Banks and the State-Dependent Effects of Monetary Policy*

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February 20, 2025

Abstract

We show that the response of banks' net interest margin (NIM) to monetary policy shocks is state dependent. Following a period of low (high) Federal Funds rates, a contractionary monetary policy shock leads to a significantly increase (decrease) in NIM. The response of aggregate economic activity exhibits a similar state dependent pattern. To explain these dynamics, we develop a banking model in which households' attentiveness to deposit interest rates is influenced by social interactions. We embed this framework within a heterogeneous-agent NK model in which state-dependent responses in NIM to a monetary policy shock generate state-dependent responses in aggregate economic activity. Our estimated model accounts well quantitatively for our key empirical findings.

JEL codes: E52, G21.
Keywords: Net interest rate margin, banks, social interactions, monetary policy, state dependence.

*We thank Daniel Greenwald for his comments and Kyra Carmichael for excellent research assistance.
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1 Introduction

A bank's net interest margin (NIM) is the difference between the rate of return on its assets and the per-dollar cost of its liabilities. This paper shows that the response of banks' NIM to a monetary policy shock is state dependent. Following a period of low Federal Funds rates, a contractionary monetary policy shock leads to a significant rise in NIM. In contrast, after a period of high Federal Funds rates, the same shock results in a decline in NIM. We find that aggregate economic activity displays a similar state-dependent response to monetary policy shocks. Real GDP, the stock market, aggregate consumption, and investment fall more sharply when a contractionary policy shock follows a period of low rather than high Federal Funds rates.

To account for these empirical findings, we proceed in two steps. First, we develop a partial equilibrium banking model and use it to study the mechanisms that generate state dependence in NIM. Second, we embed that model in a New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model to analyze how state dependence in NIM translates into state dependence in macroeconomic aggregates. We estimate nonlinear versions of the partial and the general equilibrium models using Bayesian estimation methods as in Christiano, Trabandt, and Walentin [2011] and Christiano, Eichenbaum, and Trabandt [2016]. The estimated models account well for the patterns of state dependence observed in the data and allow us to quantify the different forces at work in our banking and DSGE models.

A key feature of the banking model is that the fraction of households attentive to deposit interest rates depends on the level of the interest rate. This dependence arises from social dynamics between attentive and inattentive households. Inattentive households may become attentive after interacting with attentive households who are more likely to discuss interest rates when rates are high.[1]

There are three key effects at work in our banking model. First, higher interest rates reduce the present value of future bank profits. Free entry into banking implies that current profits must increase to compensate for this effect. The spread between the Federal Funds rate and deposit rates widens, thereby increasing NIM. This effect is stronger when interest rates are low because a marginal increase in interest rates has a greater impact on present values.

Second, rising interest rates increase the number of attentive depositors, who receive higher deposit interest rates than inattentive depositors. This effect, which reduces NIM, is stronger when interest rates are high because there are more attentive depositors who can convert inattentive depositors.

Third, expectations of a future rise in the number of attentive depositors reduce banks' expected profits. With free entry, current NIM must increase to offset this effect. This force is stronger at low interest rates because banks weigh future profitability more heavily.

[1] Our emphasis on the importance of inattentive depositors in banking is consistent with a recent Capital One survey, which finds that 57 percent of respondents check their savings accounts less than once a month or not at all, and 48 percent are unaware of their savings account interest rate. See "Why Banks May Be Hoping You're Not Paying Attention," by Ben Blatt, New York Times, Feb. 2, 2025.

In a low interest rate scenario, the first and third effects dominate, leading to an increase in NIM. Conversely, in the high-interest rate scenario, the second effect prevails, causing NIM to decline. In the estimated partial equilibrium model, NIM rises in response to a positive monetary policy shock that follows a period of low interest rates. In contrast, NIM falls when the same shock occurs after a period of high interest rates.

We embed our banking model in an NK DSGE model where bank profits flow to people with a much lower MPC out of liquid wealth than those who receive interest income from banks. Because of social dynamics, the share of attentive households is higher after a period of high interest rates. As a result, the pass-through from an increase in the policy rate to deposit rates is more pronounced, increasing household income and dampening the contractionary effect on aggregate demand. In this way, the DSGE model generates state-dependent responses in NIM that translate into state dependence in macroeconomic aggregates. In Section 4.4 we present data-based calculations to support the view that the differential effect of a policy shock on aggregate demand is large (on the order of 120 billion dollars) due to the state dependence in NIM.

The paper is organized as follows. Section 2 discusses briefly how our paper contributes to the literature. Section 3 discusses our data and empirical results. Our partial equilibrium banking model is discussed in Section 4. Section 5 presents our DSGE model. Section 6 concludes.

2 Literature Review

Our paper contributes to three important strands of the literature. The first is a large empirical and theoretical literature on the role of banks in the monetary transmission mechanism. Prominent examples include work by Cúrdia and Woodford [2010], Driscoll and Judson [2013], Gertler and Karadi [2015], Piazzesi, Rogers, and Schneider [2019], and Bianchi and Bigio [2022]. Our work is particularly related to a strand of the literature that emphasizes the deposit channel of monetary policy and the cyclical properties of NIM (see, for example, Drechsler, Savov, and Schnabl [2017, 2018, 2021] and Begenau and Stafford [2022]). Our empirical results are consistent with the findings of Greenwald et al. [2023], who show that the impact of the Federal Funds rate on deposit interest rates is nonlinear, with the effect increasing as the level of the Federal Funds rate rises. Our paper makes two significant contributions to this literature. First, we show that the responses to monetary policy shocks of NIM, deposit interest rate spreads, and key macroeconomic aggregates are state dependent. Second, we propose a model that is consistent with this state dependence.

The second strand of literature explores the MPC out of liquid wealth and its macroeconomic implications in models with heterogeneous agents. Key papers in this area include Johnson, Parker, and Souleles [2006], Parker, Souleles, Johnson, and McClelland [2013], Jappelli and Pistaferri [2014], Kaplan and Violante [2014], Debortoli and Galí [2017], Kueng [2018], Auclert, Rognlie, and Straub [forthcoming], Ganong et al. [2020], and Fagereng, Holm, and Natvik [2021]. Our contribution to this literature is to show how households with a high MPC out of liquid wealth can create state-dependent responses of aggregate variables to a monetary policy shock.

The third related line of research emphasizes the role of social interactions in shaping people's expectations. This body of work includes papers by Kelly and Gráda [2000], Carroll [2003], Iyer and Puri [2012], and Burnside, Eichenbaum, and Rebelo [2016]. See Carroll and Wang [2023] for an excellent survey. Relative to this literature, we show that social dynamics can be a fruitful way of modeling changes in people's inattention and the implied consequences for the response of the banking industry and macroeconomic aggregates to monetary policy shocks.

3 Data

Our empirical analysis uses detailed data from the Consolidated Reports of Condition and Income (Call Reports) obtained from the FDIC[2]. These reports are filed quarterly by all national banks, state-member banks, insured state-non-member banks, and savings associations. For each financial institution, we obtain data on the following variables from the call reports: total outstanding assets, total income, total outstanding loans, total loan income, total outstanding liabilities, total expenses, total outstanding deposits, total deposits expense, outstanding transaction deposits, transaction deposits expense, outstanding saving deposits, saving deposits expense, outstanding time deposits, time deposit expenses, outstanding foreign deposits, and foreign deposit expense.

Using these data, we construct the following variables: the ratio of total loans to total assets, the ratio of total deposits to total liabilities, the ratio of transaction deposits to total liabilities, the ratio of saving deposits to total liabilities, the ratio of time deposits to total liabilities, and the ratio of foreign deposits to total liabilities. In addition, we construct data on (i) the quarterly interest income rate on assets, measured as the ratio of total interest earned to total outstanding assets, (ii) the average interest expense rate on liabilities, measured as the ratio of total interest expense to total outstanding liabilities, (iii) the average loan interest income rate, measured as the ratio of total interest income from loans to total outstanding loans, (iv) the total deposit expense rate, measured as the ratio of total interest expense on deposits to total outstanding deposits, (v) the total transaction deposit expense rate, measured as the ratio of total interest expense on transaction deposits to total outstanding transaction deposits, (vi) the total saving deposit expense rate, measured as the ratio of total interest expense on saving deposits to total outstanding saving deposits, (vii) the total time deposit expense rate, measured as the ratio of total interest expense on time deposits to total outstanding time deposits, and (viii) the total foreign deposit expense rate, measured as the ratio of total interest expense on foreign deposits to total outstanding foreign deposits.

We compute two measures of NIM: (i) core NIM, computed as the difference between the average loan interest income rate and the average deposit interest expense rate, and (ii) overall NIM, computed as the difference between the average interest income rate on all assets and the average interest expense rate computed above. Our empirical analysis uses this data aggregated at the national level. To assess robustness, we re-do our analyses using data from only the 50 largest financial institutions. In all cases, we use quarterly data from 1985:1 to 2019:4. We chose this end date to abstract from the effects of COVID-19.

[2]See the FDIC website.

We obtain the following aggregate variables from FRED: Real GDP (GDPC1), Real Personal Consumption Expenditure (PCCE96) and Prices (PCEPI), Real Gross Private Domestic Investments (GPDIC1), Real Durables Consumption (DDURRA3Q086SBEA), Real Non-Durable Consumption (DNDGRA3Q086SBEA), Real Services Consumption (DSERRA3Q086SBEA), S&P500 index (SP500), the Federal Funds Rate (FEDFUNDS), 1 Year Treasury Yield (GS1), 2 Years Treasury Yield (GS2), 10 Years Treasury Yield (GS10), the 15-Year Fixed Rate Mortgage Average (MORTGAGE15US). We obtain the updated excess bond premium time series from the Federal Reserve Board[3].

We use two measures of exogenous shocks to monetary policy. The first measure is constructed by Bauer and Swanson [2022], who use high-frequency movements in the one-, two-, three-, and four-month-ahead Eurodollar futures contracts (ED1–ED4) in a 30-minute window of time around Federal Open Market Committee (FOMC) announcements.[4] Bauer and Swanson orthogonalize these movements to variables summarizing the information set available to financial markets before the FOMC announcement: a measure of the surprise component of the most recent non-farm payrolls release (as measured by the deviation of the actual outcome from the consensus forecast), employment growth over the last year, the log change in the Standard & Poor's 500 index (S&P 500) from three months before the day of the FOMC announcement, the change in the yield curve slope over the same period, the log change in a commodity price index over the same period, and the option-implied skewness of the 10-year Treasury yield from Bauer and Chernov [2024]. For convenience, we refer to this measure of a monetary policy shock as the 'Bauer-Swanson shock measure.'

We base our second measure of a monetary policy shock on a recursive-style identification assumption of the type used in Bernanke and Mihov [1998] and Christiano et al. [1999], amongst others. In particular, we identify a time t shock to monetary policy as the residual in a regression of the Federal Funds rate on contemporaneous and four lags of real GDP, the PCE price index, the excess bond premium (the part of credit spread not explainable by expected default risk), and the yield curve slope.[5] The presence of the contemporaneous variables reflects the assumption that the Federal Reserve sees those variables when making its monetary policy decisions and the assumption that those variables are pre-determined relative to the monetary policy shock (see Christiano et al. [1999] for a discussion). For convenience, we refer to this measure of a monetary policy shock as the 'recursive shock measure.'

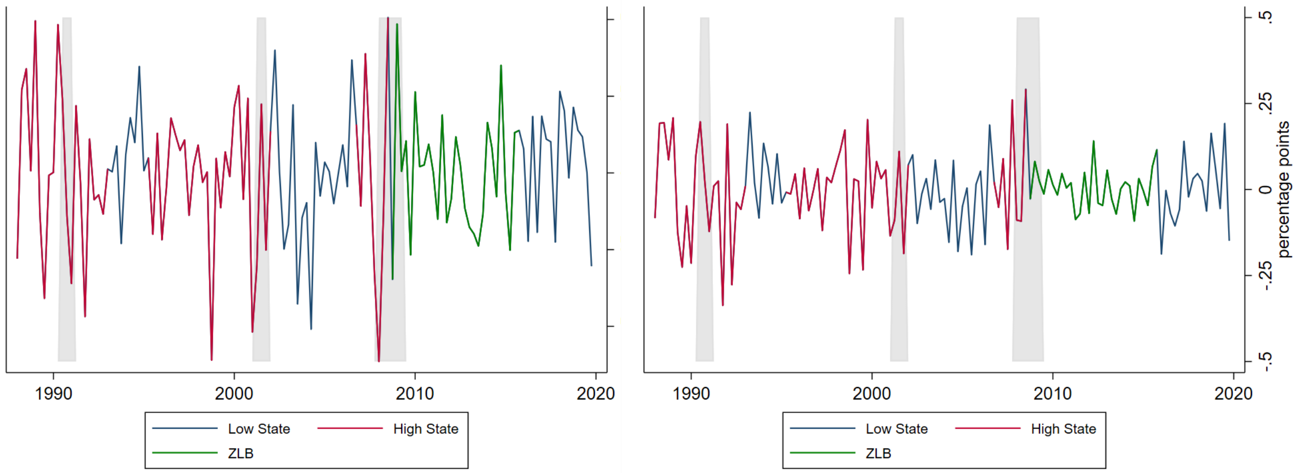
The figure below displays the two shock measures. Colors blue, red, and green depict periods in which the average policy rate is higher than 4 percent, lower than 4 percent, or at the ZLB. In our empirical work, we use the 4 percent threshold to define whether interest rates are high or low.

[3]See FRB Updated Excess Bond Premium data.

[4]Bauer and Swanson [2022] follow Nakamura and Steinsson [2018] and use the first principal component of the changes in ED1–ED4 around FOMC announcements rescaled so that a one-unit change in the principal component corresponds to a 1 percentage point change in the ED4 rate.

[5]See Caldara and Herbst (2019) for the importance of controlling for the lagged values of the excess bond premium.

Figure 1: Choleski vs Bauer & Swanson Shock



(a) Panel A. Choleski

(b) Panel B. Bauer and Swanson

Note: Recession dates are depicted in grey.

Both shocks are mean zero by construction. The table below reports the standard deviation of the shock measures over the whole sample and subsamples.

Table 1: Standard deviation of policy shocks

Shock Measure	Full Sample	Low Rates	High Rates	ZLB	Low Rates and ZLB
Recursive	0.22	0.20	0.20	0.26	0.19
Bauer & Swanson	0.11	0.11	0.14	0.06	0.08
Observations	128	42	57	29	71

4 Empirical Results

In this section, we investigate the state-dependent nature of the effect of monetary policy shocks on loan rates, deposit rates, NIM, and aggregate economic activity. The key state variable in our analysis is whether policy interest rates were high or low before the monetary policy shock. We measure that state using an indicator variable that takes the value one when the average level of the FFR in the previous six quarters is higher than a threshold value of $\bar{R}$ equal to 4 percent and zero, otherwise. The average value of the FFR is 1.47 percent (5.61 percent) when the average of the previous six quarters' FFR is less (greater) than 4 percent.[6] This approach is broadly consistent with Pfäuti [2023], who shows that the public's attention to inflation doubles when inflation exceeds 4 percent.

[6] With a threshold value of $\bar{R}$, there are an approximately equal number of observations when $\mathbb{I}_{\{MA(R)>\bar{R}\}} = 0$, and $\mathbb{I}_{\{MA(R)>\bar{R}\}} = 1$ if we exclude observations when the ZLB is binding. We control for a binding ZLB using a dummy variable that takes on the value 1 when FFR is lower than 50 basis point and zero otherwise. In practice we found that our results were not significantly affected if we set $\bar{R}$ to values slightly higher (4.50) or lower (3.50) than 4%.

4.1 Estimating the State-Dependent Response to a Monetary Policy Shock

We consider the following local projection equation:

$$Y_{t+h} = \alpha_h + \beta_{0,h} MP_t + \beta_{1,h} \mathbb{I}_{\{MA(R)>\bar{R}\}} + \beta_{2,h} MP_t \times \mathbb{I}_{\{MA(R)>\bar{R}\}} + A_h(L)Y_t + B_h(L)MP_t + C_h(L)Z_t + \varepsilon_{t+h}. \quad (1)$$

Here, Y_{t+h} is the time $t+h$ value of the variable of interest, i.e., one of our financial outcome variables, aggregate real activity indicators, or a measure of inflation. For the macroeconomic aggregates and inflation, h ranges from one to H. In the case of NIM, the index h ranges from zero to H. The variable MP_t denotes the time t value of the monetary policy shock. The variable $\mathbb{I}_{\{MA(R)>\bar{R}\}}$ is an indicator variable that is equal to one when the average level of the FFR across the last six quarters is higher than $\bar{R} = 4$ percent and zero otherwise. We refer to the state when $\mathbb{I}_{\{MA(R)>\bar{R}\}} = 1$ as the high interest rate state and the state when $\mathbb{I}_{\{MA(R)>\bar{R}\}} = 0$ as the low interest rate state.

As is common in the literature, we include other control variables in the local projection (see, for example, Bauer and Swanson (2023)). The variables $A_h(L)Y_t$ and $B_h(L)MP_t$ denote the values of Y_{t-j} and MP_{t-j}, $j = 1, 2, 3, 4$. Since Z_t includes real GDP, consumption, investment, or the excess bond premium, $A_h(L) = 0$ is superfluous when these are the outcome variables.The variable $C_h(L)Z_t$ denotes a vector lag polynomial of additional controls: contemporaneous and four lags of real GDP, PCE prices, investment and consumption, four lags of the excess bond premium, and the yield curve slope. Finally, ε_{t+h} denotes the time $t+h$ regression error.

The coefficient $\beta_{0,h}$ measures the effect of a monetary policy shock on Y_{t+h} in the low state, i.e., when the average level of the time t Federal Funds rate, FFR_t, across the last six quarters, is lower than $\bar{R} = 4$ percent. The coefficient $\beta_{1,h}$ captures the fixed effect of a high average value of past interest rates. The coefficient $\beta_{2,h}$ measures the differential effect of a monetary policy shock on Y_{t+h} in the high state, i.e., when the average value of FFR_t in the last six quarters is higher than $\bar{R} = 4$ percent. The sum $\beta_{0,h} + \beta_{2,h}$ provides the total response of Y_{t+h} to a monetary policy shock, conditional on the shock occurring in the high state, i.e., when $\mathbb{I}_{\{R_{t-1,t-6}>\bar{R}\}} = 1$.

Our benchmark specification does not control for periods in which the ZLB is binding. In the Appendix, we show our results are not sensitive to including a dummy variable and an additional interaction term for the monetary policy shock for those periods.[7]

In the following subsections, we summarize our results by plotting the benchmark-effect sequence $\beta_b = \{\beta_{0,h}\}_{h=0}^{H}$ and the total-effect sequence $\beta_T = \{\beta_{0,h} + \beta_{j,h}\}_{h=0}^{H}$, $j = 1, 2$ with 68% and 90% confidence bands.[8]

4.2 The Federal Funds Rate and Financial Variables

In this subsection, we investigate the state-dependent effects of a monetary policy shock on the Federal Funds rate and financial variables. We report the results of estimating regression (1) for different specifications of the dependent variable.

[7] Our estimation framework assumes that positive and negative monetary policy shocks have symmetric effects. The state dependence that we document is robust to distinguishing between positive and negative shocks.

[8] We construct confidence bands assuming a zero correlation between $\beta_{0,h}$and $\beta_{2,h}$.

The results are organized in two panels of four columns for each variable of interest. Panels A and B contain the results obtained using the recursive shock and Bauer-Swanson shock measure, respectively. The size of the policy shock is normalized to induce an initial rise of 100 basis points (on an annualized basis) in the FFR.

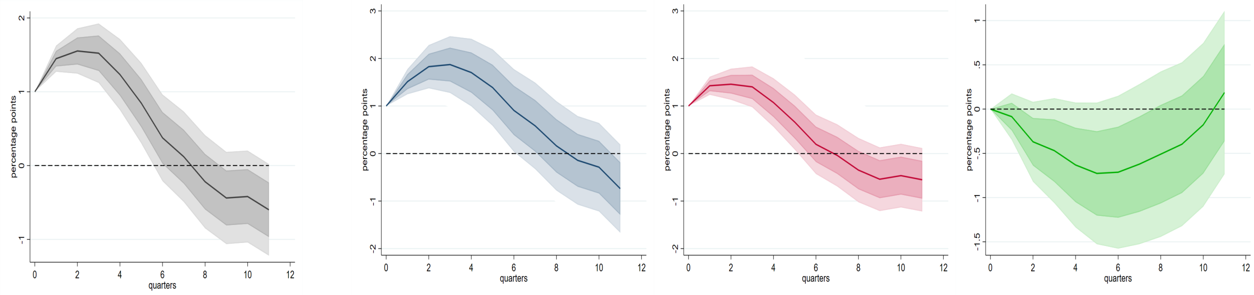
The first column in each panel reports the sequence $\beta_0 = \{\beta_{0,h}\}_{h=0}^{H}$ estimated in a version of the regression (1) where $\{\beta_{1,h}, \beta_{2,h}\}_{h=0}^{H}$ are both restricted to zero. These estimates represent the benchmark impulse response when we do not allow for state dependence. The second column in each panel reports the sequence $\beta_0 = \{\beta_{0,h}\}_{h=0}^{H}$, which corresponds to the impulse response of the outcome variable to a monetary policy shock in the low state. The third column in each panel reports the estimated impulse response sequence $\beta_H = \{\beta_{0,h} + \beta_{2,h}\}_{h=0}^{H}$ to a monetary policy shock in the high state. Finally, the fourth column of each panel reports our estimate of $\beta_{Diff} = \{\beta_{2,h}\}_{h=0}^{H}$. That sequence corresponds to the estimated difference in the impulse response function to a monetary policy shock in high and low states.

Figure 2 reports our results for the FFR. For both measures of the monetary policy shock, a contractionary shock induces a persistent increase in the FFR for roughly two years. Significantly, there is relatively little evidence of state dependence in the response of the FFR. These results are robust to the shock measure that we use.

Figure 2: ***Federal Funds Rate, response to a monetary policy shock***

Panel A: Choleski-style Identification

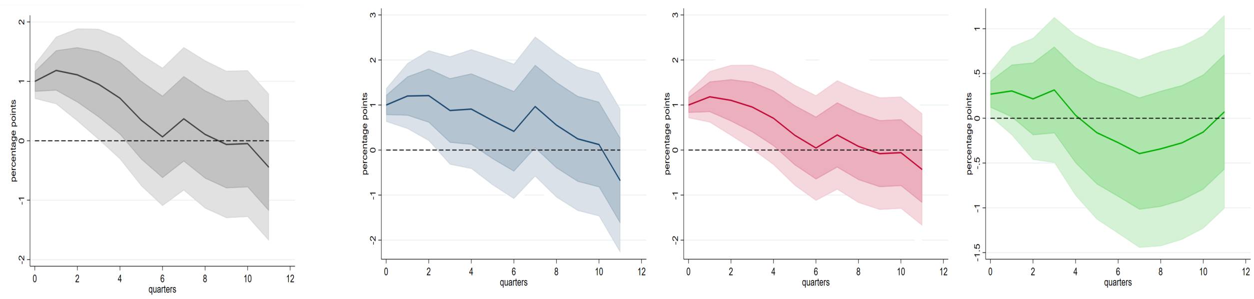
No State-Dependence **Allowing for State Dependence**



(a) Baseline Response (b) Response in low rate state (c) Response in high rate state (d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence **Allowing for State Dependence**



(e) Baseline Response (f) Response in low rate state (g) Response in high rate state (h) Difference Low vs High

Note: Solid Lines in the first three columns depict point estimates of the response of Federal Funds Rate to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

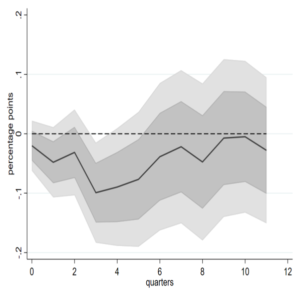
Figure 3 reports our results for NIM. Three results emerge. First, if we do not allow for state dependence, both shock measures imply that NIM falls by a modest amount after a contractionary monetary policy shock. Second, once we allow for state dependence, a different pattern emerges. The second column shows that a contractionary policy shock (however measured) in the low state induces a significant and persistent rise in NIM, with the maximal rise ranging from 20 to 23 basis points, depending on the shock measure. In contrast, the third column shows that for both shock measures, a policy shock in the high state causes a significant and persistent *fall* in NIM, with the maximum drop ranging from 15 to 21 basis points, depending on the shock measure. Third, the fourth column shows that the difference in NIM's response when the shock occurs in the low and high states is statistically significant for both shock measures.

Figure 3: ***NIM, response to a monetary policy shock***

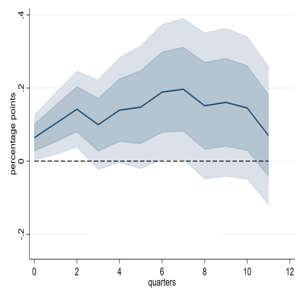
Panel A: Choleski-style Identification

No State-Dependence

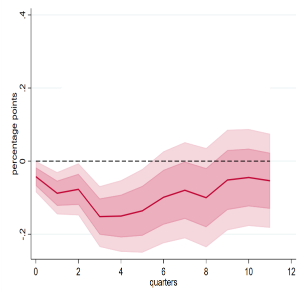
Allowing for State Dependence



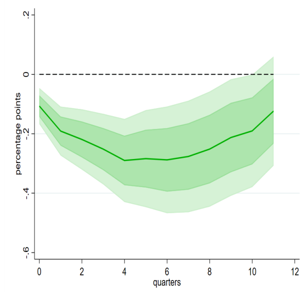
(a) Baseline Response



(b) Response in low rate state



(c) Response in high rate state

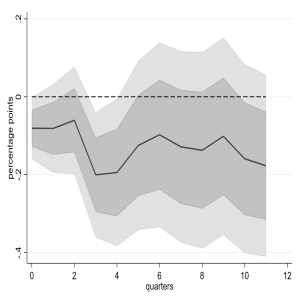


(d) Difference, low vs high state

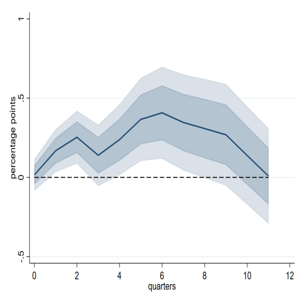
Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence

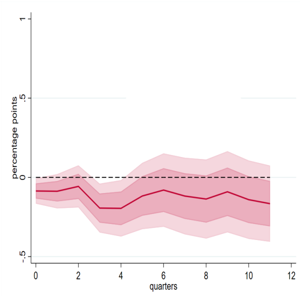
Allowing for State Dependence



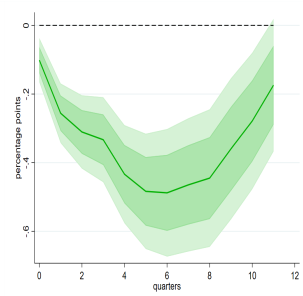
(e) Baseline Response



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

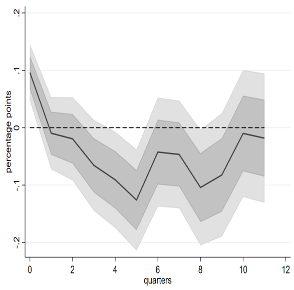
Note: Solid Lines in the first three columns depict point estimates of the response of NIM to a 100 b.p. contractionary shock to monetary policy. Shaded areas represent 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depicts the difference between the point estimates in the third and second columns. The shaded areas represent the 68% (darker) and 95% (lighter) confidence intervals.

Figure 4 shows how core NIM (the difference between the average loan interest income rate and the average deposit interest expense rate) responds to a monetary policy shock. The results are similar to those reported for NIM in Figure 3.

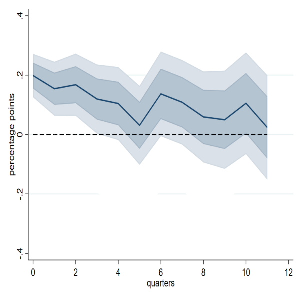
Figure 4: ***Core NIM, response to a monetary policy shock***

Panel A: Choleski-style Identification

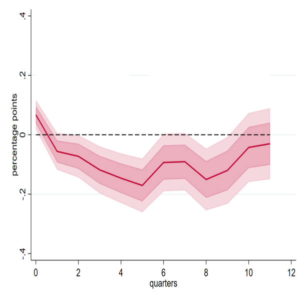
No State-Dependence | **Allowing for State Dependence**



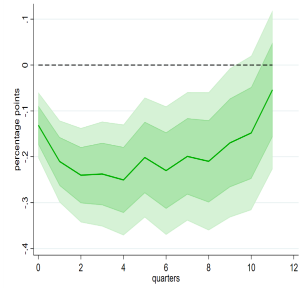
(a) Baseline Response



(b) Response in low rate state



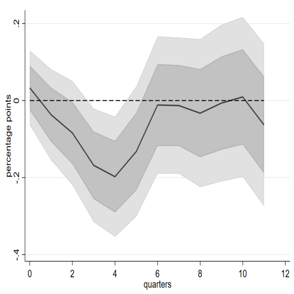
(c) Response in high rate state



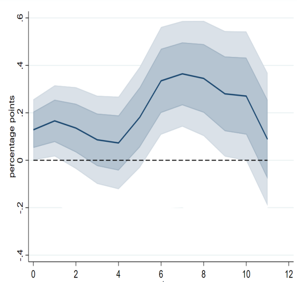
(d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

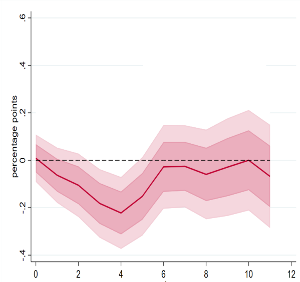
No State-Dependence | **Allowing for State Dependence**



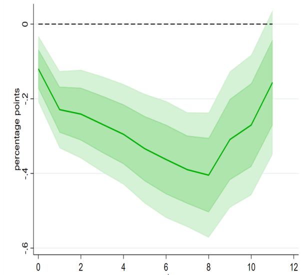
(e) Baseline Response



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

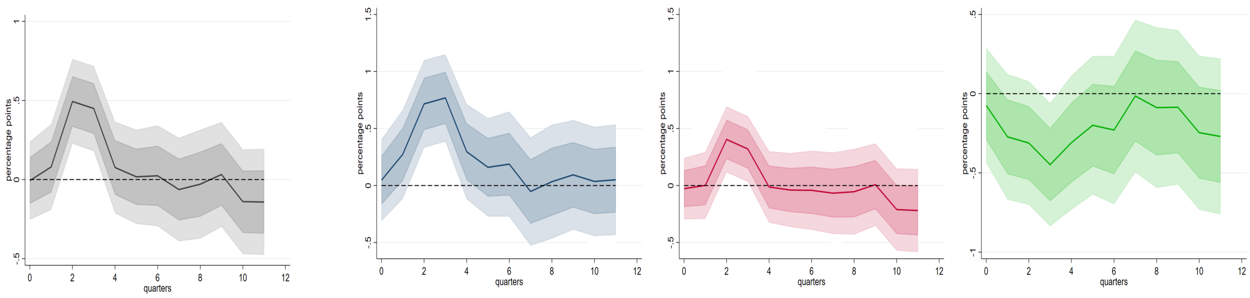
Note: Solid Lines in the first three columns depict point estimates of the response of Core NIM to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

The underlying determinants of the response of core NIM to a monetary policy shock are as follows. The level of and interest rate on transaction deposits do not respond much to a monetary policy shock. The situation is very different for time and savings deposits. Figure 5) shows that, in response to the policy shock, the spread between the interest rate on time and savings deposits rises in a state-dependent manner. So, movements in the intensive margin of interest rates on bank liabilities play a significant role in the state-dependent behavior of core NIM.

Figure 5: ***Time Deposit Rate minus Saving Deposit Rate, response to a monetary policy shock***

Panel A: Choleski-style Identification

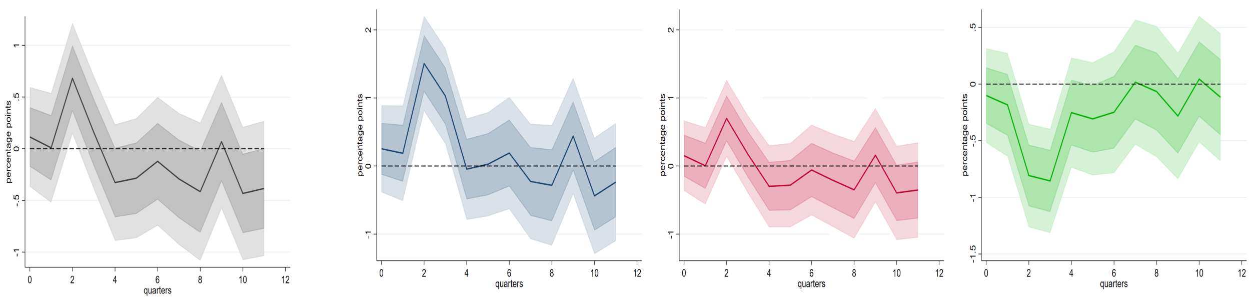
No State-Dependence | **Allowing for State Dependence**



(a) Baseline Response (b) Response in low rate state (c) Response in high rate state (d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence | **Allowing for State Dependence**



(e) Baseline Response (f) Response in low rate state (g) Response in high rate state (h) Difference Low vs High

Note: Solid Lines in the first three columns depict point estimates of the response of Time Deposits rate minus Saving Deposit Rates to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

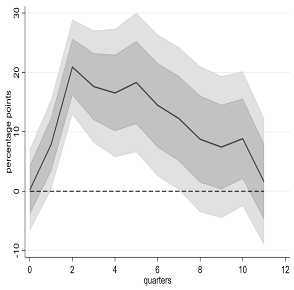
Depositors' asset allocations also play an important role in the response of Core NIM. Figure 6 shows that a contractionary monetary policy shock induces a significant switch from savings to time deposits after a contractionary monetary policy shock. For both shock measures, the response is state-dependent.

Overall, we conclude that movements in the interest rate on bank liabilities plus the reallocation of funds between time and savings deposits interact in a manner that generates state-dependent responses in NIM and core NIM to a monetary policy shock.

Figure 6: ***Time Deposits as a fraction of Saving Deposits (Outstanding Amounts), response to a monetary policy shock***

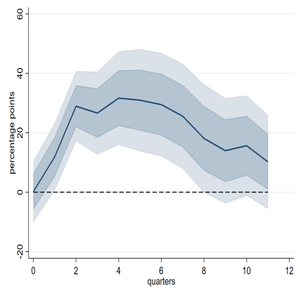
Panel A: Choleski-style Identification

No State-Dependence

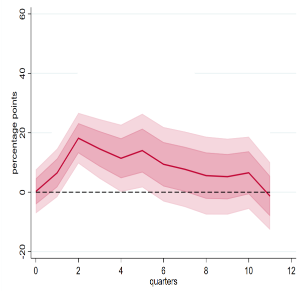


(a) Baseline Response

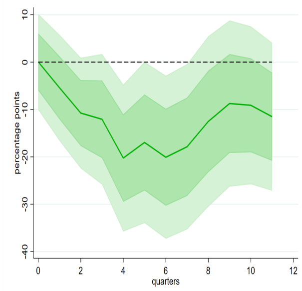
Allowing for State Dependence



(b) Response in low rate state



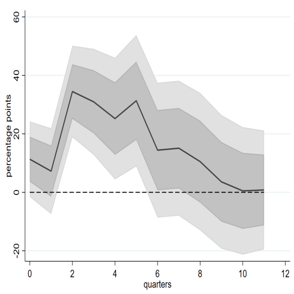
(c) Response in high rate state



(d) Difference, low vs high state

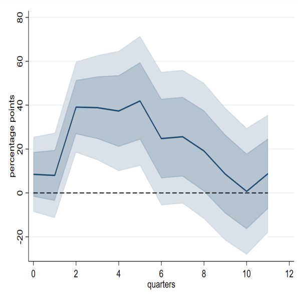
Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence

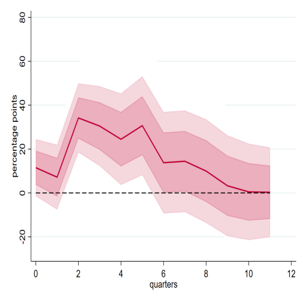


(e) Baseline Response

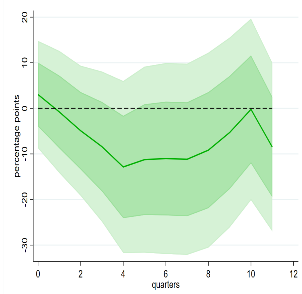
Allowing for State Dependence



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

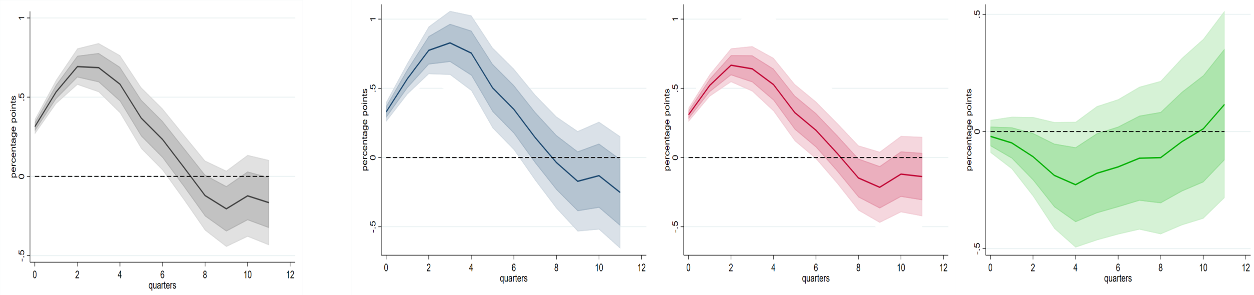
Note: Solid Lines in the first three columns depict point estimates of the response of Time Deposits as a fraction of Saving Deposits (Outstanding Amounts) to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

We now consider the response of loan rates to a contractionary monetary policy shock. Figure 7shows that loan rates rise after the shock. However, there is relatively little evidence of state dependence in that response. The key driver of state dependence in NIM is not state dependence of loan rates. It is the state dependence in deposit interest rates and the allocation of assets between savings and time deposits.

Figure 7: ***Loan Income Rate, response to a monetary policy shock***

Panel A: Choleski-style Identification

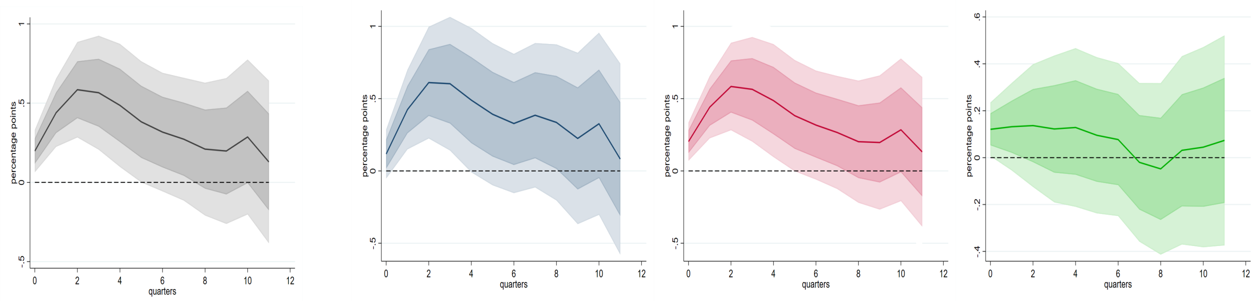
No State-Dependence **Allowing for State Dependence**



(a) Baseline Response (b) Response in low rate state (c) Response in high rate state (d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence **Allowing for State Dependence**



(e) Baseline Response (f) Response in low rate state (g) Response in high rate state (h) Difference Low vs High

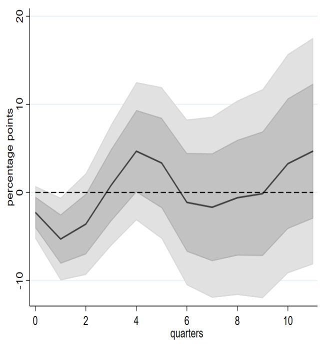
Note: Solid Lines in the first three columns depict point estimates of the response of Loan Income Rate to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

Finally, Figure 8 displays the stock market's response to a contractionary monetary policy shock. For both shock measures, the value of the stock market declines. However, the magnitude of this decline is state-dependent, with a more pronounced drop occurring following a period of low interest rates.

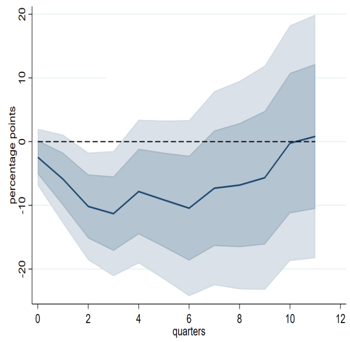
Figure 8: ***Log S&P500 deflated by PCE prices, response to a monetary policy shock***

Panel A: Choleski-style Identification

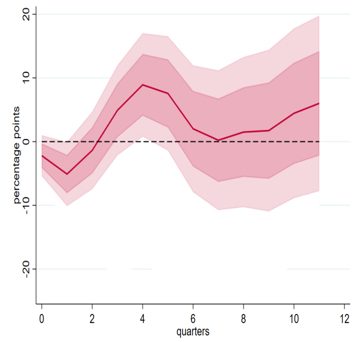
No State-Dependence | **Allowing for State Dependence**



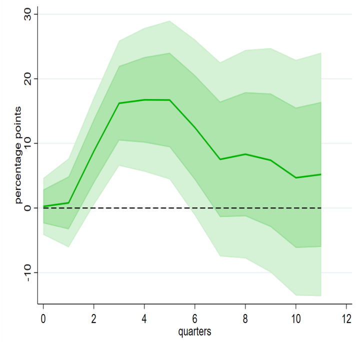
(a) Baseline Response



(b) Response in low rate state



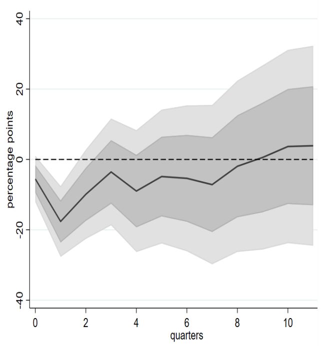
(c) Response in high rate state



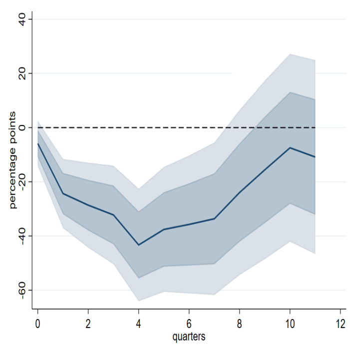
(d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

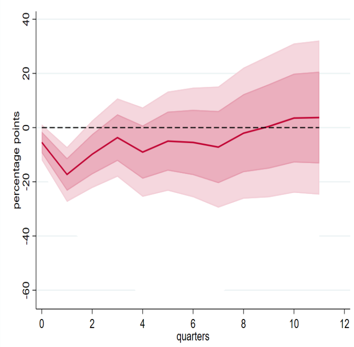
No State-Dependence | **Allowing for State Dependence**



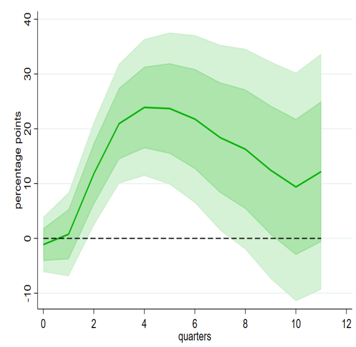
(e) Baseline Response



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

Note: Solid Lines in the first three columns depict point estimates of the response of the log of the S&P500 index to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

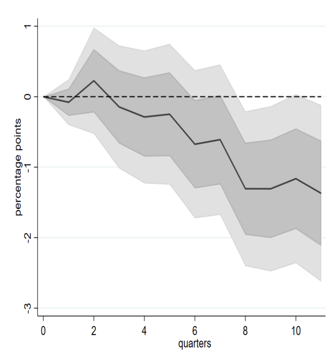
4.3 Aggregate Economic Activity and Inflation

In this subsection, we analyze the state-dependent effects of a monetary policy shock on aggregate economic activity, inflation, and the stock market. We report the results of estimating regression (1) where the dependent variable is either the log of real GDