quarter for which the FDIC policy changed. Following policy, the coefficient increases to around 0.2 by the second period after the change (denoted by $D_{t2}$), meaning that policy significantly impacted the excess reserves held by banks. This result is visual in the event-study plot in Figure 1.2. Further dividing the sample into small and large banks in the second and third columns provides evidence that larger banks were affected more heavily by policy as the decline in the difference across banks became more substantial, moving from 0.08 to almost 0.3 following two periods after the policy change. These results are also visual in Figures 1.3 and 1.4, for which the decline after policy change is more pronounced for large banks.
Figure 1.3: Event-study Plot: Small Banks

Figure 1.4: Event-study Plot: Large Banks
1.5 Conclusions

In conclusion, the previous analysis provides insight into how the FDIC policy reform changed the holding of reserves of different types of financial institutions. Specifically, we find that U.S. branches of foreign banks are more likely than U.S. banks to hold reserves to assets following the FDIC assessment that changed from a deposit-based assessment to an assets-based assessment in April of 2011. In addition, the response of large banks is significantly greater because the assessment has become more progressive with the size of a bank.

Most U.S. branches of foreign banks are not insured by the FDIC and therefore are impacted by this policy differently than insured banks. The policy increased the balance-sheet cost of insured banks, which provided an advantage to uninsured banks in the market of wholesale funding. The positive liquidity shock to this sector could manifest with more outstanding loans or higher reserve balances. The effect of the policy on the balance-sheet cost of insured banks may result in either a higher assessment payment on current holdings of deposits or in the substitution of wholesale deposits with retail deposits that require less liquidity and lower the assessment paid to the FDIC. Given the nature of the differences-in-differences regression, the coefficients can not measure the specific impact of policy on each sector; findings suggest either substitution of wholesale deposits for retail deposits for insured banks, increased reserves for uninsured banks, or a combination of both.

One of the new assessment goals was to shift the funding source of banks to more stable deposits and increase their liquidity. An extension to the current analysis may measure the time-series changes in the funding of insured banks to understand better the effectiveness of the FDIC policy reform.
CHAPTER 2

BANK PORTFOLIO CHOICE AND MONETARY POLICY TRANSMISSION IN THE FACE OF A NEW FEDERAL FUNDS MARKET

2.1 Introduction

Given the evidence in Chapter 1 suggesting new policies and regulations following the financial crisis had the unintentional effect of shifting the relative return of holding reserves, Chapter 2 studies how monetary policy depends on the heterogeneity across interbank market participants such as U.S. branches of foreign banks versus domestic banks. The data in Figure 1.2.1 shows higher excess reserves held by U.S. branches of foreign banks while no decline in interbank borrowing following policy change. The Fed’s large-scale asset purchases reduced the liquidity needed to support bank transactions. However, the interest rate on reserves allowed for arbitrage as government-sponsored enterprises (GSEs), which constituted a substantial lender in the federal funds market, was not offered a ‘policy’ rate before 2013.¹ The increase in reserves held by foreign banks is striking. It reached over 25% of all assets in aggregate, compared to an increase of 5% from the counterpart conventional banks Bech & Klee (2011). All U.S. banks could exploit the arbitrage, but we observe an absolute and proportionally higher reserve increase for foreign branches.

¹The Fed established the Overnight Reverse Repo Facility (ON RRP) to provide a floor for overnight interest rates when rates fall below the interest rate on reserve.
A pressing question for effective monetary policy is how different trade-offs affecting the relative attractiveness of holding reserves influence the federal funds market and the substitution between reserves and other assets.

I study this question by expanding the model of Bianchi & Bigio (2022) of monetary policy implementation through the banking system to include two types of bank branches instead of one. The first type consists of U.S. commercial banks (domestic banks), and the second type consists of U.S. branches of foreign banks (foreign banks). Foreign banks differ from domestic banks by government regulatory constraints because domestic banks must hold deposit insurance, while foreign banks cannot. The advantage of deposit insurance is having a more stable funding source, while the disadvantage is a higher balance-sheet cost associated with reserves.

This general equilibrium model exploits the new framework proposed by Bianchi & Bigio (2022), such that the mismatch of long-term assets and short-term liabilities is settled in a clearing market for withdrawals in deposit balances. Random transfers of deposits generate the reallocation of funds via the market for reserves; thereby, the aggregate overnight borrowing and lending, and the prospective valuation of loans of each type of bank, endogenously determine the federal funds rate. These market conditions and related liquidity costs will dictate a bank’s optimal portfolio choice. Thus, this setting determines the distribution of reserves between the two banking sectors, the associated federal funds rate, alongside each sector’s optimal portfolio.

In the model, government policy influences the interbank market with three monetary policy tools: interest on reserves (IOR),2 discount window, and overnight reserve repurchasing rate (ON RRP); the first two rates to banks, while the ON RRP rate to GSEs. Traditional monetary policy would inflict changes in the federal funds rate by changes in the market tightness. If money is tight, overnight borrowing becomes

---

2The Fed’s initial policy in 2008 was to set a separate interest for excess reserves and required reserves. Historically these rates have always been equal and today defined as the interest on reserve balances or the IORB. In this paper I use the convention of calling this policy tool IOR.
more complex, and the corresponding higher liquidity cost will reduce bank lending. However, given a market satiated with reserves, monetary policy may change market tightness by changing these policy rates, also known as corridor rates. The theoretical literature (Hornstein, 2010; Ennis, 2018) suggests that higher IOR, for example, will increase bank reserve balances and reduce the tightness of money. The implication would be an increase in lending by banks. However, we find that lending did not increase with increases in the IOR rate during the period in question (2008-2013). Allowing market participants to differ in their valuations of overnight trades of reserves provides the theoretical grounds that higher IOR is coupled with higher tightness and contraction in aggregate lending.

I calibrate the model with the market participants, including domestic and foreign banks, lending or borrowing reserves, and GSEs exogenously lending reserves. GSEs have historically been dominant lenders in the reserves market, a trend that increased with large-scale asset purchases and had implications for banks (Afonso et al., 2019). The calibrations can match crucial features such as the reserve ratios banks choose on their portfolio and their share of lending and borrowing from the interbank market. It explains the observed higher excess reserves held by U.S. branches of foreign banks following IOR policy and the consequence for bank credit supply. The main findings suggest that although interest on reserves increases the liquidity of banks’ portfolios, it has little to no effect on the market liquidity as long as GSEs are not offered the same policy rate as banks. For example, an IOR policy change from 0 to 0.5% results in higher reserves of around 3.5 percentage points, increasing from around 6 to 9.5 percent for domestic banks and approximately 0.5 to 4 percent for foreign banks. However, since GSEs were not offered the same policy rate, the interbank market rate fell, and overnight bank borrowing of reserves increased.

3A monetary policy of large-scale asset purchases is absent from the model but is calibrated by assuming exogenous lending from GSEs.
The model can capture some of the changes in regulation that affected the federal funds market.\textsuperscript{4} It explains the observed higher excess reserves held by U.S. branches of foreign banks following IOR policy and the consequence for bank credit supply. Interest on reserves is associated with higher reserve balances, while the deposit insurance policy will lower the price of reserves just for domestic banks. The main conclusion suggests that U.S. branches of foreign banks are more responsive to monetary policy tools, such as the interest on reserves because their funding source is associated with higher volatility in deposit withdrawals. Possible extensions to the current model may include the direct effects of large-scale asset purchases on banks’ portfolios, the federal funds market, and, therefore, the lending response.

The remainder of the chapter is organized as follows. The remainder of this section provides the literature review. Section 2.2 presents a comprehensive description of the model, with Section 2.3 following the detailed equations and composition of the model. Section 2.4 provides the model solution, and Section 2.5 reports the calibration exercises. Section 2.6 concludes.

2.1.1 Literature Review

One of the model’s assumptions is that the expansion of the FDIC assessment base affected banks’ liquidity costs. Hein et al. (2012) found that the new policy increased insurance premiums for large banks that rely extensively on non-deposit funding sources. Kreicher et al. (2014) studied the effect of the policy on bank balance sheets. They found that higher funding costs were passed on to lenders of short-term funds and lowered short-term U.S. dollar debt costs. The policy shifted funding of some domestic banks from abroad to more stable domestic deposits.\textsuperscript{5} In contrast, foreign

\textsuperscript{4}Such as the FDIC change in assessment base that changed the relative return of holding reserves for U.S. branches of foreign banks compared to conventional domestic banks.

\textsuperscript{5}Specifically, they estimate a 44-cent increase due to their own office for every dollar increase in reserves at non-chartered foreign banks following the central bank’s large asset purchases post the FDIC policy change.
banks drew considerable net wholesale funding from abroad, which means that the net quantity effect of the policy is not apparent.

More broadly, this paper relates to the literature on the lending channel of monetary policy. As elaborated by Bernanke & Gertler (1995), Bernanke (1990), and Kashyap & Stein (1995), the lending channel assumption is that monetary policy operations in the federal funds market matter for targeting the rate and the implications on banks’ portfolio choices. It allows central banks to alter the liquidity costs of banks and, with it, the optimal choice of reserves and loans, thereby influencing broader lending conditions.

This paper also relates to the literature on the effects of interest on excess reserves, such as Kashyap & Stein (2012), Hornstein (2010), Ennis (2018), Ireland (2014), and Cochrane (2014). These papers, among others, considered that banks might substitute other short-term securities for the additional interest-bearing reserves in the absence of liquidity constraints, which may imply a reduction in the overall lending activity of banks coupled with an increase in the interest rate. In which case, a new policy favoring U.S. branches of foreign banks’ position in wholesale funding could magnify this problem.

Ennis & Wolman (2018) measure the aggregate liquidity in the banking system in response to monetary expansions of large-scale asset purchases following the financial crisis in 2008. They find that expansion efforts by the Fed in each of the three Quantitative Easing events correspond with indefinite higher liquidity so that, in aggregate, the banking system as a whole did not substitute reserves for other forms of liquid assets. Moreover, DiSalvo (2019) documents that the share of assets held by foreign banks had not changed during this period, suggesting that cash assets substitute for other assets previously held by these institutions.6

6U.S. branches of foreign banks do not report all types of assets as domestic banks do. Therefore the portfolio asset composition of foreign banks reported in the next section includes other assets imputed by the data. The composition of assets over time supports the literature that suggests a substitution of reserves for other forms of non-liquid assets.
There is a rapidly growing stack of theoretical literature on the federal funds market. One of the first models dating back from Poole (1968) provides a static model of a bank’s choice of excess reserves and the operation of the federal funds market. More recently, Afonso & Lagos (2015) model the federal funds market given a Poisson process dictating the interbank bargaining, for which the transaction terms determine the size of the loan and the intraday distribution of rates. Bianchi & Bigio (2017) build on this literature, alongside Atkeson et al. (2015), to transform the federal funds market model into a tractable process embedded in a dynamic general equilibrium model.

With the Fed’s new conditions and complexity, a revised theoretical framework for the interbank market is on many scholars’ tables. One of the first models to present these new conditions is Bech & Klee (2011). They were the first to address the federal funds rate falling below the IOR due to the presence of GSEs in a static model. Two other seminal papers include Afonso et al. (2019) and Armenter & Lester (2017). Armenter & Lester (2017) provide a model of heterogeneous banks that differ in their balance-sheet cost associated with excess reserves. In contrast, Afonso et al. (2019) focus on changes in the federal funds market’s conditions on the distribution of reserves across banks.

The following model, I propose, builds on Duffie et al. (2007) by describing an over-the-counter (OTC) market with heterogeneity in agents’ valuation of an asset. It expands the Bianchi & Bigio (2022) model to include two banking sectors facing different marginal benefits of reserves. In the model, the valuation of reserves depends on a liquidity risk premium, the interbank market conditions, and the second-best overnight rates offered by the Fed. These defer across foreign and domestic banks and hence, have implications on the optimal portfolio choice of each sector. Furthermore, each type of bank’s aggregate portfolio choice matters for the outcome in the federal funds market. Thus, the foreign sector’s marginal benefit of its reserves will matter
per se for the domestic bank’s optimal liquidity and lending choices. The steady-state solution to the model pins down the interbank rate, that is, the federal funds rate and the excess reserves of each sector.

2.2 Informal Description of the Model

2.2.1 Overview

I extend the model of Bianchi & Bigio (2022) to include the decision problem of heterogeneous interbank market participants. Their model describes the lending channel of banks via a liquidity management problem subject to the conditions in the interbank market for reserves, in which each bank is a scaled version of a bank with unit equity.

Having homogenous market participants implies that the decision of each bank is identical, but in practice, a bank’s overnight lending decision differs. Moreover, the optimal choice of one type of bank depends on the relative valuation of the overnight loan (called the second-best rates). If these rates are not identical across interbank borrowers and lenders, the optimal outcome may be to place overnight funds at the Fed for risk-free rent. For example, GSEs were not offered any policy rate prior to 2013, so they were willing to lend for a rate below the IOR rate. In which case, domestic and foreign banks could borrow low from GSEs. The model’s scope allows for this interdependence of the differences across market participants to measure the impact on the lending decisions and pin down the expected federal funds rate.

I follow Bianchi & Bigio (2022) because their model provides a new general equilibrium framework to capture banks’ mismatch of long-term assets and short-term liabilities and its importance in implementing monetary policy through the banking system. Random transfers of deposits create a liquidity risk that determines the supply of credit and the money multiplier achieved by partitioning a bank’s deci-
sion problem into a lending stage and a balancing stage. The liquidity management problem arises because lending decisions are made during the lending stage, but imbalances created by a withdrawal shock must be settled by transferring reserves from one bank to another in the balancing stage. Similar to Kashyap and Stein (1995), when cash flows constrain banks, they need to raise new funds. Here, by borrowing from other banks in the interbank market. The endogenous conditions in the interbank market determine the liquidity cost/benefit for banks and hence the demand for precautionary reserves. Thus, the expectation of the conditions in the interbank market and policy rates will quantify the bank’s lending portfolio decision in the lending stage.

2.2.2 The Behavior of Banks

There are two types of bank branches; foreign branches differ from domestic branches by government regulatory constraints. Domestic banks must hold deposit insurance, while foreign banks cannot. The advantage of deposit insurance is having a more stable funding source, while the disadvantage is a higher balance-sheet cost associated with reserves. An additional extension includes exogenous lending of other traders (such as GSEs) that differ in their valuation of reserves.

Banks maximize utility over a stream of dividends with some risk-aversion to capture the smooth dividend distribution observed in the data. Each period is divided into a lending stage and a balancing stage. In the lending stage, risk-averse banks holding some level of equity choose the number of dividends to consume (which can be thought of as a distribution to shareholders), illiquid loans to firms, and liquid reserves, by issuing deposits from households. Because loans are illiquid at this stage, reserves serve a precautionary purpose. The random withdrawal to a bank’s deposits is drawn from a common distribution across each branch. Alas, every inflow of deposits is an outflow from another bank, meaning the net amount across banks equals
zero, or deposits never leave the banking sector.

Because the risk of deposits withdrawals depends on the type of bank, the associate precautionary reserves may be different. Foreign banks not insured by the FDIC raise funds from wholesale deposits associated with a more variable withdrawal shock. They are assumed to face higher withdrawal volatility, as observed empirically. A domestic bank’s deposits are not as volatile, but the bank must pay a Pigovian tax for its reserves that enters its utility function. The tax calibration measures the FDIC assessment for its reserves holdings. In addition, GSEs place exogenous lending in the interbank market, so the imbalances created by the withdrawal shocks give rise to an interbank market of reserve transfers from one interbank agent to another.

The interbank market, or the federal funds market, is described as an OTC market for overnight funds. Using Nash bargainings of bilateral trades determines the rate for a unit of exchange. Hence the endogenous federal funds rate is the average of these rates bargained during each period. The actual price bargained depends on the market aggregates and policy interest rate. For example, if lending offers are higher than borrowing offers, a borrower’s bargaining power is high, lowering the rate. In contrast, if lending orders are scarce, the rate in the market will tend to be higher. This ratio of orders between aggregate borrowing and lending is called market tightness. In addition, different interbank agents face different second-best rates, determined by policy and regulation. Therefore, an interbank rate bargained between two agents will depend on what type of borrower and lender are meeting, with the mass of orders across the types setting the probability of such two agents meeting in the market.

Hanson et al. (2015) describe the banks’ portfolio design such that, given deposit insurance, a bank may invest in illiquid assets to create money-like deposits because of the relative stability of such funds. With no deposit insurance, a financial institution must invest in liquid assets with low fundamental risk to create non-stable deposits. Since this simplified model banks either hold illiquid loans or liquid reserves, a higher risk of withdrawals increases the demand for reserves for this sector while remaining silent on the substitution between reserves and other liquid assets. An interesting extension would include other liquid assets that could influence demand for precautionary reserves.
After the settlements in the market, unmatched orders are satisfied with the second-best rates available from the Fed. Unless stated otherwise, GSEs’ second-best lending rate is assumed to be zero. Then the balancing-stage loans, reserves, interbank loans, deposits, and previous equity determines the following period equity of a bank. Lower interest gains on reserves and lower risk of holding household deposits increase the opportunity cost of domestic banks’ excess reserves. Hence, a domestic bank’s additional cost associated with the holdings of reserves allows foreign banks an advantage in borrowing at a lower rate than the IOR rate.\(^8\) Lastly, the model is closed with an exogenous deposit supply and loan demand level, and the federal fund budget satisfies overnight loans not settled in the interbank market.

2.3 The Model

2.3.1 Banks

The banking sector is divided into a measure of domestic banks \(i \in [0, \text{share}]\) and a measure of foreign banks \(j \in [\text{share}, 1]\), with \(\text{share}\) denoting the relative size of the domestic sector. When adding GSEs to the interbank market, \(\text{share}\) still denotes the size of domestic banks in the banking sector, while \(\bar{\text{share}}\) denotes the share of domestic banks in the economy of interbank market participants and \(\bar{a}\) the share of GSEs.

Each period \(t = 0, 1, 2, \ldots\), is partitioned into two stages: a lending stage, denoted by \(\text{lend}\), followed by a balancing stage, denoted by \(\text{balance}\). The liquidity management problem arises because lending decisions are made during the lending stage, but imbalances created by a withdrawal shock must be settled by transferring reserves from one bank to another. Banks cannot issue new loans in the balancing stage, so a

\(^8\)In practice, this distortion existed before the FDIC changed its assessment base to include reserves. Arbitrage has been possible since the introduction of an IOR rate because GSEs were not eligible for this interest rate, as documented in (Afonso et al., 2019) and (Bech & Klee, 2011).
deficit/surplus in reserves is bargained as an overnight loan contract between banks or by external markets with second-best rates settled in the next lending stage. I use the convention that $\tilde{x}_{t+1}$ denotes a portfolio variable in the lending stage and $x_{t+1}$ denotes the end-of-period portfolio variable in the balancing stage. In what follows, $D$ stands for the domestic sector, and $F$ stands for the foreign sector.

**The Lending Stage:** In each lending stage, a bank enters with some equity composed of the difference between the bank’s stock of assets and liabilities. An individual bank’s equity is defined as follows:

$$E^i_t \equiv r_t b^i_t + (r_{ior}^i - \text{tax}_t)m^i_t - r_{ff}^i m_{fft}^i - r_{dw}^i m_{dwt}^i - r_d^i d_t,$$

for $i$, referring to a domestic bank, and

$$E^j_t \equiv r_t b^j_t + r_{ior}^j m^j_t - r_{ff}^j m_{fft}^j - r_{dw}^j m_{dwt}^j - r_d^j d_t,$$

with $j$, referring to a foreign bank. The difference is that a foreign bank’s tax = 0.

Assets value includes $b_t$ loans issued at the competitively determined gross rate $r_t$ and $m_t$ reserves earning the policy gross interest rate on reserve balances denoted by $r_{ior}^i$ minus the policy determined tax denoted by $\text{tax}_t$ when applicable. The total value of liabilities includes $m_{fft}$ federal funds borrowed at the endogenously determined gross interbank rate $r_{ff}^i$, $m_{dwt}$ discount window funds borrowed at the gross policy rate $r_{dw}^i$, and $d_t$ deposits costing the competitively determined-gross rate $r_d^i$. Note that a bank may also lend federal funds. In this case, it will appear as an asset on its balance sheet.

A bank, therefore, chooses a sequence of the amount of new loans $\tilde{b}_{t+1}$, new reserves $\tilde{m}_{t+1}$, dividends denoted by $c_t$ at the current price level $P_t$, and new deposits $\tilde{d}_{t+1}$ for
all $t = 0, 1, 2, \ldots$ to maximize the expected utility function

$$
E \sum_{t=0}^{\infty} \frac{c_t^{1-\eta}}{1-\eta}
$$

(2.3-1)

over a stochastic stream of dividend payments $\{c_t\}_{t=0}^{\infty}$. Subject to

$$
P_t c_t + \tilde{b}_{t+1} + \tilde{m}_{t+1} - \tilde{d}_{t+1} \leq E_t
$$

(2.3-2)

a bank’s budget constraint at time $t$,

$$
\tilde{d}_{t+1} \leq \kappa \left( \tilde{b}_{t+1} + \tilde{m}_{t+1} - \tilde{d}_{t+1} \right)
$$

(2.3-3)

capital requirement constraint following policy regulation parameter $\kappa$, and

$$
\tilde{b}_{t+1}, \tilde{m}_{t+1}, \tilde{d}_{t+1} \geq 0 \quad \forall \ i \in [0, \text{share}], \text{ and } j \in [\text{share}, 1]
$$

(2.3-4)

the nonnegative constraints.

The budget constraint in Equation 2.3-2 specifies that a bank’s value of dividends plus new assets minus liabilities at time $t$ must be less or equal to its current equity. Equation 2.3-3 sets a leverage limit. It states banks can issue deposits with enough capital collateral to back them set by an exogenous policy parameter calibrated to match regulation.\footnote{Lenel et al. (2019) explicitly make reserves more valuable than loans with $\tilde{d}_{t+1}^i \leq \kappa (\varphi \tilde{b}_{t+1}^i + \tilde{m}_{t+1}^i - \tilde{d}_{t+1})$, for $\varphi < 1$. \footnote{Capital requirement $\kappa$ is imposed on domestic and foreign banks for two reasons. First, U.S. branches and agencies of foreign banks are regulated by the country of origin, which may require some capital leverage ratios. Second, this assumption makes the comparison of portfolio choices of each type of bank simpler, while it does not change the central message of the results. \footnote{Risk aversion is commonly used to provide the curvature needed to match dividend smoothening, as is observed in the data.}}}

At each time $t$, after lending decisions have been made, a bank will face an idiosyn-
cratic withdrawal from its deposits in the sum of $\omega \bar{d}_{t+1}$. The shock distribution is specific for each sector in that the foreign bank shock has a strictly higher standard deviation. $\omega^D_t \sim D_t(\cdot)$ is the common distribution across all domestic banks but is different from the distribution of the foreign banks $\omega^F_t \sim F_t(\cdot)$. The support $[\omega_{\text{min}}, \infty)$ with $\omega_{\text{min}} \geq -1$ requires that not all funds are withdrawn at once from a specific bank. The assumption that foreign banks face a high risk of withdrawal is based on the data and is expected since foreign banks only hold wholesale deposits that are different from household deposits. Nevertheless, I hold the assumption, as in Bianchi & Bigio (2022), that all deposits remain within the banking system so that $\int_{-\infty}^{1} \omega^D_t D_t(\cdot) + \int_{-\infty}^{1} \omega^F_t F_t(\cdot) = 0$ must hold for all $t$.

After the withdrawal shock, a bank has some reserves surplus that equals

$$x^i_t = \left( \bar{m}^i_{t+1} + \frac{r^d_{t+1} \omega^i_t \bar{d}^i_{t+1}}{r^i_{t+1}} \right) - \rho \bar{d}^i_{t+1}(1 + \omega^i_t) \quad (2.3-5)$$

for the domestic bank and

$$x^j_t = \left( \bar{m}^j_{t+1} + \frac{r^d_{t+1} \omega^j_t \bar{d}^j_{t+1}}{r^j_{t+1}} \right) \quad (2.3-6)$$

for the foreign bank, which is equal to the reserves after the shock minus what the central bank requires. A negative $x_t$ is simply a reserve deficit. $\rho \in [0, 1]$ is the reserve ratio requirement set by the monetary authority, and since foreign banks face no reserves requirement, their $\rho$ is zero. Realizations of this surplus or deficit will

\[12\]Instead of defining two distributions for each type of bank common across each type, one could define it as a function of the bank’s liquidity needs (or leverage ratio). These are observed to be significantly different across the two sectors and may result from the lack of a capital requirement on foreign banks (this will not break aggregation, as long as $F_t$ is not a function of the bank’s size).

\[13\]I use the same convention as in Bianchi & Bigio (2022), a reasonable assumption given the focus of this analysis is on the portfolio choice given its subjective risk of not having enough funds and not the risk of a run on the bank.

\[14\]The transfer of one unit from one bank to the next must be settled with $r^i_{t+1}/r^i_{t+1}$ of reserves because the interest owed on the deposit at $t + 1$ must be paid by the deposit issuer, while the interest gained on reserves for that period should be retained.
determine the amount of borrowing and lending orders entered into the federal funds market.

**The Federal Funds Market:** The federal funds market is described as an over-the-counter (OTC) market for overnight funds where Nash bargainings of bilateral trades determine the rate for a unit of exchange; hence the endogenous federal funds rate denoted by $r_{ff}^t$ is the average of these rates at $t$. As in Atkeson et al. (2015), and more recently, in Bianchi & Bigio (2022), each trade is for an infinitesimally small amount of reserves, also thought of as a dollar unit. This assumption ensures tractability, which widely simplifies the solution of the model - the added assumption, as Duffie et al. (2007), is that valuations of a loan depend on the type of bank because domestic and foreign banks face differences in the second-best outside lending rates set by the monetary authority. Because of this heterogeneity in agent valuation, individual Nash-bargaining rates will depend on the type of banks engaged in a specific trade. Second-best rates include the discount window rate $r_{dw}^t$ available for borrowing outside the market and the interest rate on reserves $r_{ior}^t$ offered for reserves not lent in the market. Domestic banks incur an additional balance-sheet cost on reserves balances equal to the $tax_t$. In practice, the actual tax assessment depends on the bank’s size. However, the tax rate is assumed to be flat for simplicity. Later, I add a third type of lender in the OTC market to represent GSEs with a second-best lending rate of zero.

Let $m_b$ and $m_l$ denote the marginal benefit for borrowing or lending in the market, and let $O_b^t$ and $O_l^t$ denote a specific type of bank’s outside borrowing or lending option. In the Nash-bargaining problem, a bank will choose the bargaining rate to maximize its benefit from trade by solving

\[
\max_{r_{ff}^t} \left( m_bO_b^t - m_b r_{ff}^t \right) \phi_t \left( m_l r_{ff}^t - m_l O_l^t \right)^{1-\phi_t},
\]
with $\phi_t \leq 1$ the bargaining power variable at time $t$. Solving for the first-order conditions, we get that

$$r_t^{ff} = (1 - \phi_t)O_t^b + \phi_t O_t^l. \quad (2.3-7)$$

Hence a rate bargained in the federal funds market must fall in the range of $[r_t^{ior} - tax_t, r_t^{dw}]$. The actual rate will depend on the market conditions described by $\phi_t$.

A bank will place borrowing or lending orders based on the realization of $x_{t+1}$ and the spread between borrowing in one market and lending in another. For example, when $E(r_t^{ff}) < r_t^{ior}$, the existing arbitrage implies a foreign bank will place borrowing orders even if it has excess reserves. The different possible cases are described in more detail in Appendix B.3. Only one round of bargaining is executed for each dollar of exchange so that $E(r_t^{ff})$ does not change across multiple cycles of trades, essentially simplifying the analysis.

A match in the market can occur between lending and borrowing orders randomly matched according to the relative mass of borrowing orders to lending orders called the market tightness variables denoted by $\theta_t$ and $\bar{\theta}_t$. Denoting $M_t^-$ and $M_t^+$ the mass of borrowing and lending orders respectfully, $\theta_t = M_t^- / M_t^+$ is the market tightness before trades have accrued, and $\bar{\theta}_t$ is the tightness accounting for matching market frictions based on a Passion probability function of arrival times, such that

$$\bar{\theta}_t = \begin{cases} 1 + (1 + e^\lambda)(\theta_t - 1) & \text{if } \theta_t > 1 \\ (1 + (\theta_t^{-1} - 1)e^\lambda)^{-(e^\lambda + \phi)} & \text{otherwise}, \end{cases} \quad (2.3-8)$$

with $\lambda$ the market friction parameter for the Poisson probability function’s arrival rate of matches calibrated to match the observed market tightness. The endogenous
bargaining weights $\phi_t$ depend on this tightness, such that

$$\phi_t = \begin{cases} \left( \left( \frac{\bar{\theta}_t}{\theta_t} \right)^{\bar{\phi}} - 1 \right) \theta_t (e^\lambda - 1)^{-1} & \text{if } \theta_t > 1 \\ \frac{1}{1 - \theta_t} \left( \left( \frac{\bar{\theta}_t}{\theta_t} \right)^{\bar{\phi}} - 1 \right) (e^\lambda - 1)^{-1} (\bar{\phi} + e^{\bar{\phi} - \lambda}) & \text{otherwise.} \end{cases} \quad (2.3-9)$$

A parameter of $\bar{\phi} = 0.5$ implies an equal bargaining parameter when the lending and borrowing orders are equal. These functions allow for exponential bargaining weights with market tightness, as suggested in Bianchi & Bigio (2017).

The market tightness and the friction parameter $\lambda$ determine the probability of matching lending orders and borrowing orders, such that

$$\gamma_t^+ = \begin{cases} 1 - e^{-\lambda} & \text{if } \theta_t \geq 1 \\ \theta_t (1 - e^{-\lambda}) & \text{otherwise} \end{cases} \quad (2.3-10)$$

and

$$\gamma_t^- = \begin{cases} 1 - e^{-\lambda} & \text{if } \theta_t \leq 1 \\ \theta_t^{-1} (1 - e^{-\lambda}) & \text{otherwise.} \end{cases} \quad (2.3-11)$$

In this form, the probabilities of $\gamma_t^+$ and $\gamma_t^-$ describe two Poisson distributions of arrival times with the rate of arrivals set by $\lambda$. For example, if $\theta_t \geq 1$, total borrowing orders exceed the total of lending orders, the probability of matching lending order $\gamma_t^+$ only depends on the market friction $\lambda$ for a match to occur. If, however, $\theta_t < 1$, this probability of a match is scaled by $\theta_t$. The analog for $\gamma_t^-$ implies that $\theta_t \leq 1$ described the case where the mass of lending orders exceeds borrowing orders.

Since the bargaining of an interbank rate depends on each side’s type, we need to keep track of each bank’s mass of borrowing and lending orders (foreign or domestic). $I_t^- \in [0, M_t^-]$ denotes the mass of domestic borrowing, and $J_t^- = M_t^- - I_t^-$ foreign
borrowing. Similarly, \( I_t^+ \in [0, M_t^+] \) and \( J_t^+ = M_t^+ - I_t^+ \) denotes the mass of domestic and foreign lending. Hence, the conditional probability of a borrowing order matched with a domestic lending order is given by

\[
\gamma_{Dt} = I_t^- / M_t^-.
\]

(2.3-12)

The conditional probability that a lending order is matched with a domestic bank is given by

\[
\gamma_{Dt}^+ = I_t^+ / M_t^+
\]

(2.3-13)

-the analog probabilities of meeting a foreign bank equal to

\[
(1 - \gamma_{Dt}) = (M_t^- - I_t^-) / M_t^-,
\]

(2.3-14)

and

\[
(1 - \gamma_{Dt}^+) = (M_t^+ - I_t^+) / M_t^+.
\]

(2.3-15)

\( s_t \) denotes the amount each bank puts in the market. Although a bank may not place lending orders beyond its excess reserves, placing borrowing orders above the deficit addresses the possibility that borrowing reserves at the interbank market occur for reasons beyond liquidity constraints.\(^{15}\) A limit (or saturation) for borrowing orders placed above a deficit is necessary to ensure a unique solution to the model. To limit this amount, define the maximum share of borrowing orders placed while still in excess to equal the current reserves on hand (i.e., \( s_t^j = -x_t^j \)). The unmatched amount of \( s_t \) will trade in the Second-best market.

With the above market structure, we can characterize the liquidity yield for banks. A domestic bank with a shock \( \omega_t^i > \omega_{st} \) has a reserves surplus. If matched in the interbank market, it will obtain a return of \( r_t^{ij} \) or otherwise \( r_t^{ior} - tax_t \). We need that

\(^{15}\)Having lending orders beyond excess is senseless if these cannot be fulfilled in the current time period.
\( r_t^{ff} \geq (r_t^{ior} - tax_t) \) for the market to exist. Hence

\[
s^i_t(\omega^i_t | \omega^i_t > \omega^*_{it}) = x^i_t,
\]

which means all excess reserves are placed in the market. In equilibrium, only a fraction of \( \gamma^+_i \) is matched and earns the return of \( r_t^{ff} \). The unmatched funds earn the net rate of \( (r_t^{ior} - tax_t) \). The resulting liquidity yield is the net gain of lending funds in the interbank market and follows

\[
\chi^+_D = \gamma^+_i \left[ D^+ \left( r_t^{ff} \right) - (r_t^{ior} - tax_t) \right].
\]

For which \( D^+(r_t^{ff}) = (1 - \phi_t)r_t^{dw} + \phi_t(r_t^{ior} - tax_t) \) is defined as the expected federal funds rate for domestic lenders over the expectation of the type of borrower they meet at the market and their respective outside rates. For the domestic lender, the expected federal funds rate is simply the Nash-bargaining weighted average of its outside lending rate and the outside borrowing rate, which in this case is equivalent across domestic and foreign borrowers. The Nash-bargaining, \( \phi_t \), is endogenously set by the mass of borrowing to lending orders on each side of the market.\(^{16}\)

Similarly, the condition \( r_t^{ff} \leq r_t^{dw} \) requires that domestic banks with a reserve deficit first place borrowing orders in the market, i.e.,

\[
s^i_t(\omega^i_t | \omega^i_t < \omega^*_{it}) = x^i_t.
\]

\( \gamma^-_i \) is the probability orders are matched, and the rest is borrowed from the central bank. The corresponding liquidity cost of a reserve deficit for a domestic bank is

\[
\chi^-_D = \gamma^-_i \left[ D^- \left( r_t^{ff} \right) - (r_t^{ior} - tax_t) \right] + (1 - \gamma^-_i) \left[ r_t^{dw} - (r_t^{ior} - tax_t) \right],
\]

\(^{16}\)For more details on how \( \phi_t \) is calculated, I refer the interested reader to Bianchi & Bigio (2017).
with \( E^D(-r_{t}^{ff}) = (1 - \phi_t)r_{t}^{dw} + \phi_t(\gamma_D t(r_{t}^{ior} - \text{tax}_t) + (1 - \gamma_D t)r_{t}^{ior}) \). Here the expected market rate depends on the probability of matching the borrowing order with either a domestic lender or a foreign lender since the second-best rates of the two are different. The liquidity cost for domestic banks is summarized as a function of the surplus \( x_i^t \) and is equal to
\[
\chi^D_i(s_t(x_t)) = \begin{cases} 
  \chi^+_D s_t^i & \text{if } x_t \leq 0 \\
  \chi^-_D s_t^i & \text{otherwise.}
\end{cases}
\] (2.3-16)

A foreign bank, facing a shock \( \omega^i_j > \omega^*_j \), can either lend to another bank at the federal funds rate or lend to the central bank to gain \( r_{t}^{ior} \) for each dollar of reserves. When the market conditions are such that \( r_{t}^{ior} \) falls below \( r_{t}^{ff} \), the bank will place lending orders for every dollar in excess in the federal funds market. However, if \( r_{t}^{ior} - \text{tax}_t \leq r_{t}^{ff} \leq r_{t}^{ior} \), a rate still within the domestic bank’s boundaries to place lending orders, a foreign bank will place borrowing orders despite excess reserves. The liquidity benefit of having excess reserves depends on if the foreign bank is a lender or an arbitrageur.\(^{17}\) Therefore, a lender’s expected return on lending is
\[
lender_t = \gamma_t^+ (E(r_{t}^{ff}) - r_{t}^{ior}),
\]
with the expected federal funds rate equal to \( E^{F^+}(r_{t}^{ff}) = (1 - \phi_t)r_{t}^{dw} + \phi_t r_{t}^{ior} \), depending on the lender’s expectation of meeting a domestic or foreign borrower given the same second-best borrowing rate, \( r_{t}^{dw} \). The arbitrage of borrowing from the federal funds market and lending to the central bank equals
\[
arbitrage_t = \gamma_t^- (r_{t}^{ior} - E(r_{t}^{ff})).
\]
For which the arbitrageur’s expected federal funds rate equal to \( E^{ab}(r_{t}^{ff}) = (1 -
\]
\(^{17}\)The presence of GSEs presents a similar condition for domestic banks, with the rate falling below \( r_{t}^{ior} \) given that GSEs’ second-best rate is zero. This possibility is revisited in the following sections with the extension of the model to include GSEs.
\( \phi_t ) r_t^{ior} + \phi_t ( \gamma_D t ( r_t^{ior} - t ax_t ) + (1 - \gamma_D t ) r_t^{ior} ) \) that depends on the arbitrage's expectation of either meeting a domestic or foreign lender given the known relative mass of the two. A foreign bank will choose to arbitrage if \( lend_t < arbitrage_t \), otherwise, it will lend its excess reserves in the market, which means that a foreign bank with excess reserves may place funds on either side of the market, depending on the expected return. Hence

\[
s_t^j ( \omega_t^j | \omega_t^j > \omega_j^* ) = \begin{cases} 
  x_t^j & \text{if } lend_t \geq arbitrage_t \\
  - x_t^j & \text{otherwise}
\end{cases}
\]

and the liquidity benefit equals

\[
\chi_{F}^+ = \begin{cases} 
  \gamma_t^+ ( \mathbb{E} ( r_t^{ff} ) - r_t^{ior} ) & \text{if } lend_t \geq arbitrage_t \\
  \gamma_t^- ( r_t^{ior} - \mathbb{E} ( r_t^{ff} ) ) & \text{otherwise.}
\end{cases}
\]

Lastly, a foreign bank with shock \( \omega_j^i < \omega_j^* \) has a reserves deficit. In which case, the condition

\[
s_t^i ( \omega_t^i | \omega_t^i < \omega_j^* ) = x_t^i
\]

states that borrowing orders are first placed in the interbank market because the discount window rate is assumed to be higher than the expected federal funds rate. The expected cost of borrowing is

\[
\chi_{F}^- = \gamma_t^- \mathbb{E} ( r_t^{ff} ) - ( r_t^{ior} - t ax_t ) + (1 - \gamma_t^- )[ r_t^{dw} - r_t^{ior} ],
\]

where \( \mathbb{E}^{F-} ( r_t^{ff} ) = (1 - \phi_t) r_t^{dw} + \phi_t ( \gamma_D t ( r_t^{ior} - t ax_t ) + (1 - \gamma_D t ) r_t^{ior} ) \), and the foreign
bank’s liquidity cost as a function of the surplus \( x_t \) equals

\[
\chi_t^F(s_t(x_t)) = \begin{cases} 
\chi_t^F s_t^j & \text{if } x_t \leq 0 \\
\chi_t^F s_t^j & \text{otherwise.}
\end{cases}
\] (2.3-17)

The friction of entering the interbank market creates a difference between the liquidity cost of borrowing and the liquidity benefit of lending. This difference is endogenous to a market’s liquidity pending domestic and foreign lending and borrowing decisions, which means that even with an abundance of reserves that fulfill the liquidity needs of domestic banks, the existence of arbitrageurs may result in a tight market. Hence the optimal portfolio of domestic and foreign banks depends on the spread between each sector’s outside rates and the distribution of reserves across them. So the endogenous federal funds rate will equal the weighted average of all rates bargained in the market, such that

\[
\rho_t^{ff} = \begin{cases} 
\gamma_t^D \text{E} (r_t^{ff}) + \gamma_t^D E (r_t^{ff}) + \gamma_t^D \text{E} (r_t^{ff}) + \gamma_t^D \text{E} (r_t^{ff}) & \text{if } lend_t \geq arbitrage_t \\
\gamma_t^D \text{E} (r_t^{ff}) + \gamma_t^D \text{E} (r_t^{ff}) + \gamma_t^D \text{E} (r_t^{ff}) + \gamma_t^D \text{E} (r_t^{ff}) & \text{otherwise.}
\end{cases}
\]

The Balancing Stage: Following a shock \( \omega_t \) to deposits, domestic end-of-balancing-stage deposits equal to

\[
d_t^{i+1} = (1 + \omega_t^{Di}) d_t^{i+1}. \tag{2.3-18}
\]

Loans are illiquid so that domestic end-of-balancing-stage loans equal

\[
b_t^{i+1} = b_t^{i+1}. \tag{2.3-19}
\]

Following the bargaining problem that depends on the match probabilities and the number of orders placed on each side of the interbank market, we get the end-of-
balancing-stage domestic reserves

\[ m_{i}^{i+1} = \tilde{m}_{i+1}^{i} + \frac{\tilde{d}_{i}^{d} \tilde{D}_{i}^{i} \tilde{d}_{i+1}^{i}}{r_{i+1}^{i, d}} + m_{fft+1}^{i} + m_{dwt+1}^{i}. \tag{2.3-20} \]

Equation 2.3-20 states that the end-of-balancing-stage reserves amount to the reserves following the withdrawal shock plus any additional reserves borrowed from the interbank market or the central bank’s discount window, denoted by \( m_{fft+1}^{i} \) and \( m_{dwt+1}^{i} \), respectively. Given the domestic bank surplus specified in 2.3-5, these overnight reserves borrowed equal to

\[
(m_{fft+1}^{i}, m_{dwt+1}^{i}) = \begin{cases} 
(-x_{i}^{i} \gamma_{i}^{-}, -x_{i}^{i}(1 - \gamma_{i}^{-})) & \text{for } x_{i}^{i} < 0 \\
(-x_{i}^{i} \gamma_{i}^{+}, 0) & \text{for } x_{i}^{i} \geq 0,
\end{cases} \tag{2.3-21}
\]

so that a negative \( m_{fft+1}^{i} \) is an overnight loan by the bank to another bank, and \( m_{dwt+1}^{i} \geq 0 \).

A foreign bank’s end-of-balancing-stage portfolio shares will follow

\[ d_{i}^{j} = (1 + \omega_{i}) \tilde{d}_{i}^{j}, \tag{2.3-22} \]

\[ b_{i}^{j} = \tilde{b}_{i}^{j}, \tag{2.3-23} \]

and

\[ m_{i}^{j} = \tilde{m}_{i+1}^{j} + \frac{\tilde{d}_{i+1}^{j} \tilde{D}_{i+1}^{j} \tilde{d}_{i+1}^{j}}{r_{i+1}^{j, d}} + m_{fft+1}^{j} + m_{dwt+1}^{j}. \tag{2.3-24} \]

Equations 2.3-22 and 2.3-23 are the end-of-balancing-stage deposits and loans. Equation 2.3-24 is the end-of-balancing-stage reserves that amount to the reserves after the withdrawal shock plus any additional reserves borrowed from the interbank market or discount window. Given the surplus for a foreign bank specified in Equation 2.3-6,
these overnight reserves borrowed and lent are equal to

\[
(m^j_{fft+1}, m^j_{dwt+1}) = \begin{cases} 
-x^j_t \gamma_t^ - , -x^j_t (1 - \gamma_t^-) & \text{for } x^j_t < 0 \\
-x^j_t \gamma_t^+ , 0 & \text{if } lend_t \geq arbitrage_t \text{ for } x^j_t \geq 0 \\
x^j_t \gamma_t^ - , 0 & \text{if } lend_t < arbitrage_t \text{ for } x^j_t \geq 0
\end{cases}
\]  

(2.3-25)

and depend on if the foreign bank with excess reserves finds it optimal to lend its excess reserves or arbitrage by borrowing against them.

With the assumption of no aggregated risk, the rest of the aggregates follow

\[
E^D_{t+1} \equiv \int_i E^i_{t+1} di, \quad E^F_{t+1} \equiv \int_j E^j_{t+1} dj, \quad B^D_{t+1} \equiv \int_i b^i_{t+1} di, \quad B^F_{t+1} \equiv \int_j b^j_{t+1} dj, \quad D^D_{t+1} \equiv \int_i d^i_{t+1} di, \quad D^F_{t+1} \equiv \int_j d^j_{t+1} dj, \quad M^D_{t+1} \equiv \int_i m^i_{t+1} di, \quad M^F_{t+1} \equiv \int_j m^j_{t+1} dj, \quad X^D_{t+1} \equiv \int_i x^i_{t+1} di, \quad X^F_{t+1} \equiv \int_j x^j_{t+1} dj, \quad DW^D_{t} \equiv \int_i m^i_{dwt} di, \quad DW^F_{t} \equiv \int_j m^j_{dwt} dj.
\]

These are the aggregate equity, loans, deposits, reserves, interbank balances, and discount window loans for the aggregates across each type of bank, respectively.

### 2.3.2 Monetary Policy, Loan Demand, and Deposit Supply

The monetary authority has a simple balance sheet of reserves denoted by \( M^s_t \) and discount window loans to domestic and foreign banks denoted by \( DW^D_t \) and \( DW^F_t \), respectively. The monetary authority sets the corridor rates \( \{r^i_{tor}, r^d_{tor}\} \) to influence banking portfolio decisions via changes in the expected liquidity cost function.\(^{18}\) In the lending stage, the budget of the monetary authority must satisfy

\[
r^i_{tor} M^s_t - r^d_{tor} (DW^D_t + DW^F_t) \leq \tilde{M}^s_{t+1}, \tag{2.3-26}
\]

\(^{18}\)The monetary authority can also influence the market by changing the reserves available with open market operations and may issue private sector loans that capture unconventional monetary policy. This extension is out of the scope of this paper addressing the steady-state solutions of a policy change.
which states that the lending-stage reserves will depend on last period reserves with interest net of the interest retained from discount window loans. The balancing-stage reserves are

\[ M^s_{t+1} = \tilde{M}^s_{t+1} + (DW^D_{t+1} + DW^F_{t+1}), \]  

(2.3-27)

and by substitution, the monetary authority budget constraint becomes

\[ r^i \sigma M^s_t - r^{dW}_t (DW^D_t + DW^F_t) \leq M^s_{t+1} - (DW^D_{t+1} + DW^F_{t+1}). \]  

(2.3-28)

Since policy directly affects both foreign and domestic banks’ interbank lending decisions, it may also indirectly affect the targeted federal funds rate, given the interaction of the two types of agents in the market. For example, in a situation where the expected federal funds rate is lower than the interest on reserve balances, an increase in funds may still result in a tight federal funds market because of the presence of arbitrageurs. In this case, the policy is dampened by their presence.

Lastly, loan demand and deposit supply depend on the relevant market rates and the exogenous semi-elasticity of credit demand \( \epsilon \) and deposit supply \( \nu \), set strictly greater than zero. Market-clearing equilibrium loans and deposits equate with

\[ B^d_{t+1} = \left( \frac{\Theta^b_t}{r^b_{t+1}} \right)^\epsilon \]  

(2.3-29)

and

\[ D^d_{t+1} = \left( \frac{\Theta^d_t}{r^d_{t+1}} \right)^{-\nu}, \]  

(2.3-30)

such that the steady-state conditions determine the intercepts \( \Theta^b_t \) and \( \Theta^d_t \).
2.3.3 Definition of the Competitive Equilibrium and Market-clearing Conditions

The competitive equilibrium is defined given the initial sequence of the distribution of \( \{d^i_0, d^j_0, b^i_0, b^j_0, m^i_{fft}, m^j_{fft}, m^i_{dw}, m^j_{dw}\} \) across banks, the deterministic sequence of government policy variables \( \{\rho_t, M^i_t, M^j_t, r^i_{t^{io}}, r^j_{t^{d^w}}\}_t \geq 0 \), the set of deterministic sequence of real prices \( \{r^b_t, r^d_t\}_t \geq 0 \), the deterministic sequence of aggregate variables \( \{D^+_t, B^+_t, M^+_t, DW^+_t, DW^F_t, X^+_t, X^F_t\}_t \geq 0 \), the stochastic sequence of matching probabilities and the federal funds rate \( \{\gamma^+_t, \gamma^-_t, \gamma^+_D, \gamma^-_D, r^{ff}_t\}_t \geq 0 \), and a stochastic sequence of banks’ policy variables \( \{\tilde{b}^i_{t+1}, \tilde{m}^i_{t+1}, \tilde{d}^i_{t+1}, c^i_t, m^i_{fft}, m^i_{dw}, \tilde{b}^j_{t+1}, \tilde{m}^j_{t+1}, \tilde{d}^j_{t+1}, c^j_t, m^j_{fft}, m^j_{dw}\}_t \geq 0 \), such that

- The variables \( \{\tilde{b}^i_{t+1}, \tilde{m}^i_{t+1}, \tilde{d}^i_{t+1}, c^i_t\} \) solve the domestic bank’s problem.
- The variables \( \{\tilde{b}^j_{t+1}, \tilde{m}^j_{t+1}, \tilde{d}^j_{t+1}, c^j_t\} \) solve the foreign bank’s problem.
- \( \{m^i_{fft}, m^i_{dw}, m^j_{fft}, m^j_{dw}\} \) are given by the conditions in the federal funds market, monetary policy, and the realized shock to deposits.
- The central bank budget constraint given in (2.3-28) is satisfied
- Aggregate loans are consistent with the exogenous demand for loans given by (2.3-29), and aggregate deposits are consistent with the exogenous supply of deposits given by (2.3-30)
- For all \( t \geq 0 \) the market clearing conditions are satisfied.

\[
\begin{align*}
B^D_{t+1} + B^F_{t+1} &= B^d_{t+1} \\
D^D_{t+1} + D^F_{t+1} &= D^*_t \\
M^D_{t+1} + M^F_{t+1} &= M^*_t
\end{align*}
\] (loan market)  
(deposit market)  
(reserves market)
\[
\int_i m^i_{fft+1} di + \int_j m^j_{fft+1} dj = 0 \quad \text{(interbank market)}
\]

- The matching probabilities \{\gamma_t^+, \gamma_t^-, \gamma_{Dt}^+, \gamma_{Dt}^-\} and \(r_t^f\) are consistent with the aggregate surplus and deficit \{\(M_t^-, M_t^+, I_t^+, I_t^-\}\) as is given by (2.3-10), (2.3-11), (2.3-12), and (2.3-13).

### 2.3.4 Government-sponsored agencies (GSEs)

Given the observed presence of GSEs in the market, it is necessary to address the implications for interbank orders and banks’ optimal portfolios. One straightforward extension is to add an exogenous level of interbank lending orders from GSEs introduced to the interbank market at each optimization stage so that the level of GSEs’ lending stays constant through iterations of the banking-side choice. The endogenous federal funds rate is also influenced by the presence of GSEs with an outside lending option of \(r_{rrp}^t\), the Overnight Reverse Repo Facility (ON RRP) rate. For this extension, we define shares of lending orders from each sector so that the mass of lending orders becomes \(M_t^+ = \bar{a}G^+ + shareD_t^+ + (1 - share)F_t^+\). Here, \(D_t^+\) and \(F_t^+\) are the lending order of the representative domestic and foreign banks, and \(G^+\) is the exogenous amount of GSEs’ interbank lending orders. The share of each lender in the aggregate market equals to \(share\), \(1 - share\), and \(\bar{a}\), respectively. In addition, the interbank market-clearing condition becomes

\[
\gamma_t^+(shareD_t^+ + \bar{a}G^+ + (1 - \bar{a} - share)F_t^+) = \gamma_t^- (shareD_t^- + (1 - share)F_t^-). \quad (2.3-31)
\]

From this formulation, we can adjust the probabilities of matching each order with either type of lender and the corresponding expected federal funds rates given the outside option for a GSE equals \(r_{rrp}\).
2.4 Model Solution

2.4.1 Solving the Banking Model

The model closely follows the related Bianchi and Bigio model (denoted as the BB model). Rather than repeating their seminal work, I describe some features of the extended domestic and foreign banking model (denoted by the DF model) in the model’s solution and refer the reader for details for its derivation to Bianchi & Bigio (2022).

Adding foreign banks to the model entails significant differences in the steady-state solution and conclusion for optimal portfolio choice. The main differences between the two banking sectors are the value of reserves in the budget constraint (the balance-sheet cost) and each sector’s distribution of the idiosyncratic shock $\omega$, as observed in the data. The latter assumption supports that U.S. branches of foreign banks’ uninsured wholesale deposits expose the bank to higher risk. The steady-state results show that this higher risk increases foreign banks’ excess reserves as expected while also changing domestic banks’ optimal portfolio choice of reserves. Albeit the relatively small share of the foreign sector to the domestic sector, foreign banks’ increase in precautionary reserves reduces the interbank market tightness and thereby lowers the liquidity cost. We can see the reasoning in the model’s solution.

Let $V_t^l(\cdot)$ define the value function of a domestic bank during the lending stage and $V_t^b(\cdot)$ the value function of a domestic bank during the balancing stage. The lending-stage stochastic problem can be stated recursively as

$$
V_t^l(E_t^l) = \max_{\{b_{t+1}, \tilde{m}_{t+1}, \tilde{d}_{t+1}, c_t^l\}} u(c_t^l) + \mathbb{E}_{\omega_t, \omega_t^l} \left[ V_t^b \left( \tilde{b}_{t+1}, \tilde{m}_{t+1}^l, \tilde{d}_{t+1}^l, \omega_t^l \right) \right],
$$

subject to the budget, capital, and non-negative constraints in Equations (2.3-2), (2.3-3), and (2.3-4), with bank preferences described in Equation (2.3-1). Then in the balancing stage, the decision problem of the domestic banks summarized recursively...
follows

\[
\text{balance } V_t^i (\tilde{d}_{t+1}, \tilde{b}_{t+1}, \tilde{m}_{t+1}, \omega_t^i) = \beta V_{t+1}^i \left( d_{t+1}^i, b_{t+1}^i, m_{t+1}^i, m_{ft,t+1}^i, m_{dwt,t+1}^i | \theta_t \right),
\]

given (2.3-18), (2.3-19), (2.3-5), (2.3-21), and (2.3-20). With the definition of equity, substituting the balancing-stage conditions into the end-of-stage variables arrives at

\[
E_{t+1}^i = r_{t+1} \tilde{b}_{t+1} + (r_{t+1} - \text{tax}_t) \tilde{m}_{t+1} - r_{t+1}^d \tilde{d}_{t+1} + \chi_{D_{t+1}} (\tilde{m}_{t+1}, \tilde{d}_{t+1}, \omega_t^i | \theta_t). \tag{2.4-32}
\]

By substituting the above into the lending-stage value function, we get

\[
\text{lend } V_t^i (E_t^i) = \max_{\{\tilde{b}_{t+1}, \tilde{m}_{t+1}, \tilde{d}_{t+1}, \tilde{c}_t^i\}} u(\tilde{c}_t^i) + \mathbb{E}_{\omega_t} \left[ \beta V_{t+1}^i (E_{t+1}^i | \theta_t) \right]
\]

subject to (2.3-2), (2.3-3), (2.4-32), and (2.3-4). \( \theta \) is endogenously determined by the aggregate ratio of borrowing to lending orders in the federal funds market and depends on both banking sectors’ optimal decisions.

Similarly, by defining \( V_t^j (\cdot) \) and \( V_t^j (\cdot) \) as the value function of a foreign bank during the lending and balancing stage, we arrive at the single-stage-stochastic recursive problem of

\[
\text{lend } V_t^j (E_t^j) = \max_{\{\tilde{b}_{t+1}, \tilde{m}_{t+1}, \tilde{d}_{t+1}, \tilde{c}_t^j\}} u(\tilde{c}_t^j) + \mathbb{E}_{\omega_t} \left[ \beta V_{t+1}^j (E_{t+1}^j | \theta_t) \right],
\]

subject to (2.3-2), (2.3-3), (2.3-4), and

\[
E_{t+1}^j = r_{t+1} \tilde{b}_{t+1} + r_{t+1}^{iorn} \tilde{m}_{t+1} - r_{t+1}^d \tilde{d}_{t+1} + \chi_{F_{t+1}} (\tilde{m}_{t+1}, \tilde{d}_{t+1}, \omega_t^j | \theta_t). \tag{2.4-33}
\]

This result follows since the bank’s choice is already made once the withdrawal shock is realized. All that matters in the lending stage is the expectations of the shock and the liquidity cost function associated with such shock. Thus there is no
maximization in the balancing stage but rather a deterministic end-of-stage portfolio of a bank given the aggregate market conditions for liquid funds.

Bianchi & Bigio (2022) further show that given the homogeneity of the utility function in $\eta$, we have that $V_t(E_t) = v_t E_t^{1-\eta} - \frac{1}{(1-\beta)(1-\eta)}$ for some function $v_t$. It follows that the maximization problem equals

$$v_tE_t^{1-\eta} - \frac{1}{(1-\beta)(1-\eta)} = \max_{\{b_{t+1}, m_{t+1}, d_{t+1}, c_t\}} \frac{c_t^{1-\eta}}{1-\eta} + \mathbb{E} \left[ \beta v_{t+1} E_{t+1}^{1-\eta} - \frac{1}{(1-\beta)(1-\eta)} \right],$$

then scaling the choice variables by $(1 - \frac{c_t}{E_t})E_t$ and defining

$$\tilde{c}_t = \frac{c_t}{E_t},$$

the real return on equity is expressed as

$$R_{t+1}^e = \frac{1}{(1 - \tilde{c})E_t} \left( r_{t+1}^{\text{bor}} \tilde{b}_{t+1} + (r_{t+1}^{\text{for}} - \text{tax}_t) \tilde{m}_{t+1} - r_{t+1}^{d} \tilde{d}_{t+1} + \chi_{t+1}(\tilde{m}_{t+1}, \tilde{d}_{t+1}, \omega|\theta_t) \right).$$

For a foreign bank, the tax is zero. Furthermore, the liquidity cost function denoted by $\chi$ is specific to each type of bank and depends on the idiosyncratic shock of each bank and the resulting market tightness denoted by $\theta_t$.

By substitution

$$v_tE_t^{1-\eta} = \max_{\tilde{b}_t, \tilde{m}_t, \tilde{d}_t \leq 0} \left[ \left( \frac{\tilde{c}_t E_t}{1-\eta} \right)^{1-\eta} + \beta (1 - \tilde{c})E_t^{1-\eta} \mathbb{E}[v_{t+1}(R_{t+1}^e)^{1-\eta}] \right],$$

subject to

$$\frac{\tilde{b}_{t+1} + \tilde{m}_{t+1} - \tilde{d}_{t+1}}{(1 - \tilde{c})E_t} = 1, \quad (2.4-34)$$

and

$$\frac{\tilde{d}_{t+1}}{(1 - \tilde{c})E_t} \leq \kappa. \quad (2.4-35)$$
Define

$$
\Omega_t \equiv \max_{\{\bar{b}_{t+1}, \bar{m}_{t+1}, \bar{d}_{t+1}, \bar{c}_t\}} \mathbb{E} \left\{ R_{t+1}^{\varepsilon_{1-\eta}} \right\}^{\frac{1}{1-\eta}}
$$

It follows that

$$
v_t = \frac{1 + (\beta(1 - \eta)\Omega_t^{1-\eta})^{1-\eta}}{1 - \eta},
$$

and from the first-order conditions of the maximization with respect to \(\bar{c}_t\)

$$
\bar{c}_t = \frac{1}{1 + (\beta v_{t+1}(1 - \eta)\Omega_t^{1-\eta})^{1/\eta}}
$$

For proofs and derivation, see Bianchi & Bigio (2022).

In what follows, I assume the log-linear utility as \(\eta \to 1\). Then the problem can be characterized with

1. A single bellman equation for each type of bank

$$
\Omega_t^i = \max_{\bar{b}_t^i, \bar{m}_t^i, \bar{d}_t^i \leq 0} \mathbb{E} \left\{ \ln \left( R_{t+1}^{c_i}(\bar{b}_t^i, \bar{m}_t^i, \bar{d}_t^i) \right) \right\},
$$

subject to the scaled balance-sheet constraint, and scaled capita constraint and non-negativity constraint as in (2.4-34), (2.4-35), and (2.3-4) for domestic banks with \([\bar{b}_t^i, \bar{m}_t^i, \bar{d}_t^i] = (1 - \bar{c}_t^i)E_t^i[\bar{b}_t^i, \bar{m}_t^i, \bar{d}_t^i]\), and

$$
\Omega_t^j = \max_{\bar{b}_{t+1}^j, \bar{m}_{t+1}^j, \bar{d}_{t+1}^j \leq 0} \mathbb{E} \left\{ \ln \left( R_{t+1}^{c_j}(\bar{b}_{t+1}^j, \bar{m}_{t+1}^j, \bar{d}_{t+1}^j) \right) \right\},
$$

subject to the relevant (2.4-34), (2.4-35), and (2.3-4) for foreign banks with \([\bar{b}_t^j, \bar{m}_t^j, \bar{d}_t^j] = (1 - \bar{c}_t^j)E_t^j[\bar{b}_t^j, \bar{m}_t^j, \bar{d}_t^j]\),

2. the value functions

$$
V_t^i(E_t^i) = v_t^i \ln(E_t^i),
$$
and

\[ V_t^j(E_t^j) = v_t^j\ln(E_t^j) \]

where

\[ \lim_{\eta \to 1} (1 - \eta)v_t = 1/(1 - \beta). \]

3. So that the optimal bank equity dividend ratios are

\[ \frac{c_t^i}{E_t^i} = 1 - \beta \]

and

\[ \frac{c_t^j}{E_t^j} = 1 - \beta. \]

Because the policy functions are linear in their equity, two banks of the same type with different equity levels are a scaled version of a bank with one equity unit. In other words, only aggregate equity of each type is a state variable for the banking side of the model with no account for the distribution of equity between individual banks within a sector; the steady-state results measure the portfolio shares of each type of representative bank. In this sense, economic aggregates, such as the steady-state solution, the distribution of reserves, and the interbank lending activity of each type of bank are scaled by the sector’s size. For example, suppose we had $5 billion worth of equity for domestically charted banks and $1 billion associated with U.S. foreign branches and agencies. In that case, the aggregates for each sector will multiply by the respective relative size of 5:1.

All banks face the same portfolio problem and interbank market conditions in the BB model. Alternatively, in the DF model, the cost function and the withdrawal shock differ across the two sectors. Because a bank’s decision is based on the expected liquidity cost, it depends on the given outside rates available to each type of bank and the market tightness. The latter is endogenous to the aggregate interbank market.
conditions that depend on the optimal choice of each type of bank and, therefore, may change the outcome of the federal funds rate.

For example, looking at the first-order conditions for reserves

\[
\frac{\partial \Omega}{\partial m} : R^b - R^m = \mathbb{E}_\omega \left( \frac{\partial \chi_t(\cdot)}{\partial m} \right) + \frac{\text{COV}_\omega \left( (R^e)^{-1}, \frac{\partial \chi_t(\cdot)}{\partial m} \right)}{\mathbb{E}_\omega \left( R^e_t \right)^{-1}},
\]

we see that a bank’s choice to increase reserves until the marginal cost equals the liquidity benefit/cost associated with lending/borrowing reserves in the federal funds market. The first term is simply the marginal cost or benefit given by the market conditions, and the second term is the risk premium associated with the withdrawal shock. If foreign banks choose large excess reserves (either because of the higher risk of withdrawals or the differential of overnight rates), it will lower a domestic bank’s deficit cost while increasing their opportunity cost of reserves.

2.4.2 Evolution of Equity and Equity Growth for Stationary Equilibrium

To establish the law of motion for the aggregate equity of each type of bank, we integrate across banks the definition of its equity and iterate one period forward to arrive at

\[
E_{t+1}^D = \tilde{M}_{t+1}^D (r_{t+1}^{ior} - t a x_{t+1}) + \tilde{B}_{t+1}^D r_{t+1} - D_{t+1}^D r_{t+1}^{d} - D W_{t+1}^D (r_{t+1}^{dw} - r_{t+1}^{ior} - t a x_{t+1})
- X_{t+1}^D (r_{t+1}^{ff} - r_{t+1}^{ior} - t a x_{t+1})
\]

(2.4-36)

and

\[
E_{t+1}^F = \tilde{M}_{t+1}^F r_{t+1}^{ior} + \tilde{B}_{t+1}^F r_{t+1} - D_{t+1}^F r_{t+1}^{d} - D W_{t+1}^F (r_{t+1}^{dw} - r_{t+1}^{ior}) - X_{t+1}^F (r_{t+1}^{ff} - r_{t+1}^{ior}).
\]

(2.4-37)

Because the model is scale-invariant, the steady-state solution must only keep track of the evolution of the average equity of each of the two banking sides. Define the average equity of each sector as \( \bar{E}_i \equiv \frac{1}{\text{share}} \int_0^{\text{share}} E_i^i d\text{share} \) and \( \bar{E}_j \equiv \frac{1}{1-\text{share}} \int_{\text{share}}^1 E_j^j d\text{share} \).
Using the equation for the domestic surplus, Equation 2.3-5, for every $E^i_t$, there is a common $\omega^i_t = \frac{\rho - \bar{m}^i_t/\bar{d}^i_t + \bar{c}^i_t}{d_t/\bar{d}^i_t - (r^i_t + \text{tax}_t + \rho)}$, implying a mass of reserves deficit in the domestic sector given by

$$I^- = \mathbb{E}_t[s(x(\omega^i))] \omega^i_s \left[ s(x(\omega^i)) | \omega^i < \omega^i_t \right] D \left[ \frac{\rho - \bar{m}^i_t/\bar{d}^i_t + \bar{c}^i_t}{d_t/\bar{d}^i_t - (r^i_t + \text{tax}_t + \rho)} \right] E^i_t$$

(2.4-38)

and a mass of the domestic surplus of reserves following

$$I^+ = \mathbb{E}_t[s(x(\omega^i))] \omega^i_s \left[ s(x(\omega^i)) | \omega^i > \omega^i_t \right] \left( 1 - D \left[ \frac{\rho - \bar{m}^i_t/\bar{d}^i_t + \bar{c}^i_t}{d_t/\bar{d}^i_t - (r^i_t + \text{tax}_t + \rho)} \right] \right) E^i_t.$$  

(2.4-39)

Similarly, using the equation for foreign surplus in Equation 2.3-6, for every $E^j_t$, there is a common $\omega^j_t = \frac{-\bar{m}^j_t/\bar{d}^j_t}{r^i_t + \rho}$. The mass of foreign deficit and surplus reserves follows

$$J^- = \mathbb{E}_t[s(x(\omega^j))] \omega^j_s \left[ s(x(\omega^j)) | \omega^j < \omega^j_t \right] F \left[ \frac{-\bar{m}^j_t/\bar{d}^j_t}{d_t/\bar{d}^j_t - (r^j_t + \text{tax}_t + \rho)} \right] E^j_t,$$

(2.4-40)

and a mass of the foreign surplus of reserves follows

$$J^+ = \mathbb{E}_t[s(x(\omega^j))] \omega^j_s \left[ s(x(\omega^j)) | \omega^j > \omega^j_t \right] \left( 1 - F \left[ \frac{-\bar{m}^j_t/\bar{d}^j_t}{d_t/\bar{d}^j_t - (r^j_t + \text{tax}_t + \rho)} \right] \right) E^j_t.$$  

(2.4-41)

To arrive at a growth rate, rewrite the law of motion of aggregate equity in Equations 2.4-36 and 2.4-37 , using the definitions of real returns for each type of bank and substituting the balancing-stage overnight funds as in Equations 2.3-21 and 2.3-25. Then with the scale-invariant properties of the mass of reserves, we have that

$$E^D_t = \left( \bar{m}^i_t + \bar{c}^i_t \right) \left( r^i_t + \text{tax}_t + \rho \right) E^i_t$$

(2.4-42)
and
\[
E^{E}_{t+1} = (\bar{m}^{i}_{t+1} r^{ior}_{t+1} + \bar{b}^{j}_{t+1} r^{d}_{t+1} - J^{-} (1 - \gamma^{-}) (r^{dw}_{t+1} - r^{ior}_{t+1}) \\
- [J^{-} \gamma^{-} - J^{+} \gamma^{+}] (r^{ff}_{t+1} - r^{ior}_{t+1})] E^{E}_{t} (1 - \bar{c}^{j}).
\]

(2.4-43)

It follows that the equity growth is equal to
\[
E^{D}_{g} \equiv \beta (\bar{m}^{i}_{t+1} (r^{ior}_{t+1} - tax_{t+1}) + \bar{b}^{j}_{t+1} r^{d}_{t+1} - J^{-} (1 - \gamma^{-}) (r^{dw}_{t+1} - r^{ior}_{t+1}) \\
- [J^{-} \gamma^{-} - J^{+} \gamma^{+}] (r^{ff}_{t+1} - r^{ior}_{t+1} + tax_{t+1}))
\]

and
\[
E^{F}_{g} \equiv \beta (\bar{m}^{i}_{t+1} r^{ior}_{t+1} + \bar{b}^{j}_{t+1} r^{d}_{t+1} - J^{-} (1 - \gamma^{-}) (r^{dw}_{t+1} - r^{ior}_{t+1}) - [J^{-} \gamma^{-} - J^{+} \gamma^{+}] (r^{ff}_{t+1} - r^{ior}_{t+1})).
\]

The equity growth rate is zero in a steady-state stationary equilibrium, so
\[
E^{D}_{g} = E^{F}_{g} = 1.
\]

2.5 Results

2.5.1 Data and Parameter Calibration

Calibration of bank-specific parameters uses the Federal Financial Institutions Examination Council (FFIEC) quarterly filings. FFIEC 031, Reports of Condition and Income (also known as the Call Reports) for domestically chartered banks, and FFIEC 002, the Report of Assets and Liabilities for branches and agencies of foreign banking organizations. The federal funds market operates daily, and ideally, one would calibrate the specific withdrawal of banks using daily data on the operations of the federal funds market. Such data exists for domestically chartered banks but
is not available for foreign branches and agencies before 2016. The lack of earlier
data on foreign banks is a problem because the data post the introduction of IOR
does not reveal the liquidity constraints of financial institutions and henceforth is not
applicable for our purpose.

Instead, I impute daily volatility for foreign banks using the ratio of quarterly
volatility across foreign and domestic banks, measured by the cross-sectional devi-
ation from the mean of each sector, and then multiplied by the daily volatility of
domestic banks. Afonso & Lagos (2015) measure the volatility to equal 0.05 based
on the daily volumes of federal funds traded as reported in FR 2420 by a sample of
134 banks.\textsuperscript{19}

Table 2.1 reports the summary statistics of total deposits, transaction accounts,
non-transaction accounts, and demand deposits, measured between 2005 Q1 to 2011
Q4 for each sector. We want to measure the liquidity need, ideally measured by total
deposits. However, since foreign branches and agencies do not file the same report
as domestically chartered banks, total deposits are not comparable between the two
sectors,\textsuperscript{20} and thus, the observed difference between the two columns could result
from the differences in the reporting form. Demand deposits are not best suited to
measure actual liquidity since these are deposits for which most transactional activi-
ties occur. However, it lends a good proxy for the difference in the volatility ratios of
total deposits because they are defined identically between the two reporting forms.

\textsuperscript{19}These banks are all domestically charted since, as mentioned, foreign branches and agencies
were not required to fill this form during this study period. The volumes are reported daily by
financial institutions in FR 2420 form but are confidential. The available data on the daily volume
is aggregated over all banks. Beginning June 2016, as part of Dodd-Frank Act recommendations,
the Fed required that FBOs with total consolidated assets of $50 billion or more establish a U.S.
intermediate holding company (IHCs). These companies must file specific reports such as FR Y-9
post the new legislation so that the aggregate volume is now available separately for domestic and
foreign banks.

\textsuperscript{20}Domestically chartered banks report total deposits, while foreign branches and agencies report
total deposits and credit balances. Domestically chartered banks report the total transaction ac-
counts, while foreign branches and agencies report the total transaction accounts and credit balances.
Similarly, domestically chartered banks report the total transaction accounts, while foreign branches
and agencies report the total transaction accounts and credit balances.
The reserve to asset ratio corresponding with different IORB rates. The red line for a higher deposit withdrawal volatility and the blue corresponds to a lower volatility.

The cross-sectional deviation of demand deposits is 0.210 for domestically chartered banks and 0.502 for foreign branches and agencies, or 2.3 times larger for foreign banks, as shown in Table 2.1. Given the empirical evidence that domestic withdrawal volatility is $\sigma_D = 0.05$ (Afonso & Lagos, 2015) and the proportion of fluctuations between the two sectors, we estimate the deviation of the withdrawal distribution for foreign banks to be $\sigma_F = 0.115$.

Figure 2.1 is an example of the steady-state effect of an increase in the volatility of withdrawals. It shows that a ceteris paribus increase in volatility will result in a higher increase of reserves in response to a policy of interest on reserve balances. We see that with the current calibration, the slope of uninsured banks is steeper. The steep slope corresponds with a greater increase in reserves to assets following a change in the IOR rate.

Other parameters of the federal funds market are market tightness and the bargaining parameter. The market tightness reflects the rate at which orders are matched,
and it is equal to $\lambda = 2.1$, as documented by Bianchi & Bigio (2022). They calibrate this by the same empirical evidence presented in Afonso & Lagos (2015) and set it to match the Fed’s fraction of discount window loans as a fraction of the total reserves. The bargaining power $\phi_t$ is endogenous and depends on whether lending orders are greater than borrowing orders or vice versa. The benchmark $\bar{\phi} = 0.5$ is set such that when lending and borrowing orders are equal $\phi_t = \bar{\phi}$, and the federal funds rate is equal to the midpoint of the banks’ second-best rates.\footnote{Appendix B.4 describes the function for $\phi$ in more detail.}

The four dates in Table 2.2 compare two policy regimes implemented during two periods: prior to and post the introduction of IOR and the change in the FDIC assessment. Steady-state values are reported in the next section. The first reference dates are 2008 Q3 and 2008 Q4, before and after introducing interest on reserves. The reference dates for the FDIC policy are 2011 Q2 and 2011 Q3, respectively. The FDIC policy was implemented in April of 2011, but the data suggest that banks did not adjust to the policy before the third reporting quarter.

The first part of the table summarizes the parameters that stay constant throughout the different policy regimes and are consistent with those calibrated by Bianchi & Bigio (2022). Other than the federal funds market parameters already discussed, these include bank preferences parameters denoted by $\{\beta, \eta\}$, and regulatory param-

<table>
<thead>
<tr>
<th>Variable</th>
<th>Domestically chartered banks</th>
<th>Foreign branches and agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Deposits*</td>
<td>Mean 1</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. 2</td>
<td>Std. Dev. 2</td>
</tr>
<tr>
<td></td>
<td>N\footnote{3}</td>
<td>N</td>
</tr>
<tr>
<td>Transaction Accounts*</td>
<td>-0.002 0.032 170912</td>
<td>-0.020 0.437 4424</td>
</tr>
<tr>
<td>Demand Deposits</td>
<td>-0.008 0.210 171164</td>
<td>-0.049 0.502 4256</td>
</tr>
<tr>
<td>Non-Transaction Accounts</td>
<td>-0.003 0.053 171164</td>
<td>-0.054 0.643 4564</td>
</tr>
</tbody>
</table>

\*The mean is the average of the cross-sectional means of the deviation from deposit growth at each period.
\*\*Total deposits of foreign branches and agencies are defined as total deposits and credit balances, and therefore may not be comparable to that of a domestic bank.
\footnote{Appendix B.4 describes the function for $\phi$ in more detail.}
eters \(\{\kappa, \rho\}\). The discount factor \(\beta = 0.981\) is calibrated to match a dividend capital interest ratio of 8\%, consistent with the literature, and the risk aversion \(\eta = 1\), implies a constant dividend-equity ratio. Both parameters are assumed to be the same across the two sectors. The regulatory parameters \(\kappa = 10\) and \(\rho = 0.1\) are consistent with a leverage ratio and reserve requirements of 90\% capital and 10\% reserves.

The relative size of domestic banks to U.S. branches of foreign banks is denoted by share and measured to be relatively constant at 85\% across the study period. This parameter is necessary to adequately estimate the probabilities of meeting different borrowers or lenders in the interbank market. The extension to the model, including GSEs, calibrates their relative size to banks at around 40\% during the relevant period and is denoted by \(a\). Overnight loans by GSEs in the federal funds market dominate the market during the Fed’s large-scale asset purchases (Craig & Millington, 2017). However, an exact number for the number of loans is not available. The total cash assets of GSEs are estimated to be $250 billion (Afonso et al., 2019), so overnight loan orders are estimated to equal 5\% of GSEs’ total equity based on the number of aggregate cash assets to total assets held by GSEs.

The second part of Table 3.3 summarizes the parameters that change between the four periods and includes regulatory parameters \(\{i_{ior}, i_{dw}, tax\}\), which are the interest on reserves, the discount window rate, and the FDIC tax assessment, respectively. The IOR is calibrated to that from FRED, Federal Reserve Bank of St. Louis. The discount window rate is calibrated to include an additional 44 monthly basis points than the reported rate estimated by Armantier et al. (2015). They document the stigma premium from the rate in the Term Auction Facility. The Term Auction Facility is an additional lending facility for banks to avoid borrowing from the discount window because borrowing from the Fed renders a bank unstable and risky, given it is a means of last resort.\(^{22}\)

\(^{22}\)Armantier et al. (2015) observe that banks will choose to pay on average 44 basis points more on a 30-day loan in the federal funds market to avoid the stigma associated with borrowing from the
The FDIC assessment base rate is calibrated to approximate the average rate paid by the average bank. In practice, CAMELS ratings are used to determine the risk category for a given bank. Riskier or larger banks pay more, meaning that the policy may have or may not have changed the individual assessment banks pay. However, it shifted costs from deposits to holding excess reserves and, more importantly, changed funding strategies. In what follows, we explore this effect on the average bank.23

The actual tax may range from 2.5 to 45 basis points depending on the bank’s risk category. For example, the assessment rate is between 9-24 basis points for a low to medium risk rating (Whalen, 2011). This exercise follows the approximation of Kotok (2011) that the new assessment aggregate response was equivalent to a tightening of central bank. However, they note that only the rate paid is observable. Therefore, the estimated stigma is a lower bound on what banks are willing to pay in the TAF facility. The estimated lower bound of this premium was as high as 146 basis points during the Lehman Brothers bankruptcy and could potentially be much more significant.

23 Although a detailed model of banks with different rates based on their risk categories is of great interest in assessing if this policy results in financial stability, it is out of this paper’s scope.
15 basis points, or a \( \text{tax} = 0.15\% \), which is a reasonable assumption since it lies in the mid-range.

### 2.5.2 Steady-State Results

The steady-state tables below provide four quantitative exercises. First, we look at the fit of the model against the observed aggregate interbank data and each sector’s aggregate reserve ratios during four reference periods. Table 2.3 compares Q3 of 2008 to Q4 of the same year, while Table 2.4 reports the subsequent Q2 of 2011 and Q3 of 2011.\(^{24}\) We compare these periods to embed two critical changes in the model: the period with interest on excess reserves (introduced to bound historically low-interest rates away from zero) and the period for which the FDIC assessment base changed. The FDIC policy essentially created a difference in the outside lending option facing domestically chartered banks to foreign branches and agencies.

The second quantitative exercise examines some of the key differences between the single representative bank and the Baseline model (with two banking sectors) to the Extended version, including GSEs. Table 2.5 shows that the implications of monetary policy of interest on excess reserves are different across the three models. The following exercise, examined in Tables 2.6 and 2.7, uses counterfactual parameters to compare the implication of the two features distinguishing domestic from foreign banks and estimate which of the two channels embedded in the model is prominent in the observed outcome of the interbank market. Following this are other counterfactuals to estimate the long-run effects of a change in additional policy tools on the market and the bank’s optimal choice. These tools include the overnight reserve repurchase rate for GSEs in Table 2.8, the discount window rate in Table 2.9, the FDIC assessment rate in Table 2.10, and the withdrawal shock of banks in Table 2.11.\(^{24}\)

\(^{24}\)The exception is that the yearly discount window rate is 44 monthly basis points higher than the reported discount window rate, as Armantier et al. (2015) estimated, due to stigma that may signal to a low-quality borrower.
Before 2008 the federal funds market operated under a scarcity of funds. After that, large-scale asset purchases by the Fed increased the abundance of available overnight funds resulting in a satiated market. In addition, because GSEs could not receive interest on excess reserves, they became the absolute lenders of overnight funds during this period. We document that bank lending in the interbank market fell from over 50% in 2006 to less than 20% by 2012. One way to calibrate this situation is by adding an exogenous level of lending orders at each iteration. Meaning that no matter the banking side choice of reserves, following the withdrawal shock, total lending orders include those by banks and an additional exogenous amount by GSEs. GSEs’ lending is assumed to face a second-best lending rate of ON RRP rate, equal to zero until September 2013. Below, the Baseline model refers to the two-sector model with no GSEs, and the Extended model, to that including GSEs facing an ON RRP rate equal to zero, while the effects of a change in the ON RRP rate are reserved for Table 2.8.

2.5.2.1 Steady-state across the two policy changes:

The three columns in Tables 2.3 and 2.4 correspond to the data, Baseline, and Extended models. The first two rows consist of lending-stage portfolio choices of each representative bank with reserves to assets equaling the ratio of liquid assets to total assets as reserves are the only liquid asset in the model. On the other hand, the reserves to asset ratio for the data column is aggregated from the individual financial Call Reports. Similarly, the reserve ratio in the model is a measure of bank liquidity, while the reserve to deposit ratio is from the Call Reports. This comparison can be misleading because banks hold various liquid assets, but it gives insight into the model’s bearing.\footnote{The appendix reports the data of liquid assets holdings, including securities of each banking sector as a function of total assets and total deposits. Although this data is more closely estimated with the Extended model, I do not use these for the comparison as the items on each of the two sectors’ balance sheets are slightly different.}
The second part of the following two tables reports the shares of interbank market activity with data on interbank borrowing and lending available from the Federal Reserves Bank of New York. Only banks generally generate interbank borrowing since they need them to clear transactions. The total borrowing share is the share of the two sectors. In contrast, interbank lending is available from different financial institutions, where historically, GSEs have been the major lenders of funds. The share of bank lending is the share of each sector as a fraction of only bank lending and is comparable to the interbank lending in the Baseline model. Total lending share is the share of each sector from the entire pool of lending observed in the market and is comparable to the interbank lending share in the Extended model, which includes GSEs. The last part of these tables reports the data and estimations of discount window loans to reserves and the interbank market rate (the effective federal funds rate) reported by the Federal Reserve Board of Governors and retrieved by the FRED website. The last row provides the estimated overall market tightness.\(^26\)

Table 2.3 is partitioned into two parts, first comparing the parameter specification of the third quarter of 2008 and below comparing the effect of IOR policy in the last quarter of 2008. We generally find somewhat better estimations with the Extended model in the third column across both periods. However, before the policy change, the models’ predictions of domestic reserves were too high, while foreign reserves were too low. As noted, because reserves are the only liquid asset in the model, this is expected. Similar conclusions apply to the ratios of the reserve to deposits. Notably, GSEs’ lending reduces the ratios substantially as the market tightness is lower with their presence. Therefore, we see that the liquidity premium is also lower with the Extended model but not low enough to match the empirical data on the federal funds rate (moving from 2.34% to 1.91% compared to the empirical average of 1.91% going

\(^{26}\)Market tightness equals \(100 \times \frac{\theta}{(1+\theta)}\) and reports the probability of matching a lending order. Thus the higher the probability, the higher the scarcity of overnight funds, the larger the bargaining power of lenders, and vice versa.
Table 2.3: Steady-state Calibrated to 2008 Q3 and 2008 Q4

<table>
<thead>
<tr>
<th></th>
<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserves to Assets</td>
<td>1.6%</td>
<td>0.5%</td>
<td>9.4%</td>
<td>1.2%</td>
<td>5.3%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>2.4%</td>
<td>0.9%</td>
<td>10.4%</td>
<td>1.3%</td>
<td>5.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Total Borrowing Share</td>
<td>55.7%</td>
<td>44.3%</td>
<td>70.0%</td>
<td>30.0%</td>
<td>85.4%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Bank Lending Share</td>
<td>42.4%</td>
<td>57.6%</td>
<td>68.1%</td>
<td>31.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Lending Share</td>
<td>15.8%</td>
<td>21.5%</td>
<td></td>
<td></td>
<td>1.7%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Discount Window Share</td>
<td>0.9%</td>
<td>0.2%</td>
<td>3.7%</td>
<td>1.0%</td>
<td>33.6%</td>
<td></td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.94%</td>
<td></td>
<td>2.85%</td>
<td>2.24%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Tightness</td>
<td></td>
<td></td>
<td>44.1%</td>
<td>22.5%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserves to Assets</td>
<td>4.4%</td>
<td>6.5%</td>
<td>11.6%</td>
<td>6.6%</td>
<td>11.2%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>6.6%</td>
<td>10.3%</td>
<td>12.7%</td>
<td>7.3%</td>
<td>12.3%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Total Borrowing Share</td>
<td>67.5%</td>
<td>32.5%</td>
<td>70.7%</td>
<td>29.3%</td>
<td>68.9%</td>
<td>31.1%</td>
</tr>
<tr>
<td>Bank Lending Share</td>
<td>70.5%</td>
<td>29.5%</td>
<td>68.6%</td>
<td>31.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Lending Share</td>
<td>23.2%</td>
<td>9.7%</td>
<td></td>
<td></td>
<td>0.5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Discount Window Share</td>
<td>0.5%</td>
<td>0.1%</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.4%</td>
<td></td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>0.51%</td>
<td></td>
<td>2.57%</td>
<td>1.91%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Tightness</td>
<td></td>
<td></td>
<td>17.5%</td>
<td>21.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The table compares two models to the data: The Baseline model consisting of foreign and domestic banks and the Extended model of two bank sectors and GSEs.

The estimations would be better with higher liquidity (calibrating more available lending from GSEs) or a lower stigma associated with the discount window rate. Both these calibrations are not perfect empirical measures. The amount of aggregate cash to assets and the ratio of GSEs’ assets to bank assets are used to estimate GSEs lending share in the absence of a better measure. Likewise, the stigma may depend on the scarcity of funds (meaning it might be higher at times of aggregate financial distress). Appendix B.1 includes Tables B.1 and B.2, with an alternative specification of these tables having no additional’ stigma’ premium and are consistent with the general results, albeit the optimal reserves of both sectors and the federal funds rate are low in this case.

Above all, the models capture well the change in reserve ratios in response to the policy change. As seen in the second part of the table, the inclusion of IOR implies the ratios of domestic banks doubled while those of foreign banks increased from 0.5% to 6.5%. Although domestic reserves are still too high in the model, the ratios down to 0.97% across the two periods).
double, explicitly from 5.3% to 11.2% in the Extended model. The Baseline model’s predictions are conversely less consistent with the data moving from 9.4% to 11.6%. However, foreign reserves ratios in both models are within the magnitude and rate of change of the empirical evidence.

In addition, interbank shares estimated by the model are comparable to the data for the period following the IOR policy. Domestic bank lending share estimate is around 69% compared to 71% in the data, and the borrowing share is around 70.0% compared to 74%. The total lending share in the third column of the Extended model is equal to zero. At the same time, we observe a decline in foreign bank lending following policy but an increase in the share of domestic lending. Still, the data on interbank lending is limited because it only reports interbank loans of Federal Home Loan banks rather than all lending by GSEs- so again, this will not be a perfect match. Historically GSEs such as Fannie Mae and Freddie Mac report federal funds jointly with repo transactions and therefore are excluded from the available data during this period. In practice, we expect the lending of GSEs to take up a more significant share of total lending than that reported in the table.

Table 2.4 repeats the comparison but coincides with the two reference periods before and preceding the FDIC policy change. The change in the deposit insurance assessment base increased the balance sheet cost associated with domestic reserves. Therefore, it essentially differentiated the outside lending rate across domestic and foreign banks. The data shows very high reserve ratios for the foreign sector that are nowhere close to what is estimated by the two models, as seen in columns two and three of this table. Even so, we find the FDIC policy change in the model estimates foreign banks will slightly increase or not change reserve ratios, and domestic banks will slightly reduce them. We will see in the preceding counterfactual steady-state that the tax on domestic reserves can replicate the ratios of reserves held by banks, but these necessitate a higher interest on reserves and a higher assessment cost. More-
Table 2.4: Steady-state Calibrated to 2011Q2 and 2011 Q3

<table>
<thead>
<tr>
<th></th>
<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserves to Assets</td>
<td>5.9%</td>
<td>31.5%</td>
<td>11.4%</td>
<td>6.2%</td>
<td>10.3%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>8.2%</td>
<td>59.7%</td>
<td>12.5%</td>
<td>6.8%</td>
<td>11.3%</td>
<td>3.8%</td>
</tr>
<tr>
<td>Total Borrowing Share</td>
<td>38.5%</td>
<td>61.5%</td>
<td>70.7%</td>
<td>29.3%</td>
<td>70.4%</td>
<td>29.6%</td>
</tr>
<tr>
<td>Bank Lending Share</td>
<td>65.5%</td>
<td>34.5%</td>
<td>68.6%</td>
<td>31.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Lending Share</td>
<td>10.6%</td>
<td>5.6%</td>
<td></td>
<td></td>
<td>8.5%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Discount Window Share</td>
<td>0.97%</td>
<td>8.1%</td>
<td>0.3%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>0.09%</td>
<td>2.00%</td>
<td></td>
<td></td>
<td>1.82%</td>
<td></td>
</tr>
<tr>
<td>Market Tightness</td>
<td>–</td>
<td>19.1%</td>
<td></td>
<td></td>
<td></td>
<td>8.2%</td>
</tr>
</tbody>
</table>

* The table compares two models to the data: The Baseline model consisting of foreign and domestic banks and the Extended model of two bank sectors and GSEs

over, the reduction in reserve ratios is coupled with a slightly lower interbank rate; however, still too high.

The comparison of the two policies concludes that the model predictions are more robust as reserves become the dominant liquid assets on the bank portfolio. In addition, we find that the calibrated share of each sector’s size and the trade-offs each face allows for reasonable estimations of the interbank market activity before the FDIC policy change but not after. The effect of massive quantitative easing during these two periods may contribute to the discrepancies since, in the absence of such liquidity, the interbank market is too tight, the interbank rate is too high, and foreign banks will not gain from borrowing overnight funds at a rate below the IOR.

2.5.2.2 Steady-states across three models:

Although estimations fall short of the empirical evidence, the previous tables showed significant differences in response to policy change across models. These differences are found to have aggregate policy implications. In the following steady-
state table, a comparison of models shows the multi-sectoral economy implications for policy. The two columns in Table 2.5 correspond to before and after a change in monetary policy. There is no interest on reserves in the first column, while in the second column, the interest is 0.5%, and the FDIC tax on domestic reserves is 0.15%. Each column is divided into three, comparing outcomes of the One Bank model, the Baseline, and the Extended model. Since the representative bank in the One-bank model is assumed to be a domestic bank, outcomes are compared with the domestic sector of the other two models in the first part of the table. In the second part, a single representative foreign bank is compared to the two other models.

### Table 2.5: Steady-state Across Three Models

<table>
<thead>
<tr>
<th></th>
<th>No IOR</th>
<th>IOR= 0.5%, tax=0.15%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Domestic Bank</td>
<td></td>
</tr>
<tr>
<td>Reserve to Assets</td>
<td>One Bank</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>9.4%</td>
<td>9.5%</td>
</tr>
<tr>
<td></td>
<td>10.0%</td>
<td>10.1%</td>
</tr>
<tr>
<td>%∆ Reserve to Assets</td>
<td>(6.4%)</td>
<td>(6.3%)</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>45.5%</td>
<td>42.9%</td>
</tr>
<tr>
<td>%∆ Market Tightness</td>
<td>37.2%</td>
<td>28.9%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.17%</td>
<td>1.10%</td>
</tr>
<tr>
<td>∆ Interbank Rate</td>
<td>1.24%</td>
<td>1.23%</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.13)</td>
</tr>
</tbody>
</table>

|                         | Foreign Banks|                       |
| Reserve to Assets       | One Bank     | Baseline              | Extended              |
|                         | 1.2%         | 1.8%                  | 0.4%                  |
|                         | 5.4%         | 6.2%                  | 3.7%                  |
| %∆ Reserve to Assets    | (350%)       | (244%)                | (825%)                |
| Market Tightness        | 39.4%        | 42.9%                 | 20.6%                 |
| %∆ Market Tightness     | 20.8%        | 28.9%                 | 22.6%                 |
| Interbank Rate          | 1.03%        | 1.10%                 | 0.92%                 |
| ∆ Interbank Rate        | 1.3%         | 1.23%                 | 0.87%                 |

*The table compares implications of monetary policy of IORB across three types of models: the One Bank model, the Baseline model consisting of foreign and domestic, and the Extended model consisting of two bank sectors and GSEs.

In the One-bank and the Baseline model, reserve ratios increase while market tightness declines, and the interbank rate is higher in response to the policy change. In comparison, the Extended model estimates of the percentage change in reserve ratios are more considerable and coupled with a higher market tightness. The reason is that a rate differential across different lenders will increase the demand for overnight borrowing. The decline in the interbank rate, in this case, is due to the more con-
siderable increase in reserves. Hence, a rate differential across interbank lenders that increases banks’ demand for overnight borrowing mitigates the policy effect of IORB. In effect, another question of interest postulates whether an increase in the observed higher reserves held by foreign banks is due to a more considerable risk of withdrawal than the interest rate differential. Tables 2.6 and 2.7 explore this question using a set of counterfactual parameters for the volatility risk and FDIC tax.

2.5.2.3 The two channels that affect bank tradeoffs:

In Tables 2.6 and 2.7, the three columns compare three cases: in column one, both sectors have the same risk with interest on reserve balances but no tax; in column two, balance-sheet costs are the same (tax = 0), but the risk of a foreign bank’s withdrawal is higher than that of a domestic bank; and in column three domestic bank’s balance-sheet costs are higher with the same risk across sectors. Table 2.6 presents the Baseline model results, and Table 2.7 that of the Extended model with GSEs. The discount window rate is set to 4%, the interest on reserves to 0.5%, and if a tax is present, it is set to equal 0.15%, consistent with the average rate in the data. Similarly, the withdrawal volatility parameter \( \sigma \) is equal to 0.05 for both banks, or 2.3 times larger for the foreign sector, as is calibrated by the data presented in Table 2.1.

Even in the absence of a higher risk of withdrawals, an FDIC tax for domestic banks (or higher balance-sheet cost) implies foreign banks will substitute loans for reserves while domestic banks will choose a lower reserves ratio (comparing columns one to three). In comparison, a change in the risk of foreign banks implies a more significant increase in reserves, more than doubling from column one to two, when the optimal domestic portfolio does not change much. Moreover, in column two, the foreign share of interbank borrowing increases when the risk is higher, while in column three, it decreases when only the tax for domestic banks is present. Hence bank liquidity
risk plays a prominent role in the optimal choice of precautionary reserves and may contribute to the observed trends. Table 2.7 repeats the exercise of Table 2.6, given the inclusion of GSEs into the model, albeit the ON RRP rate is equal to the IOR rate, so there is no price differential across outside lending rates of GSEs and banks. We find consistent results, although the reserve ratio shares are smaller because of the lower market tightness. The following table, Table 2.8, uses counterfactual rates that allow for an additional rent between overnight borrowing and lending to explore the effect of the rate differential on the current estimations.

### Table 2.7: Calibrating a Different Risk of Withdrawals and an FDIC Rate With GSEs

<table>
<thead>
<tr>
<th></th>
<th>( \sigma^d = \sigma^f = 0.05, \ tax = 0 )</th>
<th>( \sigma^d = 0.05, \sigma^f = 0.113, \ tax = 0 )</th>
<th>( \sigma^d = \sigma^f = 0.05, \ tax = 0.15% )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserve to Assets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>10.1%</td>
<td>10.2%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Foreign</td>
<td>1.1%</td>
<td>3.1%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>11.1%</td>
<td>11.2%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Domestic</td>
<td>1.2%</td>
<td>3.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Foreign</td>
<td>1.2%</td>
<td>3.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Interbank Borrow Share</td>
<td>83.6%</td>
<td>70.8%</td>
<td>86.5%</td>
</tr>
<tr>
<td>Total Lending Share</td>
<td>8.3%</td>
<td>3.8%</td>
<td>7.0%</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>1.12%</td>
<td>1.12%</td>
<td>1.13%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.57%</td>
<td>1.58%</td>
<td>1.57%</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>7.4%</td>
<td>8.4%</td>
<td>9.8%</td>
</tr>
</tbody>
</table>

The table compares the effect of a risk of withdrawal across the two sectors on the steady-states, with that of the FDIC tax rate on domestic banks.

### 2.5.2.4 Long-run effects of a change in each policy tool:

**Presence of interbank loans from GSEs**—Another important reason for the observed higher reserve ratios after introducing interest on reserve balances is the
presence of lending by GSEs. Before September 2013, when the ON RRP rate was unavailable, GSEs’ alternative overnight-lending rate was zero. The four columns in Table 2.8 correspond to the Extended model with GSEs facing a second-best rate (called the ON RRP rate) of either zero in the first and second column or equal to that of the IOR policy rate in the third and fourth column.\textsuperscript{27} The rest of the parameters are the same across the simulations: the discount window rate remains at 4\%, interest on reserves equals 0.5\% on the right part, and 0.65\% on the left part, and the balance sheet cost associated with the FDIC remains at 0.15\%. We compare two different policy rates to show how the assumption of differences in volatility can capture the vast increase in reserves by the foreign sector compared to the domestic and the implications of ON RRP policy on the effects of a change in the IOR rate.

We find that changing the IOR rate from 0.5\% to 0.65\% has an increasingly bigger impact on the reserve ratios held by foreign banks if ON RRP is zero. Reserves to assets change from 10\% to 13\% for domestic banks and from 3.9\% to 11\% for foreign banks. Also, we find that the rate differential across banks and GSEs implies interbank borrowing will increase with higher IOR, albeit the corresponding higher reserve ratios. In turn, market tightness is high and increasing with higher IOR, and therefore the interbank rate does not change. On the other hand, when the ON RRP rate is equal to the IOR rate, a higher IOR still implies a moderate increase in reserve ratios, coupled with a decline in interbank borrowing and market tightness and an increase in the interbank rate.

One important note is that the algorithm of this model may be unable to reach a steady-state given that some specific parameters allow the possibility of arbitrage rent. The failure to reach a steady-state arises when the expected interbank rate is lower than the second-best lending rate. In which case, banks may find it optimal to substitute all loans for borrowing overnight funds against their reserves. In turn,\textsuperscript{27}Historically, the ON RRP offered is around 10 to 25 basis points lower than the IOR, but this would not change the conclusion of the above simulation.
Table 2.8: Lending from GSEs in the Interbank Market and the ON RRP Rate

<table>
<thead>
<tr>
<th></th>
<th>ON RRP rate is 0%</th>
<th>ON RRP=IOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserve to Assets</td>
<td>Domestic Foreign</td>
<td>Domestic Foreign</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>10.0% 3.9%</td>
<td>13.0% 11.0%</td>
</tr>
<tr>
<td>Interbank Borrow</td>
<td>0.027 0.013</td>
<td>0.038 0.018</td>
</tr>
<tr>
<td>Interbank Lend</td>
<td>0.000 0.000</td>
<td>0.000 0.000</td>
</tr>
<tr>
<td>Interbank Borrow Share</td>
<td>68.3% 31.7%</td>
<td>67.9% 32.1%</td>
</tr>
<tr>
<td>Interbank Lending Share</td>
<td>0.0% 0.0%</td>
<td>0.0% 0.0%</td>
</tr>
<tr>
<td>Interest rate</td>
<td>1.14% 1.08%</td>
<td>1.14% 1.07%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.18% 1.18%</td>
<td>1.17% 1.07%</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>22.4% 28.3%</td>
<td>9.8% 7.3%</td>
</tr>
</tbody>
</table>

The table compares the steady-state results of adding GSEs with a second-best rate of zero and that equal to the second-best rate of banks.

the market tightness will increase, and the interbank rate will increase and eliminate the arbitrage. The problem is that a bank’s optimal portfolio switches from arbitraging to not arbitraging at each iteration, given the previous interbank activity and corresponding expected interbank rate, so there is no steady-state in this case. However, the optimal portfolio choice of banks remains. For an example, see Table B.3 in appendix B.1, in which the IOR is set to 1%. Foreign and domestic banks hold only reserves; lending or borrowing against the excess reserves depends on the current market tightness. Nevertheless, the main message remains. Banks may arbitrage and hold more reserves with no ON RRP rate, while an ON RRP equal to the IORB eliminates the arbitrage.

**Discount window rate** - The following tables, Tables 2.9- 2.11, test the changes in other parameters to measure the ceteris-paribus long-run effects of a change in some policy tools. All these tables report steady states of the Extended model (with GSEs), having the ON RRP rate and IOR equal.

Table 2.9 provides the steady-state solution for the three cases with only a change in the discount window rate from 6% in column one to 4% in column two and 3% in column three. In all cases, the IOR is zero with no FDIC tax, calibrating the rest of the parameters to those specified in Table 2.2. Results affirm that as the outside cost
of borrowing declines, the reserve to assets and the reserve ratios decline. Reserve to asset ratio declined from 9.6% to 4.0% for domestic banks and from 1.6% to 0% for foreign banks. Note that the decline in reserve ratios of domestic banks is coupled with an increase in the total interbank borrowing while that of foreign banks is not. A discount rate of 6% is estimated to be the stigma premium associated with borrowing in the federal funds market. There may be other reasons why banks hold large excess reserves in an environment of low discount window rates. One implication of this experiment is that lowering the stigma may increase the domestic sector’s reliance on the federal funds market to clear their required reserve ratios.

Table 2.9: Calibrating Different Discount Window Rates

<table>
<thead>
<tr>
<th></th>
<th>(r^{dw} = 6%)</th>
<th>(r^{dw} = 4%)</th>
<th>(r^{dw} = 3%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Domestic</td>
<td>Foreign</td>
<td>Domestic</td>
</tr>
<tr>
<td>Reserve to Assets</td>
<td>9.6%</td>
<td>1.6%</td>
<td>7.1%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>10.5%</td>
<td>1.8%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Interbank Borrow Share</td>
<td>70.1%</td>
<td>29.9%</td>
<td>79.6%</td>
</tr>
<tr>
<td>Interbank Lending Share</td>
<td>7.2%</td>
<td>3.4%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>1.17%</td>
<td>1.08%</td>
<td>1.14%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.80%</td>
<td>1.21%</td>
<td>0.94%</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>10.0%</td>
<td>17.2%</td>
<td>26.2%</td>
</tr>
</tbody>
</table>

The table compares the steady-state solutions of a lower discount window rate

---

**Calibrating different FDIC rates**  Table 2.10 compares how the FDIC tax rate influences the banks' optimal choice using the Extended model. The discount window rate remains at 4%, IOR at 0.5%, and the FDIC tax changes from 0% to 0.15%, and then 0.25% in the three columns. We find that an independent increase in the FDIC tax is associated with little to no decrease in the reserve ratios of both banks, albeit an even smaller one for foreign banks. The ratios change from 10.2% to 9.1% for domestic banks, and from 3.2% to 3.0%, between the three scenarios for a foreign bank. In addition, policy implies minor to no change to the other outcomes in the table. This example exhibits the negligible impact that the FDIC may have on its own, meaning that the observed excess funds held by both sectors relate to other
Table 2.10: The Effect of the FDIC Tax

<table>
<thead>
<tr>
<th></th>
<th>tax = 0</th>
<th>tax = 0.15%</th>
<th>tax = 0.25%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Domestic</td>
<td>Foreign</td>
<td>Domestic</td>
</tr>
<tr>
<td>Reserves to Assets</td>
<td>10.2%</td>
<td>3.2%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>11.2%</td>
<td>3.5%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Interbank Borrow Share</td>
<td>70.6%</td>
<td>29.4%</td>
<td>74.9%</td>
</tr>
<tr>
<td>Interbank Lending Share</td>
<td>8.3%</td>
<td>3.9%</td>
<td>6.9%</td>
</tr>
<tr>
<td>Interest rate</td>
<td>1.17%</td>
<td>1.07%</td>
<td>1.13%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.58%</td>
<td>1.57%</td>
<td>1.57%</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>8.6%</td>
<td>9.8%</td>
<td>10.6%</td>
</tr>
</tbody>
</table>

The table compares the steady-state solutions of an adding the FDIC tax rate for domestic banks.

changes, such as the large-scale asset purchase that occurred in proximity to the new policy.

**Large outflows of funds from the banking system** Another cited claim explaining the large excess reserves held by banks following 2008 is the need for additional liquidity. For example, Drechsler et al. (2017) show evidence that depositors pull funds away from banking institutions and into higher-yielding investments following a reduction in the interest rates offered on deposits. Fillat et al. (2018) further document the large outflows of funds from some branches and agencies of U.S. banks with parents in E.U. countries impacted by the sovereign debt crisis. One way to illustrate this is to enforce a negative mean of the withdrawal distribution, increasing the liquidity cost and optimal reserves. Table 2.11 provides the implications of decreasing the parameter for the mean of the withdrawal distribution \( \mu \), with the discount window rate remaining at 4%, the ON RRP rate equal to the IOR rate at 0.5%, and the FDIC set to 0.15%. The result is that the greater the probability of outflow of funds, the higher reserve ratios banks choose. Market tightness does not change, as expected, because outflow is offset with more liquid reserves.

In summary, the central calibration of the model to three different periods does a fair job of matching the interbank share of lending and borrowing data. However, this is only true if a higher discount window rate is calibrated associated with
Table 2.11: The Effect of a the Withdrawal Distribution

<table>
<thead>
<tr>
<th></th>
<th>$\mu = 0$</th>
<th>$\mu = 0.03$</th>
<th>$\mu = 0.05$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Domestic</td>
<td>Foreign</td>
<td>Domestic</td>
</tr>
<tr>
<td>Reserves to Assets</td>
<td>9.5%</td>
<td>3.1%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>10.4%</td>
<td>3.4%</td>
<td>12.9%</td>
</tr>
<tr>
<td>Interbank Borrow Share</td>
<td>74.9%</td>
<td>25.1%</td>
<td>75.4%</td>
</tr>
<tr>
<td>Interbank Lending Share</td>
<td>6.9%</td>
<td>3.9%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>1.13%</td>
<td>1.07%</td>
<td>1.15%</td>
</tr>
<tr>
<td>Interbank Rate</td>
<td>1.57%</td>
<td></td>
<td>1.57%</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>9.8%</td>
<td></td>
<td>10.1%</td>
</tr>
</tbody>
</table>

The table compares the steady-state solutions of increasing the probability of an outflow of fund from banks.

The documented stigma. We find that the foreign banking sector will choose higher reserver ratios mainly because of the higher risk of holding wholesale deposits. However, given some restrictive assumptions on the possible arbitrage from the interbank market, banks (both foreign and domestic) may choose to substitute illiquid loans for reserves. In such instances, increasing interest on reserve balances or lowering the average federal funds rate with open market operations would increase this substitution and have contractionary effects. Moreover, the model predicts that the FDIC balance-sheet cost has a relatively small influence on inter-banking activity, while the probability distribution and cost of an outflow in withdrawals are influential.

2.6 Conclusions

An understanding of the correspondence in the interbank market is prominent for monetary policy since various monetary policy tools are dependent on how they affect this environment. Following the financial crisis, the environment of interbank lending had changed, resulting in large excess reserve accounts, primarily held by foreign banks. Banks that participate in the federal funds market are more responsive to a change in policy (Kashyap & Stein, 2000). Hence, a shift of excess reserves from domestic banks to foreign banks emphasizes the importance of analyzing their portfolio choices because those will be the banks responding to policy. Moreover, Cetorelli & Goldberg (2008) show that balance sheets have expanded to include new
funding sources with increased international activity. Banks operating abroad can reallocate funds in a liquidity shock occurring either at home or abroad, which means this analysis is also crucial because of the role of foreign banks in the global policy transmission.

This paper proposes a general equilibrium model with two banking sectors facing a liquidity mismatch with reallocation of funds possible given an over-the-counter federal funds market for overnight funds while assuming differences in valuations of reserves. The market participants include GSEs, U.S. branches of foreign banks, and domestic banks. The heterogeneity between banks arises given the type of deposits each bank has and the FDIC assessment base that affects one type of bank differently than another. The difference between GSEs and banks is in the policy rates offered by the Fed, which are the rate of interest on reserve balances offered to only banks and the overnight repurchasing rate for GSEs. In this setting, the demand for reserves could be driven by the liquidity risk facing individual banks and the ability to arbitrage on an array of money market rates. Domestic banks’ additional cost associated with the FDIC assessment allows foreign banks an advantage in borrowing at a lower rate than the policy rate.

An important conclusion from the model is that high risks of withdrawals are sufficient to motivate significant increases in reserves and thus could be attributed to the trends we observe. U.S. branches of foreign banks may only hold wholesale deposits that attach a greater withdrawal risk and therefore require more precautionary reserves. The implication is that open market operation to lower the federal funds rate may be dampened by the foreign sector increasing reserves at times with a high risk of withdrawals.

One limitation in the current scope is that it lacks the transitional dynamic properties of large-scale asset purchases widely used by monetary policy. Such policy significantly reduces the interbank market tightness as it becomes satiated in the
availability of overnight funds and corresponds to low interbank rates. The implication of this on the current results could be significant. For example, when the market is satiated and the interbank bargaining power of lenders is small, the differential across agents’ second-best rates could result in more considerable arbitrage gains. Another issue is that in the absence of open market operations, the current model may fail to find a steady-state precisely because of the arbitrage borrowing— as banks optimize by holding extensive overnight borrowing, the market becomes tight once again. However, the policy implications remain. Reducing the differences across agents’ valuations of overnight funds is optimal for the conduct of monetary policy.
CHAPTER 3

CHANNELS OF MONETARY POLICY WITH IMPERFECT COMPETITION IN THE BANKING SECTOR

3.1 Introduction

Another channel of heterogeneity across banks that will influence the transmission of monetary policy to bank lending is the pass-through of policy rates to bank customers. Market power in the banking sector can mitigate pass-through by lowering loan spreads and increasing deposit spreads. For example, monetary policy tightening accompanied by an increase in the deposit markdowns may result in a flow of deposits away from banks. Drechsler et al. (2017) show that the increase in deposit spread will result in a substitution of deposits for bonds, thereby mitigating the effect of policy tightening. On the other hand, market power in the loan market implies that banks may lower markups on loan rates to mitigate the declining demand for loans accompanied by tighter policy, as described by Gerali et al. (2010). Y. Wang et al. (2020) are the first to address the implication of imperfect competition of both channels simultaneously. They include market power in the loans and deposits markets in a structural banking model with capital and reserve regulation. They find that bank market power explains much of the transmission of monetary policy with a reversal effect when the federal fund rate is low.

Kashyap & Stein (2012) and Cochrane (2014) advocate that the central bank can simultaneously use two policy tools to pursue two objectives. It can conventionally
subscribe the Taylor rule for price stability and set the spread between interest on reserves and the federal funds rate to target the level of money creation and bank risk. The following chapter revisits how monetary policy pass-through depends on the two market power channels, as in Y. Wang et al. (2020), while using a dynamic model in the spirit of Ireland (2014) that describe the interdependence of the two policy instruments given the added assumption of market power.

Ireland (2014) allows reserves to serve for the bank’s production of deposits. Under this setting, a decrease in the federal funds rate, per se, with no change to the interest rate on reserves, lowers its spread and increases the scarcity value of reserves needed for deposits. In a perfectly competitive market, the change in the spread implies a decline in the bank lending capacity. However, because lower interest rates are coupled with an increased demand for credit, the new assumption of market power implies a higher insufficient supply of funds for the loan demand that will increase the markup charged on these assets. On the other hand, since banks can pass through the higher cost of intermediation by lowering markdowns paid on deposits, the net effect on lending depends on the magnitude of the pass-through to each market.

A further contribution of this chapter is documenting new empirical evidence of market power in deposits and loans by utilizing a non-structural market power index proposed by Boone et al. (2004). It measures competition by comparing the effect of differences in the cost inefficiencies on a firm’s performance measured by profits, as Boone (2008), or by market share, as proposed by Van Leuvensteijn et al. (2011). With the underlying assumption that banks’ performance is more susceptible to cost inefficiencies when high competition is present. Van Leuvensteijn et al. (2011) measured the level of market competition in the loans market using loan shares across different countries. The current chapter uses a similar methodology to measure the U.S. competition ratio in the loan and deposit markets over time and across states. These estimations used to calibrate the loan and deposit makeups are superior to the
commonly used concentration ratios as empirical and theoretical evidence suggests a poor correlation between them (Leon, 2015).

I find that although banking market competition has been increasing from 2001 to 2019, the market power in the deposits market has been, on average, four times higher than in the loan market. With this assumption, the model suggests that monetary policy is mitigated with a more considerable change in loan rates. For example, banks compensate for the policy tightening by lowering the spread between the policy rate and the rate charged for a loan. Lastly, estimations from the model are compared with empirical evidence of banking market structure on the net effect of monetary policy pass-through to rates and lending following the methodology from Olivero et al. (2011), Van Leuvensteijn et al. (2013), and Khan et al. (2016). This analysis finds a positive coefficient of the interaction of tightening policy and market power on change in loans, which implies mitigation of monetary policy via bank lending.

The following chapter is organized as follows. The next part of the introduction includes a literature review. Section 3.1 provides empirical evidence of market power in the deposit and loan market. Section 3.2 presents the model, and Section 3.3 provides the model’s calibration, steady-state solution, and impulse response dynamics. Section 3.4 compares the model results to empirical evidence of monetary policy transmission to deposit loans and their rates, while Section 3.5 concludes.

3.1.1 Related literature

My paper broadly relates to the growing list of research on banks’ role in the transmission mechanism of monetary policy, pioneered by Bernanke & Blinder (1988), Kashyap & Stein (1995), and Disyatat (2011) and more commonly known as the lending channel of monetary policy. The aim is to add to this scope by structurally estimating a dynamic banking model where banks’ lending capacity impacts aggregate spending via two channels while accounting for the imperfect loan and deposit market
and their part in monetary policy transmission.

This paper also closely relates to the literature on the impact of monetary policy with interest on excess reserves following the empirical evidence described in Nguyen & Boateng (2013) and the theoretical implications as in Hornstein (2010) and Ennis (2018). I estimate a model that adopts features from Ireland (2014), describing the bank’s decision problem as a producer of deposits, allowing it to increase profits by lending the additional funds. The difference I incorporate is that because banks face imperfectly competitive markets, they maximize profits by choosing the spread between the federal funds rate and deposit and loan rates.

The most seminal dynamic models that discuss the imperfect competition in the deposit market are by Drechsler et al. (2017) and Duffie & Krishnamurthy (2016). They address the deposit channel of monetary policy. In Drechsler et al. (2017), banks’ market power over the deposit market implies that increases in the federal funds rate pass through the additional funding cost to depositors at the expense of fewer funds available for lending. Banks widen the spreads they charge on deposits, and deposits flow out of the banking system— the higher the level of market power, the higher this channel. Duffie & Krishnamurthy (2016) describe the impact of the Fed’s participation in the money market because of such a deposit channel. Sophisticated savers respond to a lower spread between the deposit rate and the federal funds rate by channeling funds to the money market, hence dampening the policy objective to increase the scarcity of available money-market funds.

Gerali et al. (2010) is one example of a DSGE model with sticky markups on loan rates. However, their paper focuses on the role of credit-supply factors in business cycle fluctuations rather than policy pass-through. Scharfstein & Sunderam (2016) and O. Wang (2018), on the other hand, are examples of dynamic models estimating the importance of the market power of banks over lending rates and the pass-through of monetary policy. Scharfstein & Sunderam (2016) model the importance of the
structure of the mortgage market on the lending channel of monetary policy, where they document that higher concentration today results in lower pass-through to the yields on mortgage-backed securities. O. Wang (2018) documents that loan rates do not fully reflect the long-run decline in bond rates. In his model, banks pass through the policy implications more heavily to borrowers and lenders in a low-rate environment. Hence, a decline in the real rate equilibrium compresses deposit spreads while increasing loan spreads. The implication is that policy pass-through of loan rates is more dampened with low equilibrium rates.

Kopecky & Van Hoose (2012) and Y. Wang et al. (2020) are examples of dynamic models with both deposits and loans in an imperfectly competitive market. Kopecky & Van Hoose (2012) look at the pass trough of policy to deposit and loan rates in the face of imperfect competition and adjustment costs, to explain the disparities in the empirical evidence of the pass-through across the globe. Y. Wang et al. (2020) is the first paper to quantify the lending channel of policy via both deposits and loans imperfectly competitive market alongside a channel of reserve and capital ratios. They find that capital requirements and market power explain much of monetary policy transmission to borrowers with a reversal effect if market power interacts with bank capital regulation given a low federal funds rate. They also find that a reserve requirement channel has little importance for lending. However, they do not address the role of the spread between the federal funds rate and the interest on excess reserves to explain changes in the scarcity value of reserves.

In addition to the literature about the pass-through of policy, I hope to contribute to the literature on conducting macroprudential monetary policy alongside conventional interest rate policy to regulate financial stability as in Stein (2012), Gertler et al. (2012), Brunnermeier & Sannikov (2014). More recently, Afanasyeva & Güntner (2020) quantify a risk channel of monetary policy and show how tightening monetary policy also increases bank appetite for risk. Such evidence stresses the need to jointly
use two monetary policy instruments to support price and financial stability. However, the extent of the banking market structure is necessary for identifying policy effects on excessive risk or leveraging independently from the optimal interest rate on economic growth and balanced inflation. To do so, I propose a DSGE model in the flavor of Ireland (2014) with the added assumption of imperfect competition in the deposit and loan market, as suggested by Y. Wang et al. (2020). The benefit of using a DSGE model with banks and sticky prices for a commodity good is the separation of the lending channel effect on the supply of loans from the real effects of monetary policy on inflation and its influence on employment and growth.

3.1.2 Stylized Facts and Measuring Market Competition

One of the assumptions embedded in the model is that banks price loans and deposits based on market power in each market. To quantify market competition’s implication on the pass-through of policy to market rates and total spending, we need a sector-specific reliable measure for each market— the loans and deposit markets. One difficulty in measuring banking competition lies in the limitation of the data because different banks offer different products. For example, saving banks would not offer the same rate for deposits as investment banks offer. Furthermore, even within a single bank, a price choice for a commercial loan may have a different markup than a home equity loan because of differences in market structure for these two instruments.

Most of the related literature uses some measure of market concentration to estimate competition (i.e., Drechsler et al. (2017), Y. Wang et al. (2020)). Concentration ratios are relatively simple to implement and provide insight into structural changes in the market; however, the new industrial organization literature advocates that it is a poor proxy for market power. For example, takeovers of inefficient banking firms in competitive markets may result in higher concentration levels precisely because the market is competitive. Moreover, the ease of entry and exit could independently set
competitive prices regardless of the level of concentration (Boone et al., 2004). This theory is backed by evidence by Beck et al. (2006) that find both market competition and market concentration reduce the fragility of the banking system. In addition, Griffith et al. (2005) found that concentration-based measures do not coincide with price-cost margins, while relative profits do.

Figures 3.1 - 3.3 compare concentration ratios with a non-structural competition measure, the Boone index, proposed by Boone (2008). The most prominent reason to adopt non-structural measures is that they are not subject to changes in market conditions such as a recession because these are comparative measures across all firms in the market (Leon, 2015). The benefit of using the Boone index is that it only assumes a limited level of homogeneity in the banks’ goods and services, while at the same time, it captures the fact that higher levels of competition imply better performance either in terms of higher profits, higher returns, or higher market shares for the more efficient banks. This approach captures market dynamics rather than a static analysis by measuring differences in the market response to changes in competition due to forces other than the concentration.

Following Schaeck & Cihák (2014), the estimated equation for the market compe-

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1Boone (2008) measures performance using profits, Van Leuvensteijn et al. (2011) use the share of loans, while Schaeck & Cihák (2014) use returns to assets.
\begin{equation}
Y_{it} = \alpha_i + \sum_{k=1}^{T} \beta_k 1n(c_{it})d_{kt} + \sum_{k=1}^{T} \beta_k d_{kt} + \varepsilon_{it}.
\end{equation}

\(Y_{it}\) equals the outcome variable measured by returns to assets, log of profits, log of the share of loans, and the log of the share of deposits relative to the market, at bank \(i\) at time \(t\). \(d_{kt}\) denotes the dummy for the time, which takes a value of 1 when \(k = t\) and zero otherwise. Next, \(c_{it}\) denotes the average variable costs, defined as the ratio between the sum of interest and personnel expenses, administrative and other operating expenses divided by the commission and trading income, interest income, fee income, and other operating income. \(T\) denotes the total number of periods and \(\varepsilon_{it}\) is the error term. Here \(\beta_t\) refers to the Boone indicator at year \(t\). \(\beta\) is monotonically decreasing with the level of market competition (Boone, 2008), so that the higher the competition, the more a firm is punished for cost inefficiencies, and an upward sloping trend means that market power is increasing.

The unbalanced panel of around 6000 banks compares the Boone index elasticity of the four outcome variables to a change in average cost that proxies the marginal cost with the Herfindahl-Hirschman Index (HHI) and the concentration level of the five largest banks (CR5) in the last two panels. The Boone index reports fixed-effects estimators and two-step difference Generalized Method of Moments (GMM)\(^2\) measured using the Federal Financial Institution Examination Council (FFEIC) data between 2001 and 2019. The data is available from the quarterly consolidated Condition, and Income report, generally referred to as the Call report and required by all U.S. reg-

\(^2\)GMM is used since changes in performance and costs could result from a third factor unrelated to competition. Using 1-2 lagged average costs and the explanatory variable as the instrument variables based on the Arellano-Bond test for AR(1) and AR(2) indicate that the model is correctly specifying. All estimation results, AR(1), AR(2), and the Sargan/Hensen test of the joint null hypothesis that the instruments are valid, i.e., uncorrelated with the error term, are reported in Appendix C.2 in Table C.6. Sargan/Hensen test determines the instrument’s validity. Under the null hypothesis, the test statistic is chi-squared distributed with the number of degrees of freedom equal to the overidentification restrictions. A rejection would indicate that the instruments are not valid. Also reported are the significant values of AR (1) and AR (2). AR (1)’s significant values show that the null hypothesis of no autocorrelation among error terms in the first difference is rejected. Non-significant values of AR (2) show that error terms in level regressions are not correlated.
ulated financial institutions. The subset includes the head of commercial office bank reports aggregated to the parent bank-level and consolidated to yearly observations.\textsuperscript{3} The aggregation of branches under a parent bank eliminates changes in the portfolio across parent and offspring that may affect the results. Appendix C.2 provides the solutions without this consolidation. Results are consistent across measures except for the measure of the share of loans outcome when using GMM estimators.

In Figure 3.1, we see that concentration and market power are not always correlated, although the upward trend in market power prevails. For example, asset concentration has increased overall but fluctuates over the study period, with a dip following the financial crisis in 2008 and another following 2010. On the other hand, GMM estimators of the two Boone indices indicate a persisting decline in the market competition following 2007. The magnitudes of the GMM estimators are elasticity measures, meaning the log of profit over the average cost of -1.7, in 2013, for example, indicates a 1.7\% decrease in profit for a 1\% increase in average costs, while the GMM estimator using ROA measures at -0.023 indicates a 2.3\% decline in ROA for a 1\% increase in average costs. Hence measuring the change in profits estimates a higher market power level than the change in a bank’s return to assets.

Figure 3.2 further compares the Boone index of deposit shares with the concentration of deposits, and Figure 3.3 shows the Boone index of loan shares as in Van Leuvensteijn et al. (2011) with the concentration of loans. The implications of cost structure inefficiencies can have a different impact on each of the products a bank offers. The model’s implications depend on this comparison between loan and deposit market competition, and estimations are used to calibrate the model parameters. Moreover, findings suggest that market competition in the deposit market does not necessarily correlate with the loan market over time. For example, GMM estimators for the deposits market in Figure 3.2 gradually declined following 2008, while the loans market

\textsuperscript{3}A parent bank is an entity that generally owns or controls another bank. The data includes around 90 banks that a parent bank controls.
Figure 3.2: Boone with Deposits Compared to Deposit Market Concentration

Figure 3.3: Boone with Loans Compared to Loan Market Concentration
shown in Figure 3.3 show some fluctuation over time with an increase in market power that later declines after 2016. A similar trend is prevalent using HHI and CR5; albeit, the concentration of loans has increased until 2010 and after that decline. Also, note that the elasticity of deposit shares is smaller than that of loan shares, meaning banks are punished less for inefficiencies in deposit creation than in loan issuance, which suggests a higher level of competition in the loan market than in the deposit market.

**Boone index across U.S. states**  Technological advancement allowed the introduction of new financial instruments that have stretched the reach of financial markets from state-wide to national or perhaps global markets. We can test for changes over the study period by plotting the distribution of the Boone index across different states, using GMM estimators for 2003 compared to 2017. Because a parent bank may relate to banks across states, the data observations for estimations across states are not aggregated to the parent bank as in the previous section. However, since a relatively small number of banks fall under a parent bank, disaggregation
Figure 3.5: Distribution of the Boone Index: With Log Share of Loans and Deposits

should not significantly change the results. In Figure 3.4, both ROA and profits do not indicate substantial changes in the index distribution over the study period, albeit there is an increase in market power. This result confirms that using state-specific measures is more reliable because different states have different levels of competition. The distribution of competition using the share of loans and deposits in Figure 3.5 shows a higher density in 2017 than in 2003, which is also higher than that shown in Figure 3.4 and means that competition levels measured by market shares have been converging to a national level over the study period.

Given the implications of Figures 3.4 and 3.5, Figure 3.6 reports the ratio of the national level of competition using the elasticities between the change in a bank’s share of deposits to a change in a bank’s share of loans in response to a change in the average costs. The result indicates that this ratio has been changing over time. Specifically, we observe an overall increase in the ratio. The empirical evidence suggests the increase is due to the divergence of the deposit and the loan market power peaking around 2014. On average, deposit market power has been four times greater, with a slight decline by the end of 2019. Given this evidence, the following section will investigate the implications of market power to the lending channel via
two monetary policy tools. One is changes in the federal funds rate (from here on, referred to as the market rate) accompanied by equivalent changes in the interest on reserves (referred to as the IOR for short). The second is changes in the spread between the two rates changing the scarcity value of reserves.

3.2 The Model

The model includes a representative household, a single retail producer, which is a final-goods-producing firm, a continuum of wholesale producers, which are intermediate-goods-producing firms indexed by \( i \in [0, 1] \), a continuum of banks indexed by \( j \in [0, 1] \), and a central monetary authority. Each wholesale firm produces a distinct, perishable good during each period \( t = 0, 1, 2, \ldots \). Hence, \( i \in [0, 1] \) may also index intermediate goods. Each bank produces a distinct deposit outlet for households. Hence, \( j \in [0, 1] \) may index deposits. Banks produce a distinct loan for each type of wholesale firm. Hence loans to firm \( i \) from bank \( j \) are indexed by a pair of \( i \in [0, 1] \) and \( j \in [0, 1] \).
3.2.1 The Representative Household

In order to address the role of banks in the economy, the representative household can hold a complex portfolio of assets, including deposits, bonds, and shares in wholesale firms producing intermediate goods. The representative household enters each period with \( M_{t-1} \) units of currency, \( B_{h,t-1} \) bonds funded by taxes, and \( s_{t-1}(i) \) shares in each wholesale firm \( i \in [0, 1] \). At the beginning of the period, the household receives \( T_t \) additional units of currency in the form of a lump-sum transfer from the monetary authority. Next, the household’s bonds mature, providing \( B_{h,t-1} \) more currency units. The household uses some of this currency to purchase \( B_{h,t} \) new bonds at the price of \( \frac{1}{r_t} \) dollar per bond, where \( r_t \) denotes the gross nominal interest rate between \( t \) and \( t+1 \), and \( s_t(i) \) new shares in each wholesale firm \( i \in [0, 1] \) at the price of \( Q_t(i) \) dollars per share.

The sum of deposits, denoted by \( D_t \), is a composite good produced by a continuum of banks. So that

\[
D_t = \int_0^1 D_t(j). 
\]

After each initial trading session at time \( t \), the total nominal value of deposits equals

\[
D_t = M_{t-1} + T_t + B_{h,t-1} - \frac{B_{h,t}}{r_t} + \int_0^1 Q_t(i)(s_{t-1}(i) - s_t(i))di. 
\] (3.2-2)

Assuming Dixit-Stiglitz markdown (as first introduced in Dixit & Stiglitz (1977)) on the deposit rate \( r^d_t(j) \), the demand for each type of household deposit \( D_t(i) \) is obtained by maximizing the total real savings over the different sets of deposits

\[
\int_0^1 r^d_t(j)D_t(j) dj, 
\]

subject to

\[
\left[ \int_0^1 D_t(j)^{\theta_d/\theta_d - 1} dj \right]^{\theta_d-1/\theta_d} \leq D_t. 
\]
In which $\theta^d \geq 1$ denotes the constant elasticity of substitution between different deposits. The first-order conditions of the demand for deposit type $j$ follow

$$D_t(j) = \left[ \frac{r^d_t(j)}{r^d_t} \right]^\theta^d - 1 D_t,$$  

and

$$r^d_t = \left[ \int_0^1 r^d_t(j) \theta^d \right]^{1/\theta^d}$$

for $t=0,1,2,\ldots$ where $r^d_t(j)$ is the gross nominal interest rate for deposits, and $r^d_t$ is the index rate for the economy.

Also, at each period $t$, the household will supply $h^q_t(i)$ units of labor to each wholesale firm $i \in [0,1]$, for a total of

$$h^q_t = \int_0^1 h^q_t(i)$$

and $h^b_t(j)$ units of labor to each bank $j \in [0,1]$, for a total of

$$h^b_t = \int_0^1 h^b_t(j).$$

The household, therefore, receives $W_t h_t$ in labor income, where $W_t$ denotes the nominal wage rate and

$$h_t = h^q_t + h^b_t$$

denotes the total hours worked in financial services and intermediate goods production.

Next, the household chooses $C_t$ units of the consumption good, priced at the nominal price $P_t$ and sold by the representative retail firm. However, this consumption
transaction requires \( h^*_t \) units of shopping time equal to
\[
  h^*_t = \frac{1}{\chi} \left( \frac{v^a_t P_t C_t}{D_t} \right)^\chi.
\] (3.2-5)

The parameter \( \chi > 1 \) governs the effort rate that increases with purchasing the consumption-good as the household economizes on its holdings of monetary assets. A scaling variable, \( v^a_t \), allows for an adverse shock to household demand for monetary services so that
\[
  \ln(v^a_t) = (1 - \rho^a_v)\ln(v^a) + \rho^a_v \ln(v^a_{t-1}) + \varepsilon^a_{vt},
\] (3.2-6)
with \( v^a > 0 \) being the steady-state level of real monetary services demanded relative to consumption. The persistence parameter satisfies \( 0 < \rho^a_v < 1 \) and the serially uncorrelated error \( \varepsilon^a_{vt} \sim N(0, \sigma^a_v) \).

At the end of period \( t \), the household receives deposit interest payments in the sum of \( r^d_t(j)D_t(j) \) for each deposit it holds in each bank \( j \in [0, 1] \), it receives a nominal dividend payment of \( F_t(i) \) for shares it owns in each wholesale firm \( i \in [0, 1] \), and a nominal dividend payment of \( V_t(j) \) for its ownership of each bank \( j \in [0, 1] \). With
\[
  V_t = \int_0^1 V_t(j) dj.
\] (3.2-7)

Once all payments are sent and received, the household carries \( M_t \) units of currency into period \( t + 1 \), where
\[
  M_t = W_t h_t + V_t + \int_0^1 F_t(i)s_t(i) di + \int_0^1 r^d_t(j)D_t(j) dj - P_tC_t.
\] (3.2-8)

Thus the household’s decision is based on observation of last period market-clearing prices described as a vector of the current prices of shares, the current price of the final good, and the current shadow value of intertemporal savings. Prices are determined by the last period’s optimal choice and market-clearing conditions. Using an
endogenous government transfer of $T_t$ allows for a passive fiscal policy to support the given interest rate path. Formally, the household chooses sequences for $B^h_t$, $s_t(i)$ for all $i \in [0, 1]$, $D_t(j)$ for all $j \in [0, 1]$, $h_t$, $C_t$, $h^*_t$, and $M_t$ for all $t = 0, 1, 2, \ldots$ to maximize its utility.

Plugging in the shopping time function and dividing by $P_t$, the optimal household decision in real terms is solved by

$$
\max_{\{C_t, B^h_t, s_t(i), D_t(j), h^*_t, h_t, M_t\}} \mathbb{E} \sum_{t=0}^{\infty} \beta^t a_t \left[ ln(C_t) - \eta (h_t + h^*_t) \right]
$$

such that

$$
C_t + \frac{M_t}{P_t} \leq \left[ \frac{W_t h_t}{P_t} \right] + \left[ \frac{V_t}{P_t} \right] + \int_0^1 \left[ \frac{F_t(i)}{P_t} \right] s_t(i) di + \int_0^1 \left[ \frac{r^d_t(j)}{P_t} \right] D_t(j) dj
$$

(3.2-9)

and

$$
\frac{D_t}{P_t} \leq \frac{1}{P_t} \left( M_{t-1} + T_t + B^h_{t-1} - \frac{B^h_t}{r_t} + \int_0^1 Q_t(i) \left[ s_{t-1}(i) - s_t(i) \right] di \right).
$$

(3.2-10)

$\eta > 0$ governs the shares of consumption and leisure, $0 < \beta < 1$ is the discount factor, and $a_t$ is a shock to household preferences following

$$
ln(a_t) = \rho_a ln(a_{t-1}) + \varepsilon_{at},
$$

(3.2-11)

with $0 \leq \rho_a < 1$ and the serially uncorrelated error $\varepsilon_{at} \sim N(0, \sigma_a)$.

Solving for the first-order conditions, we get:

$$
a_t C_t \left[ 1 - \eta \left( \frac{v^a_t P_t C_t}{D_t} \right) \right] = \Lambda_t^2,
$$

(3.2-12)

$$
\frac{P_t a_t \eta}{W_t} = \Lambda_t^2,
$$

(3.2-13)
\[ a_t \eta \left( \frac{v^o_t P_t C_t}{D_t} \right)^x = D_t \left( \frac{\Lambda^2_t r_t - \Lambda^1_t}{P_t} \right), \]  
\[ (3.2-14) \]

\[ \beta \mathbb{E} \left[ \frac{\Lambda^1_{t+1} P_t}{P_{t+1}} \right] = \frac{\Lambda^1_t}{r_t}, \]
\[ (3.2-15) \]

\[ \beta \mathbb{E} \left[ \frac{\Lambda^1_{t+1} Q(i)_{t+1}}{P_{t+1}} \right] = \frac{\Lambda^1_t Q(i)_{t} - \Lambda^2_t F_t(i)}{P_t}, \]
\[ (3.2-16) \]
and

\[ \beta \mathbb{E} \left[ \frac{\Lambda^1_{t+1} P_t}{P_{t+1}} \right] = \Lambda^2_t. \]
\[ (3.2-17) \]

Using Equations 3.2 – 15 and 3.2 – 17 we have that in equilibrium

\[ r_t = \frac{\Lambda^1_t}{\Lambda^2_t}. \]
\[ (3.2-18) \]

### 3.2.2 The Representative Retail Firm

The perfectly competitive retail firm uses intermediate goods \( Y_t(i) \) purchased at \( P_t(i) \) from a continuum of wholesale firms \( i \in [0, 1] \) operating in a monopolistic competitive market. The representative firm will then choose \( Y_t(i) \) while taking the prices of inputs and the price of the final good as given to maximize its profit, defined as

\[ \max_{Y_t(i)} P_t Y_t - \int_0^1 P_t(i) Y_t(i) di \]

such that

\[ Y_t \leq \left[ \int_0^1 Y_t(i)^{(\theta-1)/\theta} di \right]^{\theta/\theta-1}. \]
\[ (3.2-19) \]

With \( \theta \), the elasticity of substitution between inputs in the production of the final good, such that \( \theta \geq 1 \). The zero-profit condition implies that \( P_t = \int_0^1 P_t(i)^{1-\theta} di \), for all \( t = 0, 1, 2, \ldots \).

Solving the first order conditions and substitution the zero-profit conditions we get,

\[ Y_t(i) = \left[ \frac{P_t(i)}{P_t} \right]^{-\theta} Y_t. \]
\[ (3.2-20) \]
3.2.3 Wholesale Firms

The wholesale firm produces intermediate goods $Y_t(i)$ using labor $h_t^g(i)$ and the current technology $Z_t$, such that

$$Y_t(i) \leq Z_t h_t^g(i). \quad (3.2-21)$$

$Z_t$, the aggregate technology shock, follows an autoregressive process with a positive drift, given by $\ln(Z_t) = \ln(z) + \ln(Z_{t-1}) + \varepsilon_{zt}$, where $z$ is the balance-growth rate, and the serially uncorrelated error follows $\varepsilon_{zt} \sim N(0, \sigma_z)$. Each wholesale firm, $i$, needs to finance a portion of the labor wage by borrowing $L_t(i)$ funds from the bank, which will be returned to the bank with finished good $Y_t(i)$. This portion is exogenously determined by $0 \leq \phi_d \leq 1$ to match the borrowing cost affecting the total cost of production. Hence the actual labor cost equals $W_t h_t^g(i)(1 + \phi_d r_t^l)$ with

$$L_t(i) = \phi_d W_t h_t^g(i) \quad (3.2-22)$$

strictly binding in equilibrium.

Like the deposit and final goods market, the loan market is monopolistic-competitive. Using Dixit-Stiglitz markup prices, we have that demand for $L_t(i)$ is a composite good made of similar substitutes from a continuum of different banks $j \in [0, 1]$. The loan amount chosen by firm $i$ from bank $j$ solves

$$\min_{L_t(i,j)} \int_0^1 r_t^l(j) L_t(i,j) dj$$

such that

$$L_t(i) \leq \left[ \int_0^1 L_t(i,j)^{(\theta-1)/\theta l} dj \right]^{\theta l/\theta - 1}. \quad (3.2-23)$$
Which is minimizing the total amount of $L_t(i, j)$ repayments due, with the interest rate on each $L_t(i, j)$ given by $r_t^f(j)$, and the elasticity of substitution between different types of loans by $\theta^l > 1$.

Solving the first-order conditions, we get that

$$L_t(i, j) = \left[ \frac{r_t^f(j)}{r_t^l} \right]^{-\theta^l} \bar{L}_t(i), \quad (3.2-24)$$

$r_t^f(j)$ is the interest rate charged by bank $j$, $r_t^f = (\int_0^1 r_t^f(j)^{-\theta^l} dj)^{1/(1-\theta^l)}$, is the index loan markup for interest rates on loans to firms, and $\bar{L}_t(i)$ is the aggregate total volume of loans to firm $i$ for all $t = 0, 1, 2, \ldots$.

Since the intermediate goods substitute imperfectly for one another in producing the finished good, the wholesale firms sell their output in a monopolistic competitive market. Hence, during each period $t = 0, 1, 2, \ldots$, wholesale firms set the current period nominal price $P_t(i)$ given the retail firm’s demand for input $i$ described by Equation 3.2-20, but facing quadratic adjustment cost as in Rotemberg (1982), expressed in units of the finished goods and given by

$$\frac{\phi_p}{2} \left[ \frac{P_t(i)}{\pi P_{t+1}(i)} - 1 \right]^2 Y_t. \quad (3.2-25)$$

In Equation 3.2-25, the cost parameter follows $\phi_p > 1$, and the gross, steady-state inflation rate follows $\pi > 1$.

Price adjustment cost makes the wholesale firm’s problem dynamic: it chooses a sequence for $P_t(i)$ for all $t = 0, 1, 2, \ldots$, to maximize its real market value, defined as the difference between its share price in two consecutive periods. Discounting and adjusting to real terms, we get that the firm is maximizing its real market value by solving

$$\max_{P_t(i)} \mathbb{E} \sum_{t=0}^{\infty} \beta^t \Lambda^2 \left[ \frac{F_t(i)}{P_t} \right].$$
such that

$$\frac{F_t(i)}{P_t} = \frac{P_t(i)}{P_t} Y_t(i) - \left( W_t \frac{N_t(i)}{P_t} h_t^T(j) - \int_0^1 r_t^T(j) L(i, j) dj \right) \frac{\phi_p}{2 \pi \frac{P_t+1(i)}{P_t+1(i)} - 1} Y_t.$$

(3.2-26)

$\Lambda_t^2$ is the Lagrange multipliers from the household’s equity-pricing optimal condition in Equation 3.2-16. Rewrite Equation 3.2-26 as

$$\frac{F_t(i)}{P_t} = \left[ \frac{P_t(i)}{P_t} \right]^{1-\theta} Y_t - \left( 1 + \phi_d \int_0^1 r_t^T(j) dj \right) \left[ \frac{P_t(i)}{P_t} \right]^{-\theta} \left( W_t \frac{Y_t(i)}{Z_t} \right) - \frac{\phi_p}{2 \pi \frac{P_t+1(i)}{P_t+1(i)} - 1} Y_t$$

(3.2-27)

using Equations 3.2-20, 3.2-21, 3.2-22, 3.2-24, and 3.2-25; then, the first-order condition for the wholesale firm can be written as

$$\beta \phi_p \mathbb{E} \left\{ \Lambda_{t+1}^2 \left( \frac{P(i)_t}{\pi P_{t-1}(i)} - 1 \right) \frac{Y_{t+1} P_{t+1}(i) P_t}{\pi P_t(i)^2} \right\}$$

$$= \Lambda_t^2 \left[ \phi_p \left( \frac{P_t(i)}{\pi P_{t-1}(i)} - 1 \right) \left( \frac{Y_t P_t}{\pi P_{t-1}(i)} \right) \right]$$

$$- (1 - \theta) \left( \frac{P_t(i)}{P_t} \right)^{-\theta} Y_t - \theta \left( 1 + \phi_d \int_0^1 r_t^T(j) dj \right) \left( \frac{P(i)_t}{P_t} \right)^{-\theta} \left( W_t \frac{Y_t(i)}{Z_t} \right).$$

(3.2-28)

3.2.4 Banks

Money creation of banks as a production function requires reserves $N_t^n(j)$ and labor $h_t^n(j)$ to create bank deposits $D_t(j)$ used to finance loans. These two inputs substitute imperfectly given the equation

$$\frac{D_t(j)}{P_t} \leq x_d^T \left[ x^n \left( \frac{N_t^n(j)}{P_t} \right)^{(n-1)/n} + (1 - x^n) \left( Z_t h_t^n(j) \right)^{(n-1)/n} \right]^{(n-1)/n}$$

with $n > 0$, governing the elasticity of substitution between reserves and waged labor, and $0 < x^n < 1$ setting the share of reserves used in equilibrium. $x_d^T$ is the banking productivity shock that follows

$$\ln(x_d^T) = (1 - \rho_d^T) \ln(x_d^T) + \rho_d^T \ln(x_{t-1}^d) + \varepsilon_d^T$$

(3.2-29)
with \( x^d > 0 \), and \( 0 \leq \rho^d_x < 1 \), and the serially uncorrelated error \( \varepsilon^d_{xt} \sim N(0, \sigma^d_x) \).

In this formulation, once reserves offer an interest rate equal to the market rate, the banks will have infinite demand for reserves. To allow for a well-defined equilibrium, a small labor cost for reserves determines the unique finite real quantity of reserves. This cost is described by

\[
Z_t h^v_t(j) \geq \phi_v \frac{N^v_t(j)}{P_t}, \quad (3.2-30)
\]

and the sum of aggregate bank labor is with \( 0 \leq \phi_v < 1 \) set as the cost parameter. Hence, maintaining reserves requires an \( h^v_t \) amount of labor to maintain reserves following a constant cost rate with increasing reserve balances. The sum of aggregate bank labor is then

\[
h^b_t = \int_0^1 h^v(j) dj + \int_0^1 h^a(j) dj. \quad (3.2-31)
\]

Since loans and deposits substitute imperfectly for one another for firms and households, the representative bank sells its output in a monopolistic-competitive market. Thus during each period \( t = 0, 1, 2, \ldots \), the bank sets the nominal price \( r^l_t(j) \) and \( r^d_t(j) \) for its loans and deposits, subject to the requirement that it satisfy the wholesale firm’s demand for loans, described by Equation 3.2-24, and the household’s demand for deposits, as described by Equation 3.2-3. Reserves earn interest at the gross rate \( r^v_t \), and bonds earn the market rate \( r_t \). The profits of the bank are therefore equal to

\[
V_t(j) = (r^l_t(j) - 1) L_t(j) + (r_t - 1) B^b_t(j) + (r^v_t - 1) N^v_t(j) \\
- (r^d_t(j) - 1) D_t(j) - W_t(h^a_t(j) + h^v_t(j)). \quad (3.2-32)
\]

Hence, for each period \( t = 0, 1, 2, \ldots \), the bank chooses the sequence \( r^l_t(j), r^d_t(j), B^b_t(j), N^v_t(j), h^a_t(j), h^v_t(j) \) to maximize its real market value

\[
\max_{\{r^l_t(j), r^d_t(j), B^b_t(j), N^v_t(j), h^a_t(j), h^v_t(j)\}} \left[ \frac{V_t(j)}{P_t} \right]
\]
subject to the balance-sheet constraint that follows

\[ L_t(j) + B_t^b(j) + N_t^v(j) \leq D_t(j), \]  

(3.2-33)

and the deposit production technology

\[ \frac{D_t(j)}{P_t} \leq x_t^d \left[ (x^n)^{1/\nu} \left( \frac{N_t^v(j)}{P_t} \right)^{(\nu-1)/\nu} + (1 - x^n)^{1/\nu} (Z_t h_t^n(j))^{(\nu-1)/\nu} \right]^{\nu/(\nu-1)}. \]  

(3.2-34)

By substituting Equations 3.2-30, and 3.2-33, we get that the value of the bank can be written as

\[
\frac{V_t(j)}{P_t} = (r^d_t(j) - r_t) \left[ \frac{L_t(j)}{P_t} \right] + \left( r^v_t - \frac{\phi^v W_t}{P_t Z_t} - r_t \right) \frac{N_t^v(j)}{P_t} - (r^d_t(j) - r_t) \left[ \frac{D_t(j)}{P_t} \right] - \frac{W_t h_t^n(j)}{P_t}.
\]

Then using Equation 3.2-34, the first-order conditions with respect to \( N_t^v(j) \) and \( h_t^n(j) \) can be rewritten as

\[
\frac{N_t^v(j)}{P_t} = \left( r^v_t - r_t - \frac{W_t \phi^v}{P_t Z_t} \right)^{-\nu} (r^d_t(j) - r_t)^\nu (x^d)^{\nu-1} \frac{D_t(j)}{P_t} (x^n),
\]

(3.2-35)

and

\[
h_t^n(j) = (r_t - r^d(j))^\nu (x^d)^{\nu-1} \frac{D_t(j)}{P_t} (1 - x^n) (Z_t)^{\nu-1} \frac{W_t}{P_t} ,
\]

(3.2-36)

and using 3.2-3 and 3.2-24, the first-order conditions of the bank’s problem, with respect to the rates \( r^l_t(j) \), and \( r^d_t(j) \), follow

\[
r^d_t(j) = \left( \frac{\theta^d_t - 1}{\theta^d_t} \right) r_t,
\]

(3.2-37)

and

\[
r^l_t(j) = \left( \frac{\theta^l_t}{\theta^l_t - 1} \right) r_t.
\]

(3.2-38)
3.2.5 Monetary Policy

The monetary policy independently adjusts the short-term nominal interest rate \( r_t \) (market rate policy) to changes in inflation and output growth, and the interest paid on reserves balances \( r_v^t \) (the IOR rate policy). These policies follow

\[
\ln(r_t/r) = \rho_r \ln(r_{t-1}/r) + \rho_\pi \ln(\pi_t/\pi) + \rho_g \ln(g_{t-1}/g) + \varepsilon_{rt} \tag{3.2-39}
\]

and

\[
\ln(r_v^t) = \ln(\tau_t) + \alpha \ln(r_t), \tag{3.2-40}
\]

for which

\[
\ln(\tau_t) = (1 - \rho_\tau) \ln(\tau) + \rho_\tau \ln(\tau_{t-1}) + \varepsilon_{\tau t} \tag{3.2-41}
\]

provides a shock to the IOR policy, \( g_t \) equals the growth rate, \( r, \pi, \) and \( g \) denote the steady-state values of market rate, inflation, and growth. Then the monetary policy chooses the persistence coefficients, which are all larger or equal to zero. The serially uncorrelated errors follow \( \varepsilon_{rt} \sim N(0, \sigma_r) \) and \( \varepsilon_{\tau t} \sim N(0, \sigma_\tau) \).

A bank’s first-order conditions imply that the monetary policy can independently target the real supply of reserves and the market interest rate, meaning that any attempt to influence the price level must be accompanied by a proportional change in the nominal quantity of reserves. The first of the two monetary policy equations, Equation 3.2-39, allows the central bank to prescribe a market interest rate that follows a modified Taylor rule such as Taylor (1993) for balancing inflation and output growth while holding the spread between the interest on reserves constant with \( \alpha = 0, \tau = 1 \). In contrast, Equation 3.2-40 allows a policy of the spread between the interest on reserves and the market rate to change to influence the cost of money creation.
3.2.6 Money Demand

There are two monetary aggregates. The first is the simple-sum aggregate of monetary services measured using

\[ M^s_t = D_t. \]  \hspace{1cm} (3.2-42)

The second monetary aggregate evolves according to

\[ M_t = M_{t-1} + (B_{t-1}^h - B_t^h/r_t) + T_t + (r_{t-1}^v - 1)N_{t}^v + (r_t - 1)B_t^h, \]  \hspace{1cm} (3.2-43)

with

\[ N_t^v = \int_0^1 N_t^v(j) dj \]  \hspace{1cm} (3.2-44)

denoting the total reserves. Meaning that monetary policy affects all the monetary services demanded by households. Lastly,

\[ B_t^h = \int_0^1 B_t^h(j) dj \]  \hspace{1cm} (3.2-45)

denotes the total bank bonds, and

\[ rr_t = N_t^v/D_t \]  \hspace{1cm} (3.2-46)

denotes the reserve ratio at each date \( t = 0, 1, 2, \ldots \).

3.2.7 Symmetric Equilibrium

The model allows for enough symmetry that all banks and wholesale firms make identical decisions for all \( i \in [0, 1] \) and \( j \in [0, 1] \). So in the model solution of the symmetric equilibrium we have \( Y_t(i) = Y_t, \) \( h_t^q(i) = h_t^q, \) \( L_t(i, j) = \bar{L}_t(j), \) \( L_t(j) = L_t, \) \( D_t(j) = D_t, \) \( B_t^h(j) = B_t^h, \) \( N_t^v(j) = N_t^v, \) \( h_t^v(j) = h_t^v, \) \( h_t^v(j) = h_t^v, \) \( P_t(i) = P_t, \) \( r_t^d(j) = r_t^d, \)
\( r_t^l(j) = r_t, \quad V_t(j) = V_t, \quad F_t(i) = F_t, \) and \( Q_t(i) = Q_t. \)

The balance-growth path consists of an allocation \( \{C_t, Y_t, g_t, h_t^s, h_t^v, h_t^a, h_t^r, h_t^v, F_t, V_t, A_t^1, A_t^2, M_t, M_t^s, T_t, B_t^b, B_t^b(j), N_t^v, L_t, D_t, rr_t, v_t^a, a_t, Z_t, Z_t, x_t^d, \tau_t\} \), such that give the prices \( \{P_t, W_t, Q_t, r_t^l, r_t^d, v_t^a\} \), household’s, firms’, and banks’ choice solve the symmetric stationery transformed maximization problem, for which the market-clearing conditions impose that \( B_t^b = 0, B_t^b(j) = 0 \) for all \( j \in [0, 1] \), \( s(i) = 1 \) for all \( i \in [0, 1] \), all labor markets clear, and the resource constraint of \( Y_t = C_t + L_t \) holds for all \( t = 0, 1, 2, \ldots \).

### 3.3 Results

Most of the parameters used for the steady-state solution and transition dynamics are calibrated to match Ireland (2014), which uses quarterly data before the financial crisis with no interest on reserves. Table 3.3 summarizes all these parameters. His data analysis yields estimates of the coefficients for the Taylor rule governing monetary policy as in Equation 3.2-39 so that \( \rho_r = 0.95, \rho_\pi = 0.20, \) and \( \rho_g = 0.15. \)

\( z = 1.005 \) and \( \pi = 1.005 \) imply an annualized steady-state growth and an inflation rate of 2% each, while setting the steady-state market rate to 6% yields a quarterly discount factor of \( \beta = 0.995. \) The intermediate goods markup \( \theta = 6. \) This parameter is calibrated to correspond to the relevant literature yielding a steady-state markup price of 20%. Lastly, \( \phi_v = 50 \) yields an average price adjustment around every 3.75 quarters.

Interest rates are not reported in the Call reports and therefore must be estimated. The interest rates on deposits and loans are estimated by dividing the total interest expenses/income by their totals. For example, interest expenses of the total transaction account divided by its amount yields a quarterly steady-state rate...\(^4\)

---

\(^4\)The implementation of the model described above assumes that all bonds are both zero in equilibrium. An extension to the current analysis would add non-zero bonds in equilibrium to include the critical substitution of bonds with other assets given changes in rates.
Table 3.1: Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady-state inflation</td>
<td>( \pi = 1.005 )</td>
</tr>
<tr>
<td>Market rate persistence parameter</td>
<td>( \rho_r = 0.95 )</td>
</tr>
<tr>
<td>Inflation persistence parameter</td>
<td>( \rho_\pi = 0.20 )</td>
</tr>
<tr>
<td>Growth persistence parameter</td>
<td>( \rho_g = 0.15 )</td>
</tr>
<tr>
<td>Steady-state growth</td>
<td>( z = 1.005 )</td>
</tr>
<tr>
<td>Discount factor</td>
<td>( \beta = 0.995 )</td>
</tr>
<tr>
<td>Price adjustment cost</td>
<td>( \phi_p = 50 )</td>
</tr>
<tr>
<td>Markup on intermediate goods</td>
<td>( \theta = 6 )</td>
</tr>
<tr>
<td>Markdown on deposits</td>
<td>( \theta_d = 70 )</td>
</tr>
<tr>
<td>Markup on loans</td>
<td>( \theta_l = 300 )</td>
</tr>
<tr>
<td>Diminishing returns to holdings of deposits</td>
<td>( \chi = 5 )</td>
</tr>
<tr>
<td>Weight on leisure versus consumption</td>
<td>( \eta = 2.5 )</td>
</tr>
<tr>
<td>Elasticity of substitution between reserves and banking labor</td>
<td>( \nu = 0.25 )</td>
</tr>
<tr>
<td>wage-in-advance labor cost</td>
<td>( \phi_d = 0.4 )</td>
</tr>
<tr>
<td>Reserves cost</td>
<td>( \phi_v = 5 \times 10^{-6} )</td>
</tr>
<tr>
<td>Share of reserves relative to labor in producing deposits</td>
<td>( \nu^a = 0.9 )</td>
</tr>
<tr>
<td>Steady-state level of the relative demand of deposits to consumption</td>
<td>( \nu^d = 0.9 )</td>
</tr>
<tr>
<td>Deposit productivity in the banking</td>
<td>( \rho^d = 0.95 )</td>
</tr>
<tr>
<td>Demand of deposits persistence parameter</td>
<td>( \rho^d = 1 )</td>
</tr>
<tr>
<td>Preference shock persistence</td>
<td>( \rho^s = 0.5 )</td>
</tr>
<tr>
<td>IOR persistence parameter</td>
<td>( \rho^\tau = 0.5 )</td>
</tr>
<tr>
<td>Deposit productivity persistence parameter</td>
<td>( \rho^d = 0.5 )</td>
</tr>
<tr>
<td>Volatility of money demand</td>
<td>( \sigma_{\pi} = 0.01 )</td>
</tr>
<tr>
<td>Volatility of preference</td>
<td>( \sigma_{\pi} = 0.01 )</td>
</tr>
<tr>
<td>Volatility of technology</td>
<td>( \sigma_{\pi} = 0.01 )</td>
</tr>
<tr>
<td>Volatility of monetary policy</td>
<td>( \sigma_r = 0.0000625 )</td>
</tr>
<tr>
<td>Volatility of reserves policy</td>
<td>( \sigma_r = 0.0003125 )</td>
</tr>
<tr>
<td>Volatility of banking productivity</td>
<td>( \sigma^d_{\pi} = -\ln(10) )</td>
</tr>
</tbody>
</table>

of 0.025%. Unfortunately, a good estimate for the loan rate is more challenging to acquire, mainly because the reported income includes interest plus fees- estimates of the period from 2001 to 2019 yield a mean rate between 5% to 8% across the 95% confidence interval, which means the variance is significant. The relative Boone indicator across the loan and deposit market, as reported in Section 3.1, suggests the parameters \( \theta_l \) should around 4.5 times larger than \( \theta_d \). This calibration of \( \theta = 70 \) and \( \theta_l = 300 \) corresponds with a quarterly steady-state deposit and loan rates of 0.06% and 1.85%, respectively, suggesting the market power in the deposit market is more than four times higher than the loans market, and the rates are within the confidence intervals of the estimated mean rates.

I conduct two experiments. First, with no interest on reserves for \( \tau = 1 \) and \( \alpha = 0 \), and second, with interest on reserves with \( \alpha = 1 \), \( \tau = 1 - 0.000625 \) that, sets the interest rate 25 basis points below the policy rate. A critical assumption of the model
is that firms must fund labor costs using a loan from the bank. The benchmark calibration of $\phi_d = 0.2$ means that 20% of the total wages are funded with a loan. These loans are accounted for in units of the single finished good. Another important assumption is the existence of a shopping-time cost- this creates a demand for the deposits, which are the only monetary asset that reduces the cost related to shopping for consumption goods. Ireland (2014) uses data on the M2 monetary services quantity index, price index, and real personal consumption expenditures with the associated chain-type price index from the National Income Product Accounts. It yields an estimate of $\chi = 5$.

Next, the banking parameters include those in deposit production. The elasticity of substitution between labor and reserves equals $\nu = 0.25$, with the relative reserves to labor needed for deposit creation set at $x_n = 0.75$. Because of a lack of banking data on this matter, the calibration assumes low substitutability between these two factors and that substantial reserves are required. Lastly, $\phi_v$, the associated cost with holdings of reserves, is set to be small enough not to influence other macro variables but, at the same time, ensure determinacy.

The rest of the parameters matched to those provided by Ireland (2014) are $\rho_a = 0.95$ and $\rho_a = 1$, which suggests that the shocks to the demand for deposits and preferences are highly persistent. Contrary, $\rho_x = 0.50$ and $\rho_x = 0.50$ introduce more modest persistence in the shocks to the banking productivity and the spread between the market interest rate and the interest rate paid on reserves. Setting $\sigma_v = 0.01$, $\sigma_a = 0.01$, and $\sigma_z = 0.01$ make one-standard-deviation money demand, preference, and technology shocks, equivalently, to one-percentage-point shocks. $\sigma_r = 0.000625$ means that the monetary policy shock leads to a 25- basis-point change in the annualized, short-term interest rate, $\sigma_r = 0.0003125$ is half that size, and $\sigma_x = \ln(10)$ sets an adverse shock reducing the bank productivity by an entire order of magnitude.
3.3.1 The Steady-State Effects

Table 3.2: Steady-state Values With Interest on Reserves

<table>
<thead>
<tr>
<th>IOR policy</th>
<th>( r_v = 0 )</th>
<th>( r_v = r - 0.25 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Interest Rate</td>
<td>1.0151</td>
<td>1.0151</td>
</tr>
<tr>
<td>Output</td>
<td>0.3220</td>
<td>0.3220</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.2774</td>
<td>0.2774</td>
</tr>
<tr>
<td>Shopping Time</td>
<td>0.0002</td>
<td>0.0002</td>
</tr>
<tr>
<td>Hours Worked</td>
<td>0.3244</td>
<td>0.3244</td>
</tr>
<tr>
<td>Real Reserves</td>
<td>0.0337</td>
<td>0.0337</td>
</tr>
<tr>
<td>Real Deposits</td>
<td>0.0783</td>
<td>0.0783</td>
</tr>
<tr>
<td>Real Loans</td>
<td>0.0446</td>
<td>0.0446</td>
</tr>
<tr>
<td>Real Wage</td>
<td>0.6958</td>
<td>0.6958</td>
</tr>
<tr>
<td>Money Supply</td>
<td>0.0783</td>
<td>0.0783</td>
</tr>
<tr>
<td>Money Demand</td>
<td>0.0968</td>
<td>0.0973</td>
</tr>
<tr>
<td>Interest Rate on Reserves</td>
<td>1.0000</td>
<td>1.0145</td>
</tr>
<tr>
<td>Interest Rate on Deposits</td>
<td>1.0006</td>
<td>1.0006</td>
</tr>
<tr>
<td>Interest Rate on Loans</td>
<td>1.0185</td>
<td>1.0185</td>
</tr>
<tr>
<td>Bank Profit</td>
<td>0.0165</td>
<td>0.0170</td>
</tr>
</tbody>
</table>

The columns in Table 3.3.1 refer to the steady-state solution of the model comparing two policies with no interest on reserves and interest on reserves at a constant spread of 25 yearly basis points. For the first, setting \( \alpha = 0 \), \( \tau = 1 \), and the second \( \alpha = 1 \) and \( \tau = 1 - 0.000625 \). Where in both cases, \( \rho = 0 \) and \( \sigma = 0 \), meaning the policy is permanent. The steady-state balance growth is set by \( z \), the steady-state rate of technological advancement. The coefficients of the Taylor rule and the inflation target determine the steady-state market interest rate by applying the conventional Fisher relationship \( \pi z/\beta \). Hence, the steady-state values are not impacted by the interest payment on reserves.

Similarly, the steady-state interest rates on deposits and loans are governed by the market interest rate and, therefore, independent of the monetary policy of interest on reserves. Lastly, the steady-state values of real output, deposits, loans, reserves, and money supply are too the same with and without interest on reserves. The exception is for bank profit and money demand, although the effect is too small to impact other real macro variables.
3.3.2 Dynamic Effects of Macroeconomic Shocks

Figure 3.7: Impulse Response Functions Comparing a Policy of Interest on Reserves: Macroeconomic Shocks I

Shocks include positive technology shock, a positive preference shock, and a conventional contractionary monetary policy shock to output, price level, interest rate, labor hours, and banking labor hours. IOR regime is in red.

Figures 3.7 and 3.8 plot the impulse response of a one-percentage-point positive shock to preferences, technology, and a conventional monetary policy shock, leading to a 0.25% increase in the annualized target interest rate. Implications of the impulse response functions depend on the choice of $\phi_d$. Alternative specifications and the implications are reserved for Appendix C in Figures C.1 and C.2.

Looking at the first row of Figure 3.7, we see that with and without an IOR policy,
the impulse response functions of a preference shock are only somewhat consistent with macro theory. Specifically, a positive shock to preferences causes a decline in consumption and a jump in the market interest rate following a slow decay to the original steady-state value and a permanent increase in the price level.\(^5\) Labor hours and labor for deposit creation are consistent with the decrease in output. In the first row of Figure 3.8, we see positive transitional effects on loans and deposits coupled with a slight decline in reserves. The effect of the preference shock on deposit and loan rates is negative and persistent. The major difference between the two policies of interest on reserves in red and no interest on reserves in blue is a dampening of the impact of the shock on the market interest rate and a lower deposit rate following a policy of interest on reserves.

The second column in Figures 3.7 and 3.8, which corresponds to a technology shock, follows what we expect from such models and is consistent with macro theory. Namely, technological advancement is coupled with higher output, lower price level, temporary lower interest rates, more labor hours, fewer reserves, more deposits, and loans coupled with higher interest on loans and lower interest on deposits. Still, the loan interest rate change reaches over a 10% increase, which is consistent with the assumption that market power in this market is relatively low. Across policies, the change is again most relevant to the deposits and market interest rates that decline a bit less with the policy of interest on reserves (in red).

The last column of these impulse responses in Figures 3.7 and 3.8 corresponds to a contractionary monetary policy shock. A 0.25% change in the annualized target interest rate has the conventional impact on output even larger with interest on reserves. However, the impact on the price level is reversed. The reversal of policy implications on the price level changes with higher levels of \(\phi_d\) but results in a negative optimal reserve ratio in steady-state. Adding bonds to the banking portfolio may change the

\(^5\)The decline in consumption becomes positive with lower levels of \(\phi_d\), which is the ratio of consumption goods funded with loans.
Figure 3.8: Impulse Response Functions Comparing a Policy of Interest on Reserves: Macroeconomic Shocks II

Shocks include positive technology shock, a positive preference shock, and a conventional contractionary monetary policy shock to real reserves, real deposits, deposit interest rate, real loans, and loans interest rate. IOR regime is in red.
current results.

In addition, the contractionary policy will have a positive transitional impact on the market rate, accompanied by lower total labor. However, higher labor is used for deposit creation as the shock has a positive transitional effect on deposits despite the theory. The increase is due to higher interest rates on deposits given higher market rates. The stock of loans declines slightly while the interest rate decreases by around 5% with no interest on reserves in blue to 10% with interest on reserves in red. Interest on reserves has implications for policy both on output, inflation, and bank balance sheet because the liquidity cost of banks matters both for the production cost associated with funding wages using loans and for the higher shopping cost associated with a lower deposit rate.

An important side note on the difference between this model and Ireland’s model is that the change in reserves holdings due to these three macro shocks and the presence of IOR policy are different. In Ireland, the decision to pay interest on reserves affects both the level and the sign of its change. With no interest on reserves, a shock to the maker rate has the convention of affecting the frictional reserves system, whereby the liquidity effect of lowering reserves is responsible for the increase in the federal funds rate and the market rate. Then, with interest on reserves, a change in the market rate (holding a constant spread between the two rates) implies increased reserves. The increase is due to the increase of deposits and the spread between the market rate and the competitively determined interest rate on deposits. This channel is quite different in my mode because a change in the IOR policy does not affect the spread between the market and deposit rates. Contrary, monetary policy’s impact on output is affected by the IOR policy. The changes, however small, emphasize the role of IOR policy in the interplay of the pass-through of monetary policy to deposit and loan rates, given monopolistic power in this market.
3.3.3 Dynamic Effects of Financial Shocks

Figure 3.9: Impulse Response Functions Comparing a Policy of Interest on Reserves: Financial Sector Shocks I

Shocks include a money demand shock, shock to bank sector productivity, and of a one time change in IOR policy to output, price level, interest rate, labor hours, and banking labor hours. IOR regime is in red.

Figures 3.9 and 3.10 display the dynamic response of a one-percentage-point shock to the money demand, a negative banking productivity shock, and a one-time change to the interest on reserves of 0.125% in annual terms. The first row corresponds to a shock to the demand for money entering the consumption good’s shopping cost. We find a positive transitional effect on output coupled with a decline in the price level that becomes persistent with interest on reserves in red. Similarly, the market interest
rate will increase but less so with interest on reserves. In the first row of Figure 3.10, the persistence of a change to the deposit will depend on the IOR policy, showing a higher persistence with interest on reserves. We also see a transitional increase in the number of real deposits and loans while a decrease in real reserves.

Figure 3.10: Impulse Response Functions Comparing a Policy of Interest on Reserves: Financial Sector Shocks II

Shocks include a money demand shock, shock to bank sector productivity, and of a one time change in IOR policy to real reserves, real deposits, deposit interest rate, real loans, and loans interest rate. IOR regime is in red.

In the second row of these two figures, we experiment with a significant negative shock to banking productivity to resemble a run on the financial system. Hence the implications are immense; however not consistent with macroeconomic theory
on the price level. A financial run will result in a transitional decrease in output and labor coupled with a decrease in the market rate but an increase in the price level instead of a decline. In contrast, the traditional macroeconomic theory would suggest that lower output and interest rates should be coupled with lower inflation. Nevertheless, these transitional increases are coupled with a transitional decrease in loans and their rate, shown in Figure 3.10. At the same time, reserves and deposits decline substantially, as does the interest paid for deposits. In addition, the presence of interest on reserves will dampen the decline of the market interest rate and affect the price level. Otherwise, the shock has equivalent implications across the two policy regimes.

The last experiment is a shock to interest on reserves, meaning a transitional change in the interest on reserves of 0.125% annually. The implication for the market is a transitional decline in output coupled with a transitional decline in the market and deposit rates. Although total labor hours show a transitional decline too, banking labor hours increase to match the higher level of deposit and reserves. Again, the impact on loans and their rates is very high and reflects the reduction in output. Although the unrealistic size of the change, the experiment shows how a policy shock to the spread between the market rate and the interest on reserves can pass through to loan and deposit rates and therefore has implications for output and inflation.

3.4 Empirical Analysis

The model results suggest that market structure matters for the pass-through of rates and the balance sheet of banks. The following section estimates how well the data support these results by measuring the marginal effect of market power on the pass-through of monetary policy to loan and deposit rates and bank funding and lending. I estimate four models. The first two models estimate the marginal effect of market power and monetary policy on the change in the sum of loans or deposits.
Then the second two models estimate the correlation between market power and the spread between loans or deposits and market rates. For all the regressions, the data set is the same as in the previous sections and exploits the Boone indicator using profits, loan share, and returns to assets to measure the level of competition in each state $s$ at time $t$.

The first two models take the following form,

\[
\Delta \ln(L_{ist}) = \beta_1 + \beta_2 M_{Pt-1} + \beta_3 B_{Is} + \beta_4 (MP \times BI)_{st} + \beta'_5 X_{it} + \beta_6 \Delta \ln(L_{i,t-1}) + \varepsilon_{ist}
\]

and

\[
\Delta \ln(D_{ist}) = \beta_1 + \beta_2 M_{Pt-1} + \beta_3 B_{Is} + \beta_4 (MP \times BI)_{st} + \beta'_5 \sum_{k=0}^{k=1} X_{i,t-k} + \beta'_6 \sum_{k=1}^{k=2} \Delta \ln(D_{i,t-k}) + \varepsilon_{ist}.
\]

In Equations 3.4-47 and 3.4-48, the log change in the bank’s total loans/deposits, denoted by $L$ and $D$, respectively, are regressed against monetary policy changes measured by changes in the market rate in the previous period and denoted by $MP$,$^6$ market competition denoted by $BI$, and the interaction term of the two by $MP \times BI$. The model further controls for bank-specific characteristics: bank size measured by the log of assets; bank liquidity measured by the sum of liquid assets to total assets; and bank capital calculated as the sum of the bank’s total equity capital divided by total assets, and the last terms consist of the lags of loans or deposits for the individual bank.$^7$

For the second part of this analysis, we need an estimate of market rates. Since the loan rate is not observed, I use the same calculated ratios from the calibration in Section 3.3 by dividing the income/expenses generated from loans or deposits by their

---

$^6$The rate is zero for periods before introducing interest on excess reserves policy.

$^7$Dynamic models, such as Equations 3.4-47 and Equation 3.4-48, are prone to an endogenous variable bias because lagged dependent variables are likely correlated with the error term (endogeneity between change in loans at t-1 to other items on banks portfolio). Therefore, Equation 3.4-48 has extra lags because, in the regression estimation, the Arellano-Bond test for AR (1) and AR (2) in first-differencing requires the additional time lag in deposit growth for the equation to be correctly specified, with no autocorrelation with the error term.
total quantity. I further divide loans into loans backed by real estate, industrial or commercial, and credit card loans and estimate the corresponding rates. The interest rate spread is measured by taking the difference between the bank rate and the market rate proxied by the interest rate on 3-month Treasury bonds. \( S^l = R^l - R^{th3} \) is the spread on loans, and \( S^d = R^{th3} - R^d \) is the spread on deposits.

Hence the interest-rate model equation follows

\[
S^l_{ist} = \alpha_0 + \alpha_1 BI_{st} + \theta_s + \tau_t + \varepsilon_{ist} \tag{3.4-49}
\]

and

\[
S^d_{ist} = \alpha_0 + \alpha_1 BI_{st} + \theta_s + \tau_t + \varepsilon_{ist}, \tag{3.4-50}
\]

in which \( BI_{st} \) is the competition indicator measured over the U.S. and across time. \( \theta_s \) and \( \tau_t \) are state and year fixed-effects vectors. With \( \varepsilon_{ist} \) the error term. Standard errors are clustered at the state level.\(^8\) Estimations of market competition’s coefficient, \( \alpha_1 > 0, \) indicate higher spreads in less competitive markets.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \ln(\text{Loans}) )</td>
<td>0.018</td>
<td>0.085</td>
<td>-9.87</td>
<td>10.0</td>
</tr>
<tr>
<td>Real Estate Spread</td>
<td>0.11</td>
<td>0.99</td>
<td>-0.0036</td>
<td>154</td>
</tr>
<tr>
<td>Commercial &amp; Industrial Spread</td>
<td>0.042</td>
<td>0.67</td>
<td>-0.0042</td>
<td>122.0</td>
</tr>
<tr>
<td>Credit Card Spread</td>
<td>0.097</td>
<td>1.20</td>
<td>-1.33</td>
<td>211</td>
</tr>
<tr>
<td>Monetary Policy Shock</td>
<td>0.011%</td>
<td>0.33%</td>
<td>-1.35%</td>
<td>0.57%</td>
</tr>
<tr>
<td>Boone Index Across States</td>
<td>-0.56</td>
<td>1.18</td>
<td>-22.9</td>
<td>5.46</td>
</tr>
<tr>
<td>Boone ( \ln(\text{Profit}) )</td>
<td>-4.19</td>
<td>0.50</td>
<td>-5.08</td>
<td>-3.20</td>
</tr>
<tr>
<td>Boone Loan Share</td>
<td>-0.91</td>
<td>0.41</td>
<td>-1.72</td>
<td>-0.41</td>
</tr>
<tr>
<td>Boone Deposit Share</td>
<td>-0.25</td>
<td>0.20</td>
<td>-0.52</td>
<td>0.072</td>
</tr>
<tr>
<td>Marginal Effect of Competition</td>
<td>-0.0087</td>
<td>0.53</td>
<td>-5.95</td>
<td>30.9</td>
</tr>
<tr>
<td>Market Rate</td>
<td>0.014</td>
<td>0.015</td>
<td>0.00020</td>
<td>0.050</td>
</tr>
<tr>
<td>( \ln(\text{Deposits}) )</td>
<td>0.016</td>
<td>0.081</td>
<td>-5.48</td>
<td>10.5</td>
</tr>
<tr>
<td>( \ln(\text{Assets}) )</td>
<td>12.1</td>
<td>1.38</td>
<td>7.71</td>
<td>21.6</td>
</tr>
<tr>
<td>Capital</td>
<td>0.11</td>
<td>0.044</td>
<td>-0.034</td>
<td>1.00</td>
</tr>
<tr>
<td>Liquidity</td>
<td>0.088</td>
<td>0.078</td>
<td>0</td>
<td>0.99</td>
</tr>
<tr>
<td>Rate on 3 month T-bill</td>
<td>1.40%</td>
<td>1.54%</td>
<td>0.020%</td>
<td>4.98%</td>
</tr>
</tbody>
</table>

The unit of observation is a bank in a state in a year.

\(^8\)Call reports include all states for all year, and we have 51 clusters.
Note that loan and deposit rates are proxies for the actual bank rates. As a result, in Table 3.3, the summary statistics of the variables used in the following regressions suggest that estimations of market rates may be poor indicators of the actual rates, as the maximum rate is estimated too high. For this reason, the regression results for the pass-through of policy to rates provide a glimpse of the subsample that includes rates below 40%, with the complete sample regressions reserved for Appendix C.2. The sample included in all regressions consists of all commercial banks, where excluding other financial institutions restricts the estimations to a group that provides a relatively homogenous product. A further partition is possible to check for the robustness of the estimates.

The first regression results in Table 3.4 show the effects of the interaction between market power and monetary policy on changes in deposits and loans. Using the market power indicator given by returns to assets (ROA) for the first two columns and log of profits for the second two. The entire table with all indicators and controls is in Appendix C.2, Figure C.4. The marginal effect of policy in column one measures 6.27. It is significant and suggests a dampening of the lending channel of monetary policy with higher market power. Alternatively, the higher the Boone measured using ROA, the higher the market competition and the more effectively the monetary policy’s pass-through to bank loans.\(^\text{10}\)

On the other hand, the interaction term is not significant in the corresponding regression using profits in column 3. Also surprising is the difference in signs of the

---

\(^9\)Commercial banks include depository trust companies, credit card companies, commercial bank charters, private banks, development banks, limited charter banks, and foreign banks.

\(^{10}\)All estimation results report the Hansen test’s significance for excluding groups for the relevance of excluded instrument variables. This statistic provides a measure of instrument relevance, and rejection of the null hypothesis indicates that the model is identified. The Sargan/Hensen test of the joint null hypothesis that the instruments are valid, i.e., uncorrelated with the error term, is used to determine the instrument’s validity. Under the null hypothesis, the test statistic is chi-squared distributed with the number of degrees of freedom equal to the overidentification restrictions. A rejection would indicate that the instruments are not valid. Also reported are the significant values of AR (1) and AR (2). AR (1)’s significant values show that the null hypothesis of no autocorrelation among error terms in the first difference is rejected. Non-significant AR (2) values show that GMM is correctly specified, and there are no identification issues.
Boone coefficients, which is significant for both but with a positive using log of profits and a negative using ROA. We do not find statistically significant coefficients for the marginal effect of market power $\beta_4$ on the deposit channel of monetary policy, indicating a low correlation between the two. The low magnitude of the estimated coefficients hinders the deposit balance does not change much in response to monetary policy and market power interaction. However, if market power allows banks to change the spreads between market and deposit rates, we expect higher market rates to imply lower spreads coupled with outflow.

Table 3.4: Market Competition and Policy Pass-through on Loans and Deposits

<table>
<thead>
<tr>
<th></th>
<th>With ROA</th>
<th>With Log(Profits)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% $\Delta$Loans (1)</td>
<td>% $\Delta$Deposits (2)</td>
</tr>
<tr>
<td>Boone Index</td>
<td>$-2.615^{**}$</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>(1.121)</td>
<td>(0.878)</td>
</tr>
<tr>
<td>MP Shock at t-1</td>
<td>0.079^{**}</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>ME of Competition</td>
<td>6.272^{**}</td>
<td>0.321</td>
</tr>
<tr>
<td></td>
<td>(2.813)</td>
<td>(2.774)</td>
</tr>
<tr>
<td>Time Dummy</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>AR(1) P Value</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>AR(2) P Value</td>
<td>0.017</td>
<td>0.282</td>
</tr>
<tr>
<td>Sargan/Hensen P Value</td>
<td>0.547</td>
<td>0.050</td>
</tr>
<tr>
<td>Instruments</td>
<td>134</td>
<td>194</td>
</tr>
<tr>
<td>Number of Banks</td>
<td>4939</td>
<td>4991</td>
</tr>
<tr>
<td>Observations</td>
<td>245,868</td>
<td>239,774</td>
</tr>
</tbody>
</table>

Note: All models report results of two-step system GMM dynamic panel model. Significant values of AR (1) reject null hypothesis of no autocorrelation among error terms. Insignificant values of AR (2) is insignificant show error terms in level regressions are not correlated. Insignificant values of Sargan/Hensen indicate instruments are valid. Standard errors reported in parenthesis.

The subsequent regressions in Table 3.5 summarize the effects of market competition on the rate pass-through of the subsample of observations that have estimated rates below 40%. Competition is positive and only statistically significant with spreads of commercial and industrial loans and negatively related to deposit spread but not statistically significant. The other spreads do not significantly correlate with market power. Suppose higher competition in the industrial and commercial loan market exists relative to other loan markets. We would expect banks to be
price-takes in this market and the estimations of $\alpha_1$ to be higher, as confirmed by the regression results. However, this $\alpha_1$ coefficient is not significant using the whole sample, as shown in Table C.7, indicating the data limitations of this proxy as an indicator for the actual change in bank rates.

### Table 3.5: Market Competition and Monetary Policy on Pass-through to Spreads

<table>
<thead>
<tr>
<th>Dependent variable: Loan and Deposit Spreads</th>
<th>Real Estate (1)</th>
<th>I&amp;C (2)</th>
<th>Credit Card (3)</th>
<th>Deposit (4)</th>
<th>Deposit to Loan (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boone ROA</td>
<td>0.0021</td>
<td>0.0033***</td>
<td>−0.0096</td>
<td>−0.0000</td>
<td>0.0024</td>
</tr>
<tr>
<td>(0.0060)</td>
<td>(0.0012)</td>
<td>(0.0072)</td>
<td>(0.0005)</td>
<td>(0.0061)</td>
<td></td>
</tr>
<tr>
<td>Bank-Specific</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Time</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Observations</td>
<td>84,999</td>
<td>67,399</td>
<td>63,204</td>
<td>269,065</td>
<td>84793</td>
</tr>
</tbody>
</table>

*Note:*

- $p<0.1$;
- $*p<0.05$;
- $**p<0.01$;
- $***p<0.001$.

The unit of observation is a bank in a state in a year sampled for rates below 40%. Standard errors reported in parenthesis.

### 3.5 Conclusion

The chapter adds to the literature evaluating the importance of the banking market competition in the pass-through of monetary policy to deposit and lending rates and deposit and lending balances. Theory suggests that greater market power, either in loans or deposits, will imply that banks will change the spread between the market and bank rates. So that higher market power implies monetary policy increase of the market rate will be coupled with a higher spread on loans and a more considerable decline in lending, and a lower spread on deposits with smaller outflows of deposits.

The DSGE model assumes sticky prices with monopolistic power for banks while utilizing a non-structural competition index proposed by Boone (2008) to calibrate the model. The Boone index indicates that commercial banks have experienced a decline in market power over the last two decades, with some market power in the loans market and even higher levels in the deposit market. The simulations suggest that a monetary policy shock increasing the market rate will be coupled with a proportionally smaller increase in deposit rates such that the spread between them declines. In
addition, loan rates will decline. This channel is magnified with a policy of interest on reserves. We find that a change in the interest on reserves, such that the spread between market policy rates and reserves shrink, will also lower the market rate, deposit rates, and loan rates as funding becomes cheaper and more reserves are used to back loans. However, total loans decline because reserves become more valuable to the bank.

The current model can only capture parts of the theory while remaining inconsistent with others. For example, contractionary monetary policy implies higher inflation. The same holds for a shock increasing the interest on reserves. One simplification of the model solution is the absence of bonds in equilibrium. However, the presence of substitution between reserves and bonds, loans and bonds, and even household deposits and bonds is essential to capture the optimal decision of banks, given their ability to choose a monopolistic price for their services.

My interest in further research would be to entangle these channels, affecting monetary policy’s impact on bank lending and rates. A greater emphasis on using interest on reserves to target bank risk is needed to understand the central bank’s macro-prudential stance on using interest on reserve policy independently from targeting market rates.
BIBLIOGRAPHY


APPENDIX A.

APPENDIX FOR CHAPTER 1

A.1 Additional Tables

Table A.1: Summary Statistics Non-consolidated Uninsured

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>25%</th>
<th>75%</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Assets ($Billion)</td>
<td>11,995</td>
<td>8.122</td>
<td>34.264</td>
<td>0</td>
<td>0.014</td>
<td>2.077</td>
<td>521.667</td>
</tr>
<tr>
<td>ER ($Billion)</td>
<td>11,995</td>
<td>0.690</td>
<td>4.265</td>
<td>0</td>
<td>0</td>
<td>0.002</td>
<td>95.431</td>
</tr>
<tr>
<td>Cash ($Billion)</td>
<td>11,995</td>
<td>0.866</td>
<td>4.369</td>
<td>0</td>
<td>0</td>
<td>0.087</td>
<td>95.488</td>
</tr>
<tr>
<td>Cash (% of Assets)</td>
<td>11,995</td>
<td>0.189</td>
<td>0.283</td>
<td>0</td>
<td>0.001</td>
<td>0.257</td>
<td>1.000</td>
</tr>
<tr>
<td>Deposits ($Billion)</td>
<td>11,995</td>
<td>2.281</td>
<td>8.053</td>
<td>0</td>
<td>0</td>
<td>0.152</td>
<td>75.650</td>
</tr>
<tr>
<td>Deposits (% of Liabilities)</td>
<td>11,995</td>
<td>0.167</td>
<td>0.281</td>
<td>0</td>
<td>0</td>
<td>0.222</td>
<td>1</td>
</tr>
<tr>
<td>Loans ($Billion)</td>
<td>11,995</td>
<td>1.791</td>
<td>8.892</td>
<td>0</td>
<td>0</td>
<td>0.535</td>
<td>196.873</td>
</tr>
<tr>
<td>Loans (% of Assets)</td>
<td>11,995</td>
<td>0.289</td>
<td>0.349</td>
<td>0</td>
<td>0</td>
<td>0.562</td>
<td>1.011</td>
</tr>
<tr>
<td>Securities ($Billion)</td>
<td>11,995</td>
<td>0.482</td>
<td>2.384</td>
<td>0</td>
<td>0</td>
<td>0.050</td>
<td>49.325</td>
</tr>
<tr>
<td>Securities (% of Assets)</td>
<td>11,995</td>
<td>0.148</td>
<td>0.252</td>
<td>0</td>
<td>0</td>
<td>0.175</td>
<td>1.090</td>
</tr>
</tbody>
</table>

Table A.2: Summary Statistics Non-consolidated Insured

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>25%</th>
<th>75%</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Assets ($Billion)</td>
<td>245,859</td>
<td>1.587</td>
<td>30.064</td>
<td>0</td>
<td>0.066</td>
<td>0.315</td>
<td>1948.150</td>
</tr>
<tr>
<td>ER</td>
<td>245,859</td>
<td>0.048</td>
<td>1.406</td>
<td>-1.525</td>
<td>0</td>
<td>0</td>
<td>210.929</td>
</tr>
<tr>
<td>Cash ($Billion)</td>
<td>245,859</td>
<td>0.113</td>
<td>2.672</td>
<td>0</td>
<td>0.003</td>
<td>0.016</td>
<td>302.301</td>
</tr>
<tr>
<td>Cash (% of Assets)</td>
<td>245,859</td>
<td>0.069</td>
<td>0.079</td>
<td>-0.002</td>
<td>0.025</td>
<td>0.082</td>
<td>1.000</td>
</tr>
<tr>
<td>Deposits ($Billion)</td>
<td>245,859</td>
<td>0.879</td>
<td>17.270</td>
<td>0</td>
<td>0.031</td>
<td>0.210</td>
<td>1190.738</td>
</tr>
<tr>
<td>Deposits (% of Liabilities)</td>
<td>245,859</td>
<td>0.787</td>
<td>0.340</td>
<td>0</td>
<td>0.836</td>
<td>0.985</td>
<td>1.178</td>
</tr>
<tr>
<td>Loans ($Billion)</td>
<td>245,859</td>
<td>0.892</td>
<td>14.459</td>
<td>0</td>
<td>0.039</td>
<td>0.211</td>
<td>778.147</td>
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<td>Loans (% of Assets)</td>
<td>245,859</td>
<td>0.637</td>
<td>0.168</td>
<td>0</td>
<td>0.545</td>
<td>0.757</td>
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<td>Securities ($Billion)</td>
<td>245,859</td>
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<td>5.395</td>
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<td>0.009</td>
<td>0.061</td>
<td>369.913</td>
</tr>
<tr>
<td>Securities (% of Assets)</td>
<td>245,859</td>
<td>0.214</td>
<td>0.154</td>
<td>0</td>
<td>0.099</td>
<td>0.300</td>
<td>0.998</td>
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Table A.3: Regression Results Unconsolidated Data

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>RoverA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDIC</td>
<td>-0.005***</td>
<td>-0.140***</td>
</tr>
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<td></td>
<td>(0.0004)</td>
<td>(0.001)</td>
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<tr>
<td>log(Liabilities)</td>
<td>0.038***</td>
<td>0.027***</td>
</tr>
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<td></td>
<td>(0.0005)</td>
<td>(0.0005)</td>
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<tr>
<td>log(Securities)</td>
<td>-0.004***</td>
<td>-0.003***</td>
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<tr>
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<td>(0.0001)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>log(Loans)</td>
<td>-0.014***</td>
<td>-0.012***</td>
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<tr>
<td></td>
<td>(0.0003)</td>
<td>(0.0003)</td>
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<td>log(Deposits)</td>
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<td>-0.0001</td>
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<tr>
<td></td>
<td>(0.0002)</td>
<td>(0.0002)</td>
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<tr>
<td># of Employees</td>
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<td>-0.0001***</td>
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<tr>
<td></td>
<td>(0.00001)</td>
<td>(0.00001)</td>
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<td>FDIC : Size</td>
<td>0.017***</td>
<td>0.017***</td>
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<td>(0.0005)</td>
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<tr>
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<td>✓</td>
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<tr>
<td>Time</td>
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<tr>
<td>Observations</td>
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<td>148,451</td>
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<tr>
<td>R²</td>
<td>0.061</td>
<td>0.105</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.031</td>
<td>0.076</td>
</tr>
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</table>

Note: *p<0.1; **p<0.05; ***p<0.01
Table A.4: Event Study Regression With Controls

<table>
<thead>
<tr>
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<th>Dependent variable: RoverA</th>
</tr>
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<tbody>
<tr>
<td>Dtmin4</td>
<td>-0.102***</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
</tr>
<tr>
<td>Dtmin3</td>
<td>-0.094***</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
</tr>
<tr>
<td>Dtmin2</td>
<td>-0.109***</td>
</tr>
<tr>
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<td>(0.008)</td>
</tr>
<tr>
<td>Dtmin1</td>
<td>-0.066***</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
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<td>Dt0</td>
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<td>(0.008)</td>
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<td>Dt1</td>
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<td>Dt2</td>
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</tr>
<tr>
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<td>(0.008)</td>
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<td>Dt3</td>
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<tr>
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<td>logSecurities</td>
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<td>logLoans</td>
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<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>logDeposits</td>
<td>0.001***</td>
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<tr>
<td></td>
<td>(0.0004)</td>
</tr>
<tr>
<td>Size</td>
<td>-0.004***</td>
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<td>(0.0001)</td>
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<td>Q1</td>
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<tr>
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<tr>
<td>Q2</td>
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</tr>
<tr>
<td></td>
<td>(0.001)</td>
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<td>Q3</td>
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<td>(0.001)</td>
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<tr>
<td>Dt0:Char_Size</td>
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<td>Observations</td>
<td>33,152</td>
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<tr>
<td>R²</td>
<td>0.127</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.098</td>
</tr>
</tbody>
</table>

*Note:* *p*<0.1; **p**<0.05; ***p***<0.01
APPENDIX B.

APPENDIX FOR CHAPTER 2

B.1 Additional Steady-State Tables

The following Tables report the steady-state solution for the central result in which no stigma premium is attributed to borrowing from the discount window facility. In Table B.1, the change in reserves ratio between the three periods is much lower than the conclusion with the discount window rate with the stigma as in the main text. Other than that, we see the federal funds rate is closer than that observed during these periods, although not as low. Also, note that even though the discount window rate increase from 0.5% to 0.75%, reserve ratios reduce to zero, moving from the second to the third column once the FDIC policy is introduced. This result counters the hypothesis that an FDIC assessment associated with a higher balance-sheet cost for domestic banks will increase the opportunity cost of reserves. The conclusion holds for Table B.2, which reports an example with a low discount window rate for the extended model.

The last table shows two iterations of one of the simulations in which there is no steady-state. Increasing the IOR slightly above 1% will result in this extensive arbitrage by both foreign and domestic banks who optimally choose to issue only interbank loans, so the reserve to deposit ratio is 100%. A problem with the model given such specification arises because it fails to find a steady-state in the interbank
Table B.1: Alternative Steady-state Solution With a Lower Discount Window Rate as Reported by the Federal Reserves

<table>
<thead>
<tr>
<th></th>
<th>2008,Q3</th>
<th>2008,Q4</th>
<th>2011,Q2</th>
<th>2011,Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Domestic</td>
<td>Foreign</td>
<td>Domestic</td>
<td>Foreign</td>
</tr>
<tr>
<td>Reserve to Assets</td>
<td>8.6002</td>
<td>0.5312</td>
<td>9.7128</td>
<td>2.2982</td>
</tr>
<tr>
<td>Reserve Ratio</td>
<td>9.4602</td>
<td>0.5843</td>
<td>10.6841</td>
<td>2.5281</td>
</tr>
<tr>
<td>Interbank Borrow</td>
<td>0.0132</td>
<td>0.0048</td>
<td>0.0109</td>
<td>0.0044</td>
</tr>
<tr>
<td>Interbank Lend</td>
<td>0.0115</td>
<td>0.0064</td>
<td>0.0105</td>
<td>0.0051</td>
</tr>
<tr>
<td>Discount Window</td>
<td>0.0046</td>
<td>0.0017</td>
<td>0.0015</td>
<td>0.0006</td>
</tr>
<tr>
<td>Interbank Lending Share</td>
<td>64.2450</td>
<td>35.7550</td>
<td>67.3727</td>
<td>32.6273</td>
</tr>
<tr>
<td>DW/Reserves</td>
<td>0.5674</td>
<td>18.9083</td>
<td>0.1682</td>
<td>1.6354</td>
</tr>
<tr>
<td>Interest rate</td>
<td>2.6465</td>
<td>2.4320</td>
<td>1.6479</td>
<td>1.5842</td>
</tr>
<tr>
<td>Market Tightness</td>
<td>54.2%</td>
<td>39.6%</td>
<td>41.8%</td>
<td>44.1%</td>
</tr>
</tbody>
</table>
| Federal funds rate | 2.48   | 1.78    | 1.23    | 1.22    

Table B.2: Alternative Steady-state Solution With a Lower Discount Window Rate as Reported by the Federal Reserves, Including GSEs

<table>
<thead>
<tr>
<th></th>
<th>2008,Q3</th>
<th>2008,Q4</th>
<th>2010,Q4</th>
<th>2011,Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Domestic</td>
<td>Foreign</td>
<td>Domestic</td>
<td>Foreign</td>
</tr>
<tr>
<td>Reserve to Assets</td>
<td>0.1937</td>
<td>0.1002</td>
<td>0.3124</td>
<td>0.1189</td>
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<tr>
<td>Reserve Ratio</td>
<td>0.2131</td>
<td>0.1103</td>
<td>0.3436</td>
<td>0.1308</td>
</tr>
<tr>
<td>Interbank Borrow</td>
<td>0.0733</td>
<td>0.0060</td>
<td>0.0723</td>
<td>0.0059</td>
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<tr>
<td>Interbank Lend</td>
<td>0.0001</td>
<td>0.0024</td>
<td>0.0001</td>
<td>0.0024</td>
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<tr>
<td>Discount Window</td>
<td>0.0102</td>
<td>0.0008</td>
<td>0.0101</td>
<td>0.0008</td>
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<tr>
<td>Interbank Borrow Share</td>
<td>92.4656</td>
<td>7.5344</td>
<td>92.4004</td>
<td>7.5996</td>
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<tr>
<td>Interbank Lending Share</td>
<td>0.1277</td>
<td>3.0659</td>
<td>0.1356</td>
<td>3.0677</td>
</tr>
<tr>
<td>DW/Reserves</td>
<td>56.5900</td>
<td>50.4634</td>
<td>34.5572</td>
<td>42.2915</td>
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<tr>
<td>Interest rate</td>
<td>2.4376</td>
<td>2.4254</td>
<td>1.5743</td>
<td>1.5691</td>
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<tr>
<td>Market Tightness</td>
<td>35.8%</td>
<td>35.9%</td>
<td>24.3%</td>
<td>25.7%</td>
</tr>
<tr>
<td>Federal funds rate</td>
<td>1.52</td>
<td>1.22</td>
<td>0.94</td>
<td>0.95</td>
</tr>
</tbody>
</table>

market. It happens because when optimal to borrow against all reserves, the market becomes tight as borrowing orders exceed lending orders. Tightness implies a higher expected federal funds rate that will result in interbank lending instead. If banks find it optimal to lend all excess reserves, the market becomes satiated again, and rates decline. The limitation of the model is that the algorithm jumps from a tight to a satiated market and never reaches a steady state.
Table B.3: Presence of Arbitrage with No Steady-state Solution (Two Consecutive Iterations)

<table>
<thead>
<tr>
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<th>Domestic</th>
<th>Foreign</th>
<th>Domestic</th>
<th>Foreign</th>
</tr>
</thead>
<tbody>
<tr>
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<td>90.86%</td>
<td>90.83%</td>
<td>90.86%</td>
<td>90.83%</td>
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<td>Reserve Ratio</td>
<td>99.95%</td>
<td>99.93%</td>
<td>99.95%</td>
<td>99.93%</td>
</tr>
<tr>
<td>Interbank Borrowing Share</td>
<td>NaN</td>
<td>NaN</td>
<td>100%</td>
<td>0</td>
</tr>
<tr>
<td>Interbank Lending Share</td>
<td>67.3%</td>
<td>13.21%</td>
<td>0%</td>
<td>40.52%</td>
</tr>
<tr>
<td>Interbank Borrow</td>
<td>0</td>
<td>0</td>
<td>0.671</td>
<td>0</td>
</tr>
<tr>
<td>Interbank Lend</td>
<td>0.141</td>
<td>0.029</td>
<td>0</td>
<td>0.028</td>
</tr>
<tr>
<td>Discount Window</td>
<td>0</td>
<td>0</td>
<td>0.094</td>
<td>0</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>1.12%</td>
<td>1.19%</td>
<td>1.11%</td>
<td>1.17%</td>
</tr>
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<td>Interbank Rate</td>
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</tr>
<tr>
<td>Market Tightness</td>
<td>23.3%</td>
<td>24.6%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

liquidity ratios

B.2 Data

Figure B.2 plots the liquidity to assets of each sector (the dotted lines) and reserve to assets for each sector (the solid lines). The red line corresponds to Uninsured U.S. branches of foreign banks, and the black line corresponds to the domestically chartered insured banks. We see a slight substitution of reserves for foreign banks following the introduction of interest on excess reserves, but not for domestic banks.

This paper’s macroeconomic variables are from the Federal Financial Institutions Examination Council (FFIEC) quarterly filings. FFIEC 031, Reports of Condition and Income (also known as the Call Reports) for domestically chartered banks, and
https://www.newyorkfed.org/fed-funds-lending

The share of GSEs overnight loan orders to total assets: Board of Governors of the Federal Reserve System (U.S.), Government-Sponsored Enterprises; Total Assets Held by FHLB (Balance Sheet), Level [BOGZ1FL404090430Q], retrieved from FRED, Federal Reserve Bank of St. Louis;
https://fred.stlouisfed.org/series/BOGZ1FL404090430Q
Board of Governors of the Federal Reserve System (U.S.), Government-Sponsored Enterprises; Total Assets (Balance Sheet), Level [BOGZ1FL404090405Q], retrieved from FRED, Federal Reserve Bank of St. Louis;
https://fred.stlouisfed.org/series/BOGZ1FL404090405Q

https://www.newyorkfed.org/fed-funds-borrowing

The share of discount window loan to reserves: Board of Governors of the Federal Reserve System (U.S.), Total Borrowings of Depository Institutions from the Federal Reserve excluding Term Auction Credit (DISCONTINUED)[DISCBORR],
retrieved from FRED, Federal Reserve Bank of St. Louis;
https://fred.stlouisfed.org/series/DISCBORR

- Board of Governors of the Federal Reserve System (US), Reserves of Depository Institutions: Total [TOTRESNS], retrieved from FRED, Federal Reserve Bank of St. Louis;
  https://fred.stlouisfed.org/series/TOTRESNS

- The interest on discount window loans: Board of Governors of the Federal Reserve System (U.S.), Discount Window Primary Credit Rate [DPCREDIT], retrieved from FRED, Federal Reserve Bank of St. Louis;
  https://fred.stlouisfed.org/series/DPCREDIT

- The interest on reserves: Board of Governors of the Federal Reserve System (US), Interest Rate on Excess Reserves [IOER], retrieved from FRED, Federal Reserve Bank of St. Louis;
  https://fred.stlouisfed.org/series/IOER

- The effective federal funds rate: Board of Governors of the Federal Reserve System (US), Federal Funds Effective Rate [FEDFUNDS], retrieved from FRED, Federal Reserve Bank of St. Louis;
  https://fred.stlouisfed.org/series/FEDFUNDS
### Table B.4: Ratio of Reserves to Assets by Bank

<table>
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<th>FBO_NAME</th>
<th>FBO_COUNTRY</th>
<th>RCFD0090</th>
<th>RCFD2170</th>
<th>RtoA</th>
<th>DT</th>
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<tbody>
<tr>
<td>NA</td>
<td>NA</td>
<td>95430475</td>
<td>102106424</td>
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<td>DEUTSCHE BANK AKTIEN.</td>
<td>GERMANY</td>
<td>88710050</td>
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<td>85218006</td>
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<tr>
<td>NA</td>
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<td>74549982</td>
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<tr>
<td>DEUTSCHE BANK AKTIEN.</td>
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<td>NA</td>
<td>NA</td>
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<td>CREDIT SUISSE AG</td>
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<td>CREDIT SUISSE AG</td>
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<td>CREDIT SUISSE AG</td>
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<td>2010q4</td>
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<td>BANK OF NOVA SCOTIA, THE</td>
<td>CANADA</td>
<td>42737162</td>
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<td>2011q4</td>
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<td>DNB BANK ASA</td>
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<td>2011q1</td>
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<td>35624720</td>
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<td>SVENSKA HANDELSB.</td>
<td>SWEDEN</td>
<td>34681030</td>
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<td>CREDIT SUISSE AG</td>
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</table>

### B.3 Bargaining Problem With Foreign and Domestic Banks

At the start of each balancing stage, each type of bank decides to borrow or lend overnight funds in the interbank market. Each has a different outside option available to it when bargaining for \( r_{t}^{ff} \). There is a tax \( \tau \) on reserves held by domestic banks. So while the outside option of overnight lending for the foreign bank is \( r_{t}^{ior} \), the outside option facing the domestic bank equals \( r_{t}^{ior} - \tau \). Because of these asymmetries, the Nash Bargaining problem takes different forms depending on which type of bank is
lending and borrowing. Where it is without saying that, in the case of only two banks, we get that in periods that both choose to borrow overnight funds or both choose to lend overnight funds, there is no trade between them in that period, and each resolves to the outside option available to it. As we will see, the choice of being a lender or a borrower could be independent of the actual amount of reserves one bank has and will lead to different bargaining solutions. As in Bianchi & Bigio (2022), I assume that banks will always prefer to settle reserves in the interbank market first. The Nash Bargaining problem for lenders and borrowers has a bargaining rate \( \varepsilon \in [0, 1] \) for each party’s bargaining power. Equal bargaining power rates are assumed for simplicity with no loss in the generality of the main conclusion.\(^1\)

As shown below, the bargaining problem of a unit of reserves has a first-order condition that provides an implicit solution for the federal funds rate in each of the four different cases.

**Case 1: Foreign bank has excess reserves while Domestic a reserves deficit**

\[
\max_{r} \left( m_{b} r_{t}^{dw} - m_{b} r_{t}^{ff} \right)^{\varepsilon} \left( m_{t} r_{t}^{ff} - m_{t} r_{t}^{ior} \right)^{1-\varepsilon}
\]

Solving for the first order conditions we get that

\[
r_{t}^{ff} = (1 - \varepsilon) r_{t}^{dw} + \varepsilon (r_{t}^{ior})
\]

(B.1)

**Case 2: Domestic Bank has excess reserves while Foreign a reserves deficit**

\[
\max_{r} \left( m_{b} r_{t}^{dw} - m_{b} r_{t}^{ff} \right)^{\varepsilon} \left( m_{t} r_{t}^{ff} - m_{t} (r_{t}^{ior} - \tau) \right)^{1-\varepsilon}
\]

\(^1\)In the model, it is a function of the probability of matching in the market. So that if the probability of matching a borrowing order is low while matching a lending order is high, the bargaining power is skewed towards lenders.
Solving for the first order conditions we get that

\[ r_{ff}^t = (1 - \varepsilon)r_{dw}^t + \varepsilon(r_{ior}^t - \tau) \]  \hfill (B.2)

The asymmetry in the marginal benefit of holding excess reserves between the two banks assures a violation of the non-arbitrage condition when the federal funds rate falls between \( r_{ior}^t - \tau \), and \( r_{ior}^t \). A foreign bank can borrow additional overnight funds at \( r_{ff}^t \leq r_{ior}^t \) to lend to the Fed at \( r_{ior}^t \) for a profit, suggesting that no matter the reserve balance of the foreign bank, it will always be a borrower if it can bargain the federal funds rate below \( r_{ior}^t \).

**Case 3: Both bank have excess reserves (foreign bank borrows)**

A foreign bank will have the outside option \( r_{ior}^t \), which is the opportunity cost of not borrowing additional funds. While the domestic bank lends with a lower outside option of \( r_{ior}^t - \tau \)

\[
\max_{r_{ff}^t} \left( mb_{ior}^t - mb_{ff}^t \right) \varepsilon \left( ml_{ff}^t - ml_{ior}^t (r_{ior}^t - \tau) \right)^{1-\varepsilon}
\]

Solving for the first order conditions we get that

\[ r_{ff}^t = (1 - \varepsilon)r_{ior}^t + \varepsilon(r_{ior}^t - \tau), \]

or

\[ r_{ff}^t = r_{ior}^t - \varepsilon \tau. \]  \hfill (B.3)

**Case 4: Both banks have a deficit (Domestic bank lends)**

\[
\max_{r_{ff}^t} \left( mb_{dw}^t - mb_{ff}^t \right) \varepsilon \left( ml_{ff}^t - ml_{dw}^t \right)^{1-\varepsilon}
\]
Solving for the first order conditions we get that

\[ r_{ff}^t = r_{tw}^t \quad (B.4) \]

**B.4 Steady-State With Two Banks**

- **step 1:**
  1. Guess the initial (perfectly competitive profit-maximizing) stead-state real returns on illiquid loans \( r_{ss}^D \), and \( r_{ss}^F \), for the domestic sector and the foreign sector.
  
  2. Guess the initial steady-state market tightness for overnight funds, \( \theta_{ss} \).
  
  3. Guess the initial stead-state probabilities that a borrower of overnight funds is borrowing from a domestic bank, \( \gamma_{ss}^- \), and that a lender of overnight funds is lending to a domestic bank, \( \gamma_{ss}^+ \) (where \( \gamma_{ss}^- = (1 - \gamma_{ss}^+) \), and \( \gamma_{ss}^+ = (1 - \gamma_{ss}^-) \), are the analog probabilities that an order is met with a foreign counterpart).

- **step 2:**
  1. Based on the market tightness and monetary policy, the trading probabilities \( \gamma_{ss}^+ \), and \( \gamma_{ss}^- \) and the bargaining power \( \phi_{ss} \) are determined. Based on the initial guess for the probability of facing a domestic or a foreign bank in the market, and \( \gamma_{ss}^+ \), and \( \gamma_{ss}^- \) the corresponding expected Nash-bargaining, federal funds rate is computed and with it the corresponding liquidity cost/benefit of having reserves deficit/excess.

\[
\gamma_{ss}^+ = \begin{cases} 
 1 - e^{-\lambda} & \text{if } \theta_{ss} \geq 1 \\
  \theta_{ss}(1 - e^{-\lambda}) & \text{otherwise}
\end{cases}
\]
\[
\gamma_{ss} = \begin{cases} 
1 - e^{-\lambda} & \text{if } \theta_{ss} \leq 1 \\
\theta_{ss}^{-1} (1 - e^{-\lambda}) & \text{otherwise}
\end{cases}
\]
\[
\bar{\theta}_{ss} = \begin{cases} 
1 + (1 + e^\lambda)(\theta_{ss} - 1) & \text{if } \theta_{ss} > 1 \\
(1 + (\theta_{ss}^{-1} - 1)e^\lambda)^{-(e^{-\lambda} + \bar{\phi})} & \text{otherwise}
\end{cases}
\]
given \(\lambda\) the market friction parameter and
\[
\phi_{ss} = \begin{cases} 
\left(\left(\frac{\theta_{ss}}{\bar{\theta}_{ss}}\right)^{\bar{\phi}} - 1\right) \frac{\theta_{ss}}{\bar{\theta}_{ss}} (e^\lambda - 1)^{-1} & \text{if } \theta_{ss} > 1 \\
\bar{\phi} & \text{if } \theta_{ss} = 1 \\
\left(\frac{1}{1 - \theta_{ss}}\right) \left(\left(\frac{\theta_{ss}}{\bar{\theta}_{ss}}\right)^{\bar{\phi}} - 1\right) (e^\lambda - 1)^{-1} (\bar{\phi} + e^{\bar{\phi} - \lambda}) & \text{otherwise}
\end{cases}
\]
A parameter of \(\bar{\phi} = 0.5\) implies an equal bargaining parameter when the lending orders and borrowing orders are equal. With the current specifi-
cation, the bargaining power function is plotted in the figure above. We see that as the market is tighter bargaining parameter converters to 0.3, and as the market get satiated with more funds and $\theta_{ss}$ is closer to zero, $\phi_{ss}$ gets closer to 0.7.

The associated liquidity cost for a domestic bank that needs to borrow reserves equals:

$$\chi_D = \begin{cases} r_{dw} - r_{ior} + tax & \text{if } r_{dw} \leq r_{ff} \\ \gamma_{ss}^{-}(r_{ff} - (r_{ior} - tax)) + (1 - \gamma_{ss}^{-})(r_{dw} - (r_{ior} - tax)) & \text{otherwise,} \end{cases}$$

with the expected federal funds rate for the domestic borrower is the solution to the Nash bargaining problem such that

$$r_{1ff} = (1 - \phi_{ss})r_{dw} + \phi_{ss}(\gamma_{Dss}^{-}(r_{ior} - tax) + \gamma_{Fss}^{-}r_{ior}),$$

The liquidity benefit of having excess reserves is

$$\chi_D^+ = \gamma_{ss}^{+}(r_{ff} - (r_{ior} - tax)),$$

with the expected federal funds rate for the domestic lender equal to

$$r_{2ff} = (1 - \phi_{ss})(\gamma_{ss}^{+}D_{dw} + \gamma_{Fss}^{+}r_{dw}) + \phi_{ss}(r_{ior} - tax).$$

The liquidity cost for a foreign bank to borrower reserves equals:

$$\chi_F = \gamma_{ss}^{-}(r_{ff} - (r_{ior} - tax)) + (1 - \gamma_{ss}^{-})(r_{dw} - r_{ior})$$

\(^2\)Having $\bar{\theta}$ scaled such that the boundaries of the equation are closer to 0 and 1 failed to converge to a steady-state for the representative bank model and its extensions.
with the expected federal funds rate for a foreign borrower

\[ r_{3}^{ff} = (1 - \phi_{ss})r_{dw}^{d} + \phi_{ss}(\gamma_{Dss}(r_{ior} - tax) + \gamma_{Fss}r_{ior}). \]

The liquidity benefit of having excess reserves depends on if the foreign bank is a lender or an arbitrageur. The arbitrage of borrowing from the interbank market and lending to the fed is equal to

\[ arbitrage = \gamma_{ss}^{-}(r_{ior} - r_{ab}^{ff}) \]

with the arbitrageur’s expected federal funds rate,

\[ r_{ab}^{ff} = (1 - \phi_{ss})r_{ior} + \phi_{ss}(\gamma_{Dss}(r_{ior} - tax) + \gamma_{Fss}r_{ior}) \]

A foreign bank will choose to arbitrage if \( lend < arbitrage \), otherwise it will lend its excess reserves. In which case, the expected lending rate is

\[ r_{4}^{ff} = (1 - \phi_{ss})(\gamma_{Dss}^{+}r_{dw}^{d} + \gamma_{Fss}^{+}r_{ior}^{d}) + \phi_{ss}r_{ior} \]

A lenders expected interest rate and return on loan is:

\[ lend = \gamma_{ss}^{+}(r_{ff}^{d} - r_{ior}^{d}) \]

The resulting liquidity benefit for a foreign bank is

\[ \chi_{F}^{+} = \begin{cases} \gamma_{ss}^{+}(r_{ff}^{d} - r_{ior}^{d}) & \text{if} \ lend \geq arbitrage \\ \gamma_{ss}^{-}(r_{ior}^{d} - r_{ab}^{d}) & \text{otherwise} \end{cases} \]

2. Solve foreign and domestic banks’ optimization problem with initial guess
for reserves $\bar{m}_s^D$, and $\bar{m}_s^F$ and for deposits, $\bar{d}_s^D$, and $\bar{d}_s^F$.

Domestic surplus/deficit is defined as:

$$s^D(\omega) \equiv \bar{m}^D + r^d/r_{ior} \omega \bar{d}^D - \rho \bar{d}^D (1 + \omega).$$

$$\omega^*_D = (\rho - (\bar{m}_s^D/\bar{d}_s^D) / (\frac{r^d}{r_{ior}} - \rho)$$

is the $\omega$ at which a bank has no surplus and no deficit. Then the bank will choose $\bar{m}_s^D$, and $\bar{d}_s^D$ to maximize

$$\Omega_{ss}^D = \max_{\bar{d}^D \in [0, \bar{d}^D], \bar{m}^D \in [0, 1 + \bar{d}^D]}$$

$$\int_{\omega^*}^{\omega_D} \ln \left[ r_{ss}^D + (r_{ior} - tax - r_{ss}^D)\bar{m}^D + (r_{ss}^D - r^d)\bar{d}^D + \chi_D \max(s(\omega), 0) \right] \Phi(\omega)d\omega$$

$$+ \int_{\omega^*}^{\omega^*_D} \ln \left\{ r_{ss}^D + (r_{ior} - tax - r_{ss}^D)\bar{m}^D + (r_{ss}^D - r^d)\bar{d}^D - \chi_D \max(-s(\omega), 0) \right\} \Phi(\omega)d\omega$$

where

$$\Phi(\cdot) = \frac{e^{-\frac{\omega - \mu}{sdD}}}{sdD \left( 1 + e^{-\frac{\omega - \mu}{sdD}} \right)^2}$$

is the pdf for the logistic distribution, and

$$\bar{b}_s^D = 1 + \bar{d}_s^D - \bar{m}_s^D$$

is the choice of domestic loans given the bank’s balance sheet constraint.

Foreign surplus/deficit is defined as:

$$s(\omega)^F \equiv \bar{m}^F + r^d/r_{ior} \omega \bar{d}^F,$$
and the threshold

\[ \omega^*_F = -\frac{m_{ss}^D}{d_{ss}^D / \rho_{ior}} \]

the bank will choose \( m_{ss}^F \), and \( d_{ss}^F \) to maximize

\[
\Omega_{ss}^F = \max_{\bar{d}_F \in [0,1], \bar{m}_F \in [0,1 + \bar{d}_F]} \int_{\omega^*}^{\omega} \ln \left[ r_{ss}^F + (r^i - r_{ss}^F)\bar{m}_F + (r_{ss}^F - r^d)\bar{d}_F + \chi_F^+ \max(s(\omega), 0) \right] \Phi(\omega) d\omega \\
+ \int_{\omega^*}^{\omega} \ln \left[ r_{ss}^F + (r^i - r_{ss}^F)\bar{m}_F + (r_{ss}^F - r^d)\bar{d}_F - \chi_F^{-} \max(-s(\omega), 0) \right] \Phi(\omega) d\omega
\]

with a distribution for \( \omega \) common to all foreign banks

\[
\Phi(\cdot) = \frac{e^{-\frac{(\omega - \mu)}{sd^F}}}{sd^F \left( 1 + e^{-\frac{(\omega - \mu)}{sd^F}} \right)^2},
\]

In which the two sectors have a different standard deviation for withdrawals (foreign bank has a higher risk).

\[
\bar{b}_{ss}^F = 1 + \bar{d}_{ss}^F - \bar{m}_{ss}^F
\]

is the steady-state choice of private sector loans issued by the foreign bank.

Given log utility we get that steady-state dividends follows

\[
c_{ss} = 1 - \beta.
\]

The last equation is the same for both domestic and foreign banks and independent from the optimization problem

- step 3: Check whether banks’ policies are consistent with steady state, if not
adjust guess for \( i^{rD}_{ss} \), \( i^{F}_{ss} \), and \( \theta_{ss} \)

1. Measure the surplus and deficit of each sector:

\[
D^+ = \int_{\omega^D}^{\omega^P} s^D(\omega) \Phi(\omega, \sigma^D)d\omega,
\]

\[
D^- = \int_{\omega^D}^{\omega^P} -s^D(\omega) \Phi(\omega, \sigma^D),
\]

With foreign banks arbitraging we have that when \( i^{ior} > i^{iff}_{ab} \) the measure of surplus for this sector is added to the amount of borrowing orders.

\[
F^+ = \begin{cases}
\int_{\omega_F}^{\omega_P} s^F(\omega) \Phi(\omega, \sigma^F)d\omega, & \text{if } i^{ior} \leq i^{iff}_{ab} \\
0, & \text{otherwise}
\end{cases}
\]

and

\[
F^-_1 = \begin{cases}
\int_{\omega_F}^{\omega_P} s^F(\omega) \Phi(\omega, \sigma^F)d\omega & \text{if } i^{ior} \leq i^{iff}_{ab} \\
0, & \text{otherwise}
\end{cases}
\]

\[
F^-_2 = \int_{\omega_F}^{\omega_P} -s^F(\omega) \Phi(\omega, \sigma^F)d\omega,
\]

2. Compute the aggregate lending orders

\[
M^+ = shareD^+ + (1 - share)F^+,
\]

and the aggregate borrowing orders

\[
M^- = shareD^- + (1 - share)(F^-_1 + F^-_2)
\]
3. Measure the average federal funds rate

\[ \bar{r}^{ff} = \phi_{ss}(w^2 r^f_2 + w^4 r^f_4) + (1 - \phi_{ss})(w^1 r^f_1 + w^3 r^f_3 + w^5 r^f_{ab}) \]

with the weights of the different federal funds rate depending on the masses of each type of borrowers and masses of each type of lenders such that

\[ w^2 = share\left(\frac{\gamma^+ D^+}{M^+}\right) \]
\[ w^4 = (1 - share)\left(\frac{\gamma^+ F^+}{M^+}\right) \]
\[ w^1 = share\left(\frac{\gamma^- D^-}{M^-}\right) \]
\[ w^3 = (1 - share)\left(\frac{\gamma^- F^-}{M^-}\right) \]
\[ w^5 = (1 - share)\left(\frac{\gamma^- F^-_1}{M^-}\right) \]

4. Measure the equity growth of each sector

\[ D_{equity} = \beta(r^D_{ss} \bar{b}^D_{ss} + (r^{ior} - tax)\bar{m}^D_{ss} - r^d \bar{d}^D_{ss}) \]
\[ - (r^{dw} - r^{ior} + tax)(1 - \gamma^- ss)D^- + (\bar{r}^{ff} - r^{ior} + tax)(\gamma^+_{ss} D^+ - \gamma^-_{ss} D^-) \]

\[ F_{equity} = \beta(r^F_{ss} \bar{b}^F_{ss} + r^{ior} \bar{m}^F_{ss} - r^d \bar{d}^F_{ss}) \]
\[ - (r^{dw} - r^{ior})(1 - \gamma^- ss)F^- + (\bar{r}^{ff} - r^{ior})(\gamma^+_{ss} F^+ - \gamma^-_{ss} F^-) \]

and the aggregate equity growth of the whole banking based on the initial
size of each sector follows

\[ E^g_{ss} = \text{share}D_{equity} + (1 - \text{share})F_{equity} \]

The market clearing condition for the interbank market follows

\[ \gamma^+_{ss}(\text{share}D^+ + (1 - \text{share})F^+) = \gamma^-_{ss}(\text{share}D^- + (1 - \text{share})F^-) \]

The federal funds market clearing simply states that aggregate lending orders equal the aggregate borrowing orders matched in the market. By substitution we that the aggregate equity growth becomes

\[ E^g_{ss} = \beta[\text{share}(r^D_{ss}b^D_{ss} + (r_{ior} - \text{tax})\bar{m}^D_{ss} - r^d_d^D_{ss} - (r^d_{dw} - r_{ior} + \text{tax})(1 - \gamma^-_{ss})D^- + \text{tax} \ast (\gamma^+_D - \gamma^-_D) + (1 - \text{share})(r^F_{ss}b^F_{ss} + r_{ior}(\bar{m}^F_{ss} - r^d_{ss}d^F_{ss} - (r^d_{dw} - r_{ior})(1 - \gamma^-_{ss})F^-)] \]

5. The updated probabilities that a lending order is matched is \( \gamma^+ \). The conditional probability that this lending order is matched with a domestic bank given a match has occurred is simply the ratio of domestic banks to foreign banks which are borrowing. So that

\[ \gamma^+_D = \text{share}D^- / M^- \]

and

\[ \gamma^-_D = \text{share}D^+ / M^+. \]
Similarly, the updated probabilities that a borrowing order is matched is $\gamma^-$ and the conditional probabilities follow

$$\gamma_F^- = (1 - \text{share})(F_1^- + F_2^-)/M^-$$

$$\gamma_F^+ = (1 - \text{share})F^+/M^+.$$

Lastly, the update market tightness equal to

$$\tilde{\theta} = M^-/M^+$$

6. Update rule:

- If $|\tilde{\theta} - \theta_{ss}|$ larger than tolerance adjust guess for $\theta_{ss}$ such that

  $$\theta_{ss} = .5\theta_{ss} + .5\tilde{\theta}$$

- if $|\tilde{\theta} - \theta|$ is less than tolerance, but $|E_{ss} - 1| > tol$ check if $|D_{equity} - 1| > tol$ or $|F_{equity} - 1| > tol$, and change the guess for the interest rate on loans appropriately by decreasing/increasing the interest rates if equity is greater/lower than one (i.e change $i_{ss}^F$ if foreign equity is different from one, and change $i_{ss}^D$ if domestic equity needs to be adjusted).

Introducing GSEs:

- step 1:

1. Set an exogenous mass of GSEs lending $G^+ \in [0, 11]$, as the unit-equity GSEs’ amount of lending orders, and $a$ the size of GSEs relative to banks (for example if GSEs size is twice as large as all banks a=2). The relative mass of foreign banks, domestic banks, and GSEs is redefined as: $\bar{a} = a/(1 + a)$, $\bar{\text{share}} = \text{share}/(1 + a)$, and foreign share of lending is $(1 - \bar{a} -$
share) = (1 − share)/(1 + a). Since the GSEs share of borrowing is zero (the case where $G^{-} = 0$), share of domestic and foreign borrowing is as without GSEs and denoted by share and $(1 − share)$ respectively.

2. In the initial guess of the steady-state probabilities that a borrower of overnight funds is borrowing from a domestic bank, $\gamma_{D}^{−}$, and that a lender of overnight funds is lending to a domestic bank, $\gamma_{D}^{+}$ add the guess $\gamma_{G}^{-}$ to equal the probability that a borrower is borrowing from a GSE.\(^3\)

- step 2:

1. Adjust the expected rates and expected liquidity cost and benefit of each sector given that if a lender is a GSE, its outside option is the ON RRP rate with the probability of such occurrence.

- step 3:

1. Add $G^{+}$ to the total mass of lending so that \(\bar{M}^{+} = \bar{a}G^{+} + \text{share}D^{+} + (1 - \text{share})F^{+}\).

2. Compute the probabilities that a borrower of overnight funds is borrowing from a domestic bank a foreign bank or a GSE.

3. Use these probabilities when computing the average federal funds rate, such that if you borrow form a GSE, its outside lending option is ON RRP.

4. The new market tightness equal to

\[
\tilde{\theta} = \frac{M^{-}}{\bar{M}^{+}}
\]

\(^3\)For example, let the fraction of lending orders of a GSEs with equity 1 be 0.5 so that half of equity is put in as lending orders (this could be as large as 11, which is the total assets given banks capital constraint). Also, let’s assume that the share of GSEs is 95%, so 95% of total equity belongs to GSEs. From here we can calibrate the share of the mass of lending orders given by GSEs to be $\bar{a}G^{+} = 0.475$. 

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This means that the market clearing includes GSEs is

\[ \gamma_{ss}^+(\text{shareD}^+ + \bar{a}G^+ + (1 - \bar{a} - \text{share})F^+) = \gamma_{ss}^-(\text{shareD}^- + (1 - \text{share})F^-) \]

which equals

\[ \frac{1}{1 + a} \left( \gamma_{ss}^+(\text{shareD}^+ + (1 - \text{share})F^+ + aG^+) \right) = \gamma_{ss}^-(\text{shareD}^- + (1 - \text{share})F^-) \]

substitute this to \( E_{ss}^g \), we get

\[ E_{ss}^g = \beta [\text{share} \left( r_{ss}^D \bar{b}_{ss} + (r_{ior} - \text{tax}) \bar{m}_{ss} - r_d \bar{d}_{ss} - (r_{dw} - r_{ior} + \text{tax})(1 - \gamma_{ss}^-) \text{D}^- ight] \\
+ (r_{ff} - r_{ior} + \text{tax}) \gamma_{ss}^+ D^+ - \text{tax} \gamma_{ss}^- D^- \\
+ (1 - \text{share}) \left( r_{ss}^F \bar{b}_{ss} + r_{ior} \bar{m}_{ss} - r_d \bar{d}_{ss} - (r_{dw} - r_{ior})(1 - \gamma_{ss}^-) F^- + (r_{ff} - r_{ior}) \gamma_{ss}^+ F^+ \right) \\
- \frac{\gamma_{ss}^+(r_{ff} - r_{ior})}{1 + a} (\text{shareD}^+ + (1 - \text{share})F^+ + aG^+) \]

• Update rule remains the same.
C.1 Characterizing the Equilibrium

*The symmetric equilibrium* - The system of equation is specified by

\[
\frac{D_t}{P_t} = \frac{M_{t-1} + B_{t-1}^h - B_h^t/r + T_t}{P_t}\tag{C.1}
\]

\[h_t = h_t^g + h_t^b\tag{C.2}\]

\[h_t^g = \frac{1}{\chi} \left( \frac{v_t^a P_t C_t}{D_t} \right)^x\tag{C.3}\]

\[\ln(v_t^a) = (1 - \rho^a)\ln(v^a) + \rho^a\ln(v_{t-1}^a) + \varepsilon_{vt}\tag{C.4}\]

\[C_t + \frac{M_t}{P_t} = \frac{W_t h_t + V_t + F_t + r_d D_t}{P_t}\tag{C.5}\]

\[\ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at}\tag{C.6}\]

\[\frac{a_t}{C_t} \left[ 1 - \eta \left( \frac{v_t^a P_t C_t}{D_t} \right)^x \right] = \Lambda_2^t\tag{C.7}\]

\[a_t \eta = \frac{W_t \Lambda_2^t}{P_t}\tag{C.8}\]

\[a_t \eta \left( \frac{v_t^a P_t C_t}{D_t} \right)^x = D_t \left( \frac{\Lambda_2^t r_d - \Lambda_1^t}{P_t} \right)\tag{C.9}\]
\[ \beta \mathbb{E} \left[ \frac{\Lambda_{t+1}^1 P_t}{P_{t+1}} \right] = \frac{\Lambda_t^1}{r_t} \]  
(C.10)

\[ \beta \mathbb{E} \left[ \frac{\Lambda_{t+1}^1 Q(i)_{t+1}}{P_{t+1}} \right] = \frac{\Lambda_t^1 Q(i)_t - \Lambda_t^2 F_t(i)}{P_t} \]  
(C.11)

\[ \beta \mathbb{E} \left[ \frac{\Lambda_{t+1}^1 P_t}{P_{t+1}} \right] = \Lambda_t^2 \]  
(C.12)

\[ Y_t = Z_t h_t^q \]  
(C.13)

\[ \ln(Z_t) = \ln(z) + \ln(Z_{t-1}) + \varepsilon_{zt} \]  
(C.14)

\[ \phi_d \frac{W_t}{P_t} h_t^q = L_t \]  
(C.15)

\[ F_t = Y_t - (1 + \phi_d r_t^l) \left( \frac{W_t Y_t}{P_t Z_t} \right) - \phi_p \left( \frac{P_t}{\pi P_{t-1}} - 1 \right)^2 Y_t \]  
(C.16)

\[ \ln(x_t^d) = (1 - \rho^d) \ln(x_t^d) + \rho^d_x \ln(x_{t-1}^d) + \varepsilon_{zt}^d \]  
(C.17)

\[ \frac{D_t}{P_t} = x_t^d \left[ (x^n)^{1/\nu} \left( \frac{N_t^v}{P_t} \right)^{(\nu-1)/\nu} + (1 - x^n)^{1/\nu} (Z_t h_t^n)^{(\nu-1)/\nu} \right]^{\nu/(\nu-1)} \]  
(C.18)

\[ Z_t h_t^v = \phi_v \frac{N_t^v}{P_t} \]  
(C.19)

\[ h_t^v = h_t^v + h_t^n \]  
(C.20)

\[ B_t^b + L_t + N_t^v = D_t \]  
(C.21)

\[ \frac{V_t}{P_t} = \left( r_t^l - r_t \right) \left[ \frac{L_t}{P_t} + \left( r_t^v - \phi^v W_t \right) - r_t \right] N_t^v \]  
\[ - \left( r_t^d - r_t \right) \left( \frac{D_t}{P_t} - \frac{W_t h_t^n}{P_t Z_t} \right) \]  
(C.22)
Using Equation C.18, the first order conditions for the bank problem are

\[
\frac{N^v_t}{P_t} = \left( r^v_t - r_t - \frac{W_t \phi^v_t}{P_t Z_t} \right)^{-\nu} \left( r^d_t(j) - r_t \right)^\nu \left( x^d \right)^{\nu-1} \frac{D_t}{P_t} \left( x^n \right) \tag{C.24}
\]

\[
h^n_t = (r_t - r^d(j))^\nu (x^d)^{\nu-1} \frac{D_t}{P_t} (1 - x^n)(Z_t)^{\nu-1} W_t^{-\nu} \tag{C.25}
\]

\[
r^d_t = \left( \frac{\theta^d - 1}{\theta^d} \right) r_t \tag{C.26}
\]

\[
r^l_t = \left( \frac{\theta^l}{\theta^l - 1} \right) r_t \tag{C.27}
\]

\[
g^y_t = \frac{Y_t}{Y^t_{t-1}} \tag{C.28}
\]

\[
\ln(r_t/r) = \rho_r \ln(r_{t-1}/r) + \rho_\pi \ln(\pi_{t-1}/\pi) + \rho_g \ln(g_{t-1}/g) + \varepsilon_{rt} \tag{C.29}
\]

\[
\ln(r^v_t) = \ln(\pi_t) + \alpha \ln(r_t) \tag{C.30}
\]

\[
\ln(\tau_t) = (1 - \rho_\tau) \ln(\tau) + \rho_\tau \ln(\tau_{t-1}) + \varepsilon_{\tau t} \tag{C.31}
\]

\[
\frac{M_t}{P_t} = \frac{M_{t-1} + B^b_{t-1} - (B^h_t/r) + T_t + (r_t - 1)B^b_t + (r^v_t - 1)N^v_t}{P_t} \tag{C.32}
\]

\[
\frac{M^s_t}{P_t} = \frac{D_t}{P_t} \tag{C.33}
\]

\[
rr_t = \frac{N^v_t}{D_t} \tag{C.34}
\]

where each equation must hold for all \( t = 0, 1, 2, \ldots \). This system of 35 equations serves to determine the equilibrium behavior of 35 variables:

- 13 RealVariables: \( C_t, Y_t, g_t, h^v_t, h_t, h^2_t, h^b_t, h^n_t, h^v_t, F_t, V_t, \Lambda^1_t, \Lambda^2_t \).
- 9 Money Stock Variables and Reserve Ratio: \( M_t, M^s_t, T_t, N^v_t, B^b_t, B^h_t, L_t, D_t, rr_t \).
- 3 Prices: \( P_t, W_t, Q_t \).
- 4 Interest Rates: \( r^l_t, r^d_t, r_t, r^v_t \).
5 Shocks: $v^a_t$, $a_t$, $Z_t$, $x^d_t$, $\tau_t$.

Note that using C.1, C.2, C.5, and C.32, we have that

$$C_t + \frac{D_t + (r_t - 1)B^b_t + (r^a_t - 1)N^v_t}{P_t} = \frac{W_t (h^a_t + h^b_t)}{P_t} + N_t + F_t + V_t + r^d_t D_t$$

(C.35)

Then using C.16, C.13, C.15 and C.23, rewrite C.35 such that

$$Y_t = C_t + L_t + \frac{\phi_P}{2} \left[ \frac{P_t}{\pi P_{t-1}} - 1 \right]^2 Y_t$$

holds for all $t = 0, 1, 2, ...$

The stationary system—Many variables will be non-stationary. Real variables inherit a unit root from the non-stationary technology shock in C.14, while other nominal variables inherit a unit root from the conduct of monetary policy described by the Taylor rule C.29. However, appropriately scaled or transformed real and nominal variables will be stationary when defined as follows:

- 13 Real Variables: $c_t = C_t/Z_{t-1}$, $y_t = Y_t/Z_{t-1}$, $g_t$, $h^a_t$, $h^s_t$, $h^b_t$, $h^p_t$, $h^n_t$, $h^v_t$, $f_t = F_t/P_t Z_{t-1}$, $v_t = V_t/P_t Z_{t-1}$, $\lambda^1 = Z_{t-1} \Lambda^1_t$, $\lambda^2 = Z_{t-1} \Lambda^2_t$.

- 10 Money Stock Variables and Reserve Ratio: $m_t = M_t/P_t Z_{t-1}$, $m^s_t = M^s_t/P_t Z_{t-1}$, $t_t = T_t/P_t Z_{t-1}$, $n^v_t = N^v_t/P_t Z_{t-1}$, $l_t = L_t/P_t Z_{t-1}$, $d_t = D_t/P_t Z_{t-1}$, $b^h_t = B^h_t/P_t Z_{t-1}$, $b^b_t = B^b_t/P_t Z_{t-1}$, $\pi_t = P_t/P_{t-1}$, $w_t = W_t/P_t Z_{t-1}$, $q_t = Q_t/P_t Z_{t-1}$.

- 3 Prices: $\pi_t = P_t/P_{t-1}$, $w_t = W_t/P_t Z_{t-1}$, $q_t = Q_t/P_t Z_{t-1}$.

- 4 Interest Rates: $r^d_t$, $r^a_t$, $r_t$, $r^v_t$.

- 5 Shocks: $v^a_t$, $a_t$, $z_t = Z_t/Z_{t-1}$, $x^d_t$, $\tau_t$.

The system of equilibrium conditions can be rewritten in terms of these stationary variables as

$$d_t = m_{t-1} + b^h_t - b^b_t/r_t + t_t$$

(C.36)
\[ h_t = h^g_t + h^b_t \] (C.37)

\[ \chi h^s_t = (v^o_t c_t/d_t)^\chi \] (C.38)

\[ \ln(v^o_t) = (1 - \rho^a_v)\ln(v^a) + \rho^a_v\ln(v^o_{t-1}) + \varepsilon^a_v \] (C.39)

\[ c_t + m_t = w_t h_t + f_t + v_t + r^d_t d_t \] (C.40)

\[ \ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at} \] (C.41)

\[ \frac{a_t}{c_t}(1 - \eta(v^o_t c_t/d_t)^\chi) = \lambda^2_t \] (C.42)

\[ a_t \eta = w_t \lambda^2_t \] (C.43)

\[ a_t \eta(v^o_t c_t/d_t)^\chi = d_t(\lambda^2_t r^d_t - \lambda^1_t) \] (C.44)

\[ \frac{E(\lambda^1_{t+1})}{\pi_{t+1}} = \frac{z_t \lambda^1_t}{\beta r_t} \] (C.45)

\[ \beta E(\lambda^1_{t+1} q_{t+1}) = \lambda^1_t q_t - \lambda^2_t f_t \] (C.46)

\[ \lambda^1_t = \lambda^2_t r_t \] (C.47)

\[ y_t = z_t h^g_t \] (C.48)

\[ \ln(z_t) = \ln(z) + \varepsilon_{zt} \] (C.49)

\[ \phi d w_t h^g_t = l_t \] (C.50)

\[ f_t = y_t - (1 + \phi d r^d_t) \left( \frac{w_t y_t}{z_t} \right) - \frac{\phi_d}{2} \left( \frac{\pi_t}{\pi} - 1 \right)^2 y_t \] (C.51)

\[ \beta \phi_p E \left[ \lambda^2_{t+1} \left( \frac{\pi_{t+1}}{\pi} - 1 \right) \frac{y_{t+1} \pi_{t+1}}{\pi} \right] = \] (C.52)

\[ \lambda^2_p \phi_p \left( \frac{\pi_t}{\pi} - 1 \right) \left( \frac{y_t \pi_t}{\pi} \right) - (1 - \theta) \lambda^2_t y_t - \theta \lambda^2_t (1 + \phi_d r^d_t) \left( \frac{w_t y_t}{z_t} \right) \]

\[ d_t = x^d_t \left[ (x^n)^{1/\nu} (n^v_\nu)^{\nu-1/\nu} + (1 - x^n)^{1/\nu} (z_t h^n_\nu)^{\nu-1/\nu} \nu^{\nu-1/\nu} \right] \] (C.53)

\[ \ln(x^d_t) = (1 - \rho^d_x) \ln(x^d) + \rho^d_x \ln(x^d_{t-1}) + \varepsilon^d_{xt} \] (C.54)
\[ z_t h_t^v = \phi_v n_t^v \]  
(C.55)

\[ h_t^b = h_t^v + h_t^n \]  
(C.56)

\[ b_t^b = d_t - l_t - n_t^v \]  
(C.57)

\[ v_t = (r_t^l - r_t)l_t + (r_t^v - \frac{\phi^v w_t}{z_t} - r_t)n_t^v - (r_t^d - r_t)d_t - \frac{w_t h_t^n}{z_t} \]  
(C.58)

\[ n_t^v = \left( r_t^v - r_t - \frac{w_t \phi^v}{z_t} \right)^{-\nu} (r_t^d - r_t)^{\nu} (x_t^d)^{\nu - 1} d_t x^n \]  
(C.59)

\[ h_t^n = (r_t - r_t^d)^{\nu} (x_t^d)^{\nu - 1} d_t (1 - x^n) \frac{w_t}{z_t}^{-\nu} \]  
(C.60)

\[ r_t^d = \left( \frac{\theta^d - 1}{\theta^d} \right) r_t \]  
(C.61)

\[ r_t^l = \left( \frac{\theta^l - 1}{\theta^l} \right) r_t \]  
(C.62)

\[ g_t = \frac{y_t z_{t-1}^{-1}}{y_{t-1}} \]  
(C.63)

\[ \ln(r_t/r) = \rho_r \ln(r_{t-1}/r) + \rho_\pi \ln(\pi_{t-1}/\pi) + \rho_g \ln(g_{t-1}/g) + \varepsilon_{rt} \]  
(C.64)

\[ \ln(r_t^v) = \ln(\tau_t) + \alpha_v \ln(r_t) \]  
(C.65)

\[ \ln(\tau_t) = (1 - \rho_\tau) \ln(\tau) + \rho_\tau \ln(\tau_{t-1}) + \varepsilon_{\tau t} \]  
(C.66)

\[ m_t = \frac{m_{t-1}}{\pi_{t-1} z_{t-1}} + \frac{b_{t-1}^h}{\pi_{t-1} z_{t-1}} - b_t^h / r_t + t + (r_t^v - 1) n_t^v + (r_t - 1) b_t^b \]  
(C.67)

\[ m_t^b = d_t \]  
(C.68)

and

\[ r r_t = n_t^v / d_t \]  
(C.69)

for all \( t = 0, 1, 2... \)

**The steady state** - In the absence of shocks, the economy converges to a steady-state, in which all of the stationary variables defined above are constant over time.
Equations C.39, C.41, C.49, C.64 and C.66 determine

\[ v_t^a = v^a, \quad (C.70) \]

\[ \ln(a_t) = 1, \quad (C.71) \]

\[ z_t = z, \quad (C.72) \]

\[ x_t^d = x^d, \quad (C.73) \]

\[ \pi_t = \pi, \quad (C.74) \]

\[ \tau_t = \tau. \quad (C.75) \]

Equations C.45, C.62, C.61, and C.65 then determine

\[ r_t = r = (z/\beta)\pi, \quad (C.76) \]

\[ r_t^l = r^l = \left( \frac{\theta^l}{\theta^l - 1} \right) r, \quad (C.77) \]

\[ r_t^d = r^d = \left( \frac{\theta^d - 1}{\theta^d} \right) r, \quad (C.78) \]

and

\[ r_t^v = r^v = \tau r^\alpha, \quad (C.79) \]

while C.52 implies that

\[ \frac{w_t}{z} = \frac{w}{z} = \frac{\theta - 1}{\theta(1 + \phi d r_t^l)}, \quad (C.80) \]

Equation C.63 determines

\[ g_t^u = g^u = z, \quad (C.81) \]
and using C.43, and C.45 we get

\[ \lambda_t^2 = \lambda^2 = \eta/w \]  
(C.82)

and

\[ \lambda_t^1 = \lambda^1 = r\eta/w. \]  
(C.83)

Equations C.42 and C.44 together with the condition that \( c_t = c, \) \( d_t = d \) in steady-state imply that

\[ 1 - \eta(v^a c/d)^\chi = \lambda^2 c \]  
(C.84)

and

\[ \eta(v^a c/d)^\chi = d\lambda^2(r^d - r) \]  
(C.85)

Substitute the second of these two equations into the first to obtain

\[ d = \frac{1 - \lambda^2 c}{\lambda^2(r^d - r)}. \]

Substitute this expression back into the first equation in order to define

\[ g(c) = \eta(v^a c\lambda^2(r^d - r))^\chi - (1 - \lambda^2 c)^\chi + 1 \]

and note that the expression for \( d \) requires that

\[ 0 \leq c \leq 1/\lambda^2, \]

for \( d \geq 0 \) and \( c \geq 0 \) to hold. Since

\[ g'(c) = \chi\eta(v^a \lambda^2(r^d - r))^\chi c^{\chi-1} + (1 + \chi)\lambda^2(1 - \lambda^2 c)^\chi \geq 0, \]
with \( g(0) = -1 < 0 \) and \( g(1/\chi^2) = \eta(v^a(r^d - r))^\chi > 0 \) there is a unique value of \( c \) in the admissible range such that \( g(c) = 0 \) and hence a unique value for \( d \) as well.

Given the solution for \( c_t = c \), we have that Equation C.36, C.67, and C.40 we can write

\[
m + c + d + n - r^v n^v - r b^b = wh + n + fi + vi + r^d d. \tag{C.86}
\]

Then using C.51, C.48, C.50 and C.58, we get

\[
m - (r^d - 1)d + (r^v - 1)n^v + (r - 1)b^b + c =
\]

\[
wh^a + wh^b + y - r^l l + (rl - 1)l + (r^v - 1)n^v - (r^d - 1)d + (r - 1)b^b - wh^b
\]

so that

\[
y = c + l,
\]

is the resource constraint in the steady-state solution, and Equations C.50 and C.48 imply

\[
l = \phi_d w y / z.
\]

Solving for the two equations and two unknown variables we get that

\[
y_t = y = c(1 - \frac{\phi_d w}{z})^{-1}, \tag{C.87}
\]

\[
h_t^g = h^g = y / z, \tag{C.88}
\]

and

\[
l_t = l = \phi_d w h^g. \tag{C.89}
\]

Equation C.38 determines

\[
h_t^s = h^s = (1 / \chi)(v^a c / d)^\chi. \tag{C.90}
\]
Then using Equations C.53 we have that

\[ n^v = ((d^{\nu-1/\nu} x^{d-1} - (1 - x^n)^{1-} (zh^{n})^{\nu-1/\nu} x^{n-1/\nu}))^{\nu/nu^{-1}}, \]  

(C.91)

and with C.60, C.59, we get that

\[ n^v_t = n^v = (r^d - r)^{\nu} d(x^d)^{\nu-1} x^n (r^v - \phi^v w/z) - r)^{-\nu}, \]  

(C.92)

and

\[ h^i_n = h^n = (r - r^d)^{\nu} d(x^d z)^{\nu-1} (1 - x^n) w^{-\nu}. \]  

(C.93)

Rewriting Equation C.57 implies

\[ b^b_t = n^v + l - d. \]  

(C.94)

Rewrite Equation C.55

\[ h^v_t = h^v = \phi^v n^v / z, \]  

(C.95)

so that Equation C.56 implies

\[ h^b_t = h^b = h^n + h^v, \]  

(C.96)

and Equation C.37

\[ h_t = h = h^b + h^g. \]  

(C.97)

The bank value is

\[ v_t = v = (r^l - r) l + (r^v - \frac{\phi^v w}{z} - r)n^v + (r - r^d)d - \frac{wh^n}{z}. \]  

(C.98)
and the value of the representative firm evolves according to

\[ f_t = f = y(1 - (1 + \phi d^t)w/z). \]  
(C.99)

Rewrite C.40

\[ m = wh + f i + v i + r d d - c \]  
(C.100)

It follows that Equations C.36 and C.67 can be used to find

\[ b_t^b = b^b = 0, \]  
(C.101)

and

\[ t_t = t = m(1 - \frac{1}{\pi z} - (r^v - 1)n^v - (r - 1)b^b, \]  
(C.102)

Finally, Equations C.51 and C.52 deliver

\[ q_t = q = f \beta / (\pi - \beta), \]  
(C.103)

\[ m_t^s = m_t^s = d, \]  
(C.104)

and

\[ rr_t = rr = n^v / d. \]  
(C.105)

**The linearized system** The stationary system can be log-linearized around its steady state to determine how the economy responds to shocks. The stationary variables in the log-linear form are defined as

- 13 Real Variables: \( \hat{c}_t = ln(c_t/c), \hat{y}_t = ln(y_t/y), \hat{g}_t = ln(g_t/g), \hat{h}_t^i = ln(h_t^i/h^i), \hat{v}_t^i = ln(v_t^i/v^i), \hat{h}_t = ln(h_t/h), \hat{h}_t^g = ln(h_t^g/h^g), \hat{h}_t^b = ln(h_t^b/h^b), \hat{h}_t^v = ln(h_t^v/h^v), \hat{h}_t^s = ln(h_t^s/h^s), \hat{f}_t = ln(f_t/f), \hat{v}_t = ln(v_t/v), \hat{\lambda}_t = ln(\lambda_t^1/\lambda^1), \hat{\lambda}_t = ln(\lambda_t^2/\lambda^2). \)

- 9 Money Stock Variables and Reserve Ratio: \( \hat{m}_t = ln(m_t/m), \hat{m}_t^s = ln(m_t^s/m^s), \)

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\[ \hat{t}_t = t_t - t, \hat{n}_t^n = \ln(n_t^n/n^\nu), \hat{b}_t^b = \ln(b_t^b/b^\nu), \hat{b}_t^h = \ln(b_t^h/b), \hat{l}_t = \ln(l_t/l), \hat{d}_t = \ln(d_t/d), \hat{r}_t = \ln(r_{t}/r). \]

- 3 Prices: \( \hat{\pi}_t = \ln(\pi_t/\pi), \hat{w}_t = \ln(w_t/w), \hat{q}_t = \ln(q_t/q). \)

- 4 Interest Rates: \( \hat{r}_t^l = \ln(r_t^l/r^l), \hat{r}_t^d = \ln(r_t^d/r^d), \hat{r}_t = \ln(r_t/r), \hat{r}_t^v = \ln(r_t^v/r^v). \)

- and 5 Shocks: \( \hat{v}_t^a = \ln(v_t^a/v^a), \hat{\alpha}_t = \ln(\alpha_t), \hat{\gamma}_t = \ln(\gamma_t/\gamma), \hat{\lambda}_t^d = \ln(x_t^d/x^d), \hat{\tau}_t = \ln(\tau_t/\tau). \)

Where because the steady-state value of real monetary transfers could be negative, the approximation is linear rather than log-linear for \( t \).

Written in terms of these variables, the first-order Taylor approximations to the model's stationary equilibrium conditions yields

\[ dd_t + r^n v^n \hat{r}_t^v + (r^v - 1)n^r \hat{n}_t^n + r b \hat{r}_t + (r - 1)b^b \hat{b}_t^b = m \hat{m}_t \quad (C.106) \]

\[ h \hat{h}_t = h^g \hat{h}_t^g + h^h \hat{h}_t^h \quad (C.107) \]

\[ \hat{h}_t^a = \chi \hat{v}_t^a + \chi \hat{c}_t - \chi \hat{d}_t, \quad (C.108) \]

\[ \hat{\nu}_t^a = \rho_t^a \hat{\nu}_{t-1} + \varepsilon_{vt} \quad (C.109) \]

\[ c \hat{c}_t + m \hat{m}_t = wh \hat{w}_t + wh \hat{h}_t + w \hat{v}_t + f \hat{f}_t + r^d d \hat{r}_t^d + r^d d \hat{d}_t \quad (C.110) \]

\[ \hat{\alpha}_t = \rho_t \hat{\alpha}_{t-1} + \varepsilon_{at} \quad (C.111) \]

\[ c \hat{\alpha}_t - \chi ((a - c \lambda^2)/\lambda^2) \hat{\nu}_t^a + \chi ((a - c \lambda^2)/\lambda^2) \hat{d}_t = c \hat{\lambda}_t^2 + ((c + \chi(a - c \lambda^2)/\lambda^2) \hat{c} \quad (C.112) \]

\[ \hat{\alpha}_t = \hat{w}_t + \hat{\lambda}_t^2 \quad (C.113) \]

\[ (r/(r^d - r)) \hat{\lambda}_t^1 - (r^d/(r^d - r)) \hat{\lambda}_t^2 - (r^d/(r^d - r)) \hat{r}_t^d = \hat{\alpha}_t - \chi \hat{\nu}_t^a - \chi \hat{c}_t + (1 + \chi) \hat{d}_t \quad (C.114) \]

\[ \hat{\gamma}_t + \hat{\lambda}_t^1 = \beta \hat{r}_t + \beta \mathbb{E} \hat{\lambda}_{t+1}^1 - \beta \mathbb{E} \hat{\pi}_{t+1} \quad (C.115) \]
\[ \beta E \hat{\lambda}^1_{t+1} + \beta E \hat{\hat{q}}_{t+1} + (1 - \beta) \hat{\lambda}^2_{t} + (1 - \beta) \hat{\hat{r}}_{t} = \hat{\lambda}^1_{t} + \hat{\hat{q}}_{t} \]  
(C.116)

\[ \hat{\lambda}^1_{t} = \hat{r}_{t} + \hat{\lambda}^2_{t} \]  
(C.117)

\[ \hat{\hat{q}}_{t} = \hat{z}_{t} + \hat{\hat{h}}_{t} \]  
(C.118)

\[ \hat{z}_{t} = \varepsilon_{zt} \]  
(C.119)

\[ \hat{\hat{l}}_{t} + \hat{\hat{h}}_{t} = \hat{l}_{t}, \]  
(C.120)

with \( \hat{l}_{t} = 0 \) if \( \phi^d = 0 \).

\[ \hat{\hat{r}}_{t} = \hat{y}_{t} - (\theta - 1) \hat{\hat{w}}_{t} + (\theta - 1) \hat{\hat{\hat{z}}}_{t} - \phi_d \theta (w/z) r^l \]  
(C.121)

\[ \phi_p \beta E \hat{\hat{p}}_{t+1} = \phi_p \hat{\hat{r}}_{t} - (\theta - 1) \hat{\hat{w}}_{t} + (\theta - 1) \hat{\hat{\hat{z}}}_{t} - \phi_d \theta (w/z) r^l \]  
(C.122)

\[ (d/x^d)^{\frac{\nu - 1}{\nu}} \hat{\hat{x}}_{t} - (d/x^d)^{\frac{\nu - 1}{\nu}} \hat{x}_{t} = (x^n)^{\frac{1}{\nu}} (n^n)^{\frac{\nu - 1}{\nu}} \hat{n}_t + (1 - x^n)^{\frac{1}{\nu}} ((z h^n)^{\frac{\nu - 1}{\nu}} \hat{\hat{h}}_{t} + (1 - x^n)^{\frac{1}{\nu}} ((z h^n)^{\frac{\nu - 1}{\nu}} \hat{\hat{z}}_{t} \]  
(C.123)

\[ \hat{\hat{x}}_{t} = \rho_x \hat{x}_{t-1} + \varepsilon_{xt} \]  
(C.124)

\[ \hat{\hat{h}}_{t} = \hat{n}_t - \hat{\hat{z}}_{t} \]  
(C.125)

\[ h^b \hat{h}^b_t = h \hat{\hat{h}}^b_t + h^n \hat{\hat{n}}^n \]  
(C.126)

\[ b^b \hat{b}^b_t = d \hat{\hat{d}}_t - \hat{\hat{l}}_t - n^v \hat{n}_t \]  
(C.127)

\[ v \hat{\hat{v}}_{t} - \frac{r l}{\theta^l - 1} \hat{l}_{t} - \frac{r d}{\theta^d} \hat{d}_{t} - (r^v - \phi^v w/z - r)^{1-\nu} n^v \hat{n}_t + \frac{wh^n}{z} \hat{\hat{n}}^n = \]

\[ (\frac{l}{\theta^l - 1} + \frac{d}{\theta^d} - (1 - \nu)(r^v - \phi^v w/z - r)^{-\nu} n^v \hat{\hat{r}}_{t} + (1 - \nu)(r^v - \phi^v w/z - r)^{-\nu} n^v \hat{\hat{r}}_{t}^v \]

\[ -((1 - \nu)(r^v - \phi^v w/z - r)^{-\nu} n^v \hat{\hat{r}}_{t} - (1 - \nu)(r^v - \phi^v w/z - r)^{-\nu} n^v \hat{\hat{r}}_{t}^v \]

\[ +((1 - \nu)(r^v - \phi^v w/z - r)^{-\nu} n^v \hat{\hat{r}}_{t} - (1 - \nu)(r^v - \phi^v w/z - r)^{-\nu} n^v \hat{\hat{r}}_{t}^v \]  
(C.128)
\[ \hat{n}_t - \hat{d}_t = (\nu - 1)\hat{x}_t + \nu \phi \frac{w}{z} \left( r^v - r - \phi \frac{w}{z} \right)^{-1} \hat{w}_t - \nu \phi \frac{w}{z} \left( r^v - r - \phi \frac{w}{z} \right)^{-1} \hat{z}_t - \nu \left( r^v - r - \phi \frac{w}{z} \right)^{-1} r^v \hat{r}_t + \nu (\theta^d - 1) \hat{r}_t^d \]

\[ \hat{h}_t^v - \hat{d}_t = (\nu - 1)\hat{x}_t^d + \nu \hat{z}_t - \nu \hat{w}_t + \nu \theta^d \hat{r}_t - \nu (\theta^d - 1) \hat{r}_t^d \]

\[ \hat{r}_t^d = \frac{\theta^d - 1}{\theta^d} \hat{r}_t \]

\[ \hat{r}_t^l = \frac{\theta^l}{\theta^l - 1} \hat{r}_t \]

\[ \hat{y}_t^y + \hat{y}_{t-1} = \hat{y}_t + \hat{z}_{t-1} \]

\[ \hat{r}_t = \rho_r \hat{r}_{t-1} + \rho_n \hat{r}_{t-1} + \rho_\nu \hat{y}_{t-1} + \varepsilon_{rt} \]

\[ \hat{r}_t^v = \hat{r}_t + \alpha \hat{r}_t \]

\[ \hat{r}_t = \rho_r \hat{r}_{t-1} + \varepsilon_{rt} \]

\[ m \hat{m}_t = \frac{m}{z \pi} \hat{m}_{t-1} - \frac{m}{z \pi} \hat{\pi}_{t-1} - \frac{m}{z \pi} \hat{z}_{t-1} + \hat{t}_t + r^v \hat{n}_t^v + (r^v - 1)n^v \hat{n}_t^v + r b^b \hat{r}_t + (r - 1) b^b \hat{r}_t^b \]

\[ m^s \hat{m}_t^s = d \hat{d}_t \]

\[ r \hat{r}_t = \hat{n}_t^v - \hat{d}_t \]

**The linearized system in matrix form**— Using the initial flow vector \( f_t^0 \) to collect 25 variables \( c_t, \hat{y}_t, \hat{g}_t, \hat{h}_t, \hat{h}_t^s, \hat{h}_t^g, \hat{h}_t^b, \hat{n}_t, \hat{f}_t, \hat{\nu}_t, \lambda_t^2, \hat{m}_t, \hat{t}_t, \hat{d}_t, \hat{l}_t, \hat{n}_t^v, \hat{b}_t^b, \hat{b}_t^h, \hat{w}_t, \hat{r}_t^l, \hat{r}_t^d, \hat{r}_t, \hat{r}_t^v, \) and \( r \hat{r}_t \).

Use the initial state vector \( s_t^0 \) to collect the 15 variables \( \hat{y}_{t-1}, \hat{g}_{t-1}, \hat{m}_{t-1}, \hat{d}_{t-1}, \hat{m}_{t-1}^s, \hat{n}_{t-1}^v, \hat{b}_{t-1}^b, \hat{b}_{t-1}^h, \hat{\pi}_{t-1}, \hat{r}_{t-1}, \hat{z}_{t-1}, \hat{l}_{t-1}, \lambda_t^1, \hat{\pi}_t, \) and \( \hat{\nu}_t \).

Use the shock vector \( \xi_t \) to collect the 6 variables \( \hat{\xi}_t, \hat{\alpha}_t, \hat{z}_t, \hat{x}_t^d, \hat{\pi}_t, \) and \( \varepsilon_{rt} \).

Then Equations C.106-C.108, C.110, C.112-C.114, C.117, C.118, C.120, C.121, C.123,
C.125-C.135, C.138, and C.139 can be written as

\[ Af_0^t = Bs_0^t + C\xi_t, \quad (C.140) \]

Where A is $25 \times 25$, B is $25 \times 15$, and C is $25 \times 6$, equations C.115, C.116, C.122 can be written as

\[ Ds_{t+1}^0 + Ef_{t+1}^0 = Gs_t^0 + Hf_t^0 + J\xi_t, \quad (C.141) \]

where D and G are $15 \times 15$, F and H are $15 \times 25$, and J is $15 \times 6$, and C.109, C.111, C.119, C.124, C.134, and C.136 can be written as $\xi_t = P\xi_{t-1} + \varepsilon_t$, where

\[
P = \begin{pmatrix}
\rho_v^a & 0 & 0 & 0 & 0 & 0 \\
0 & \rho_v^a & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \rho_x^d & 0 & 0 \\
0 & 0 & 0 & 0 & \rho_r & 0 \\
0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}
\]

and

\[
\varepsilon_t = \begin{bmatrix}
\varepsilon_v \\
\varepsilon_a \\
\varepsilon_z \\
\varepsilon_d \\
\varepsilon_x \\
\varepsilon_r
\end{bmatrix}
\]
Alternative Impulse Response Functions With Higher $\phi_d$

Figure C.1: Alternative IRF with higher $\phi_d$: macroeconomic shocks

Shocks include a positive technology shock, a positive preference shock, and a conventional contractionary monetary policy shock to output, price level, interest rate, labor hours, banking labor hours, real reserves, real deposits, deposit interest rate, real loans, and loans interest rate. IOR regime is in red. $\phi_d = 0.25$
Figure C.2: Alternative IRF With Higher $\phi_d$: Financial Sector Shocks

Shocks include a positive technology shock, a positive preference shock, and a conventional contractionary monetary policy shock to output, price level, interest rate, labor hours, banking labor hours, real reserves, real deposits, deposit interest rate, real loans, and loans interest rate. IOR regime is in red. $\phi_d = 0.25$
C.2 Data Appendix

The market competition is estimated based on the reallocation of market share from inefficient firms to efficient ones, as introduced in Boone et al. (2004). The assumption is that given some level of efficiency of each bank, higher levels of competition imply better performance either in terms of higher profits or higher market shares for the more efficient banks (Van Leuvensteijn et al., 2011). Assuming some degree of homogeneity in the banks’ goods and services, relative profits or market share differences across different efficiency levels are robust in measuring market competition (Boone, 2008). This approach’s benefit is that one can capture market dynamics rather than a static analysis and measure differences in the market response to change in competition level due to forces other than the concentration. Following Boone et al. (2004),

\[
\ln \left( \frac{s_{it}}{s_{1t}} \right) = \alpha + \beta \ln \left( \frac{c_{it}}{c_{1t}} \right) + \varepsilon_{it},
\]

(C.1)

with \( \frac{s_{it}}{s_{1t}} \) defined as the relative market share (or profits) of firm \( i \), and \( \frac{c_{it}}{c_{1t}} \) the relative marginal cost of firm \( i \) that is assumed constant over time. Equation C.1 states that competition is estimated using the correlation between the performance differences and a bank’s cost efficiency. \( \beta \) is conditioned to be negative and monotonically increasing with the level of market power. A log/log equation expresses the reduction of performance from cost inefficiencies as the elasticity of a percentage drop in profits/shares of bank \( i \) due to a percentage increase in bank \( i \)’s costs. Since Equation C.1 is only observable with some error terms such that

\[
\ln \left( \frac{s_{it}u_{i}}{s_{1t}} \right) = \alpha + \beta \ln \left( \frac{c_{it}v_{i}}{c_{1,t}} \right) + \varepsilon_{it},
\]
time, and firm fixed effects are necessary for unbiased estimation of $\beta$. The $\beta$ elasticity is estimated as follows,

$$ln(s_{it}) = \alpha_i + \alpha_t - \beta ln(c_{it}) \varepsilon_{it}, \quad (C.2)$$

with $\alpha_i = \alpha - ln(u_i) + \beta ln(v_i)$ and $\alpha_t = ln(s_{1t}) - \beta ln(c_{1t})$. Approximating marginal cost with the average variable cost for simplicity. The market share of loans or deposits is equal to $s_{it} = q_{it}/\sum_j q_{jt}$, with $q_i$ and $\sum_j q_j$ defined as the number of loans/deposits in bank $i$ and the total loans/deposits quantity in the region at time $t$. A time interaction term is added to account for changes over time in the market. This model takes the following form,

$$ln(s_{it}) = \alpha_i + \sum_{k=1}^{T} \beta_{k1} ln(c_{it}) d_{kt} + \sum_{k=1}^{T} \beta_{k2} d_{kt} + \varepsilon_{it}. \quad (C.3)$$

$T$ denotes the total number of periods. $d_{kt}$ denotes the dummy for the time, which takes a value of 1 when $k = t$ and zero otherwise. $c_{it}$ denotes the average variable costs defined as the ratio between the sum of interest and personnel expenses, administrative and other operating expenses divided by the total of commission and trading income, interest income, fee income, and other operating income. $\varepsilon_{it}$ is the error term. Here $\beta_t$ refers to the Boone indicator at year $t$.

Because changes in performance and costs may result from a third factor unrelated to competition, the coefficients estimations report the Two-step Difference Generalized Method of Moments (GMM) estimations with 1-2 lagged average costs, the explanatory variable as the instrument variables.

The primary data is from U.S. commercial banks’ quarterly Consolidated Reports of Condition and Income (Call Reports). Observations are merged with the FDIC table of Attributes, which provides branch-level information on each bank. The data for the competition estimation is aggregated yearly using averages. We end up with
an unbalanced panel of about 4500 different banks between 2001 and 2019, consisting of 80,000 bank-yearly observations. Yearly observations eliminate cyclical trends that appear in income and balance sheets. Doing so allows for a more reliable measure without losing information, as we do not expect market structures to fluctuate over the year cycle. Moreover, assessing the competition indicator quarterly may wrongly reflect distortions due to efficiency gains that would not immediately translate into higher performance.

Using Equation C.3, Table C.2 reports the summary statistics across time of the two estimators over all five models, while C.1 is the corresponding summary statistics for the consolidated data. Tables C.3, C.4, C.5, and C.6 summarize the evolution of competition in the U.S. market over time by measuring the correlation of changes in average cost with changes in banks’ profits, the share of loans, deposits, returns to assets and the log of returns to assets respectively. First, with fixed-effects estimators in Table C.3 and GMM estimators in Table C.4. Second, for the consolidated data using Fixed-effects and GMM estimators in Tables C.5 and C.6. Market competition in the deposit market is evidently much higher than that of the loans market. Also, returns to assets and profits are more subject to changes in banks’ cost inefficiencies from loan market share and deposit market share. In general, the level of competition in the U.S. has been declining over time.

Figure C.3 plots the Fixed-effects and GMM estimations of market power compared to HHI and CR5 concentration ratios in the assets market over the sample time. We see that an inclining trend in market power is consistent through the three measures. Nevertheless, the difference is prevalent in the period before 2010. Between 2001 and 2010, concentration in the loans and deposit market has inclined, while Boone indicates an increasing level of market power for this period.
### Table C.1: Summary Statistics: Boone Index Consolidated to Parent Bank

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<th>Boone Estimations Across Time</th>
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<th>GMM estimators</th>
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### Table C.2: Summary Statistics: Boone Index

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*Note:* *p*<0.1; **p*<0.05; ***p*<0.01

Standard errors are reported in parentheses, F-Statistics are significant at the 0.01 level for all five models.
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<th>Year</th>
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<td>(0.599)</td>
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AR(1) P-value 0.000 0.020 0.099 0.000 0.000
AR(2) P-value 0.072 0.915 0.190 0.018 0.005
Over-iden. P-value 0.000 0.000 0.000 0.000 0.000
Instruments 52 66 63 52 52
Number of banks 4713 4713 4650 4713 4713
Observations 63161 63161 57254 63161 63161

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors are reported in parentheses
AR(1), AR(2) and Sargan/Hansen that show the GMM is correctly specified and there is no identification issue
Table C.5: Boone Index- Fixed-effects

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<th>Log(Share of Deposits)</th>
<th>ROA</th>
<th>Log(ROA)</th>
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<td>(0.153)</td>
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<td>(0.001)</td>
<td>(0.094)</td>
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Observations 79587

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors are reported in parentheses, F-Statistics are significant at the 0.01 level for all five models
Table C.6: Boone Index- GMM

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<th>Log(Profits)</th>
<th>Log(Share of Loans)</th>
<th>Log(Share of Deposits)</th>
<th>ROA</th>
<th>Log(ROA)</th>
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<td>-3.003***</td>
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<td>(0.619)</td>
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<tr>
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<td>(0.770)</td>
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<td>(0.720)</td>
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AR(1) P-value 0.000 0.000 0.000 0.000 0.000
AR(2) P-value 0.061 0.034 0.015 0.379 0.243
Over-iden. P-value 0.003 0.001 0.000 0.000 0.004
Instruments 52 52 63 52 52
Number of banks 4924 4924 4865 4924 4924
Observations 66002 59848 66002 66002 66002

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors are reported in parentheses
AR(1), AR(2) and Sargan/Hansen that show the GMM is correctly specified and there is no identification issue.
Table C.7: Regression Results for Policy Pass-through Given Market Competition

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<th>Credit Card (3)</th>
<th>Deposit (4)</th>
<th>Deposit to Loan (5)</th>
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<td>✓</td>
<td>✓</td>
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<td>67,434</td>
<td>63,755</td>
<td>269,123</td>
<td>86,746</td>
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Note:  

- p<0.1; *p<0.05; **p<0.01; ***p<0.001  
- The unit of observation is a bank in a state in a year (full sample)  
- Standard errors reported in parenthesis
Table 2A. Regression results for monetary policy pass-through 2001-2019: across states using Two-step System GMM

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<th>ln(Profit) to Loans</th>
<th>ln(Profit) to Deposits</th>
<th>Loan Share to Loans</th>
<th>Loan Share to Deposits</th>
<th>ROA to Loans</th>
<th>ROA to Deposits</th>
<th>ln(ROA) to Loans</th>
<th>ln(ROA) to Deposits</th>
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<tbody>
<tr>
<td>% change loans</td>
<td>-0.155***</td>
<td>-0.147***</td>
<td>-0.145***</td>
<td>-0.102**</td>
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<tr>
<td>% change deposits</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>b/se</td>
<td>(0.035)</td>
<td>(0.036)</td>
<td>(0.035)</td>
<td>(0.041)</td>
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<td></td>
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<tr>
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<td>% change deposits</td>
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<td>1.175***</td>
<td>0.006***</td>
<td>1.169***</td>
<td>0.024***</td>
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<td>% change loans</td>
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<td></td>
<td></td>
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<tr>
<td>% change deposits</td>
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</tr>
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<td>b/se</td>
<td>(0.005)</td>
<td>(0.268)</td>
<td>(0.002)</td>
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<td>(0.282)</td>
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<td>Boone Index across</td>
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<td>-0.001</td>
<td>0.015</td>
<td>0.005</td>
<td>-2.615**</td>
<td>0.048</td>
<td>-0.119***</td>
<td>-0.008</td>
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<tr>
<td>% change loans</td>
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<tr>
<td>% change deposits</td>
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<tr>
<td>b/se</td>
<td>(0.037)</td>
<td>(0.021)</td>
<td>(0.039)</td>
<td>(0.011)</td>
<td>(1.121)</td>
<td>(0.878)</td>
<td>(0.036)</td>
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<td>ME of Competition</td>
<td>0.005</td>
<td>-0.005</td>
<td>0.116</td>
<td>-0.014</td>
<td>6.272**</td>
<td>0.321</td>
<td>0.016</td>
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<tr>
<td>b/se</td>
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<td>(0.021)</td>
<td>(0.085)</td>
<td>(0.023)</td>
<td>(2.813)</td>
<td>(2.774)</td>
<td>(0.038)</td>
<td>(0.017)</td>
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<td>MP Shock at t-1</td>
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<td>0.024</td>
<td>0.079**</td>
<td>0.012</td>
<td>0.067</td>
<td>-0.020</td>
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<td>% change deposits</td>
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<td>b/se</td>
<td>(0.046)</td>
<td>(0.016)</td>
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<td>(0.076)</td>
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<tr>
<td>L.% change loans</td>
<td>-0.023**</td>
<td>-0.023**</td>
<td>-0.023*</td>
<td>-0.021*</td>
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<td>% change deposits</td>
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<tr>
<td>b/se</td>
<td>(0.012)</td>
<td>(0.011)</td>
<td>(0.013)</td>
<td>(0.012)</td>
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<tr>
<td>L2.% change deposits</td>
<td>-0.019***</td>
<td>-0.019***</td>
<td>-0.018**</td>
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<td>% change deposits</td>
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<tr>
<td>b/se</td>
<td>(0.007)</td>
<td>(0.006)</td>
<td>(0.007)</td>
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All models report results of two-step system GMM dynamic panel model. Significant values of AR (1) show that null hypothesis of no autocorrelation among error terms in first difference is rejected. AR (2) is insignificant showing that error terms in level regressions are not correlated. Value of Sargan/Hensen is insignificant, indicating that instruments are valid.

Results of AR (1), AR (2) and Sargan/Hensen show that GMM is correctly specified and there are no identification issues.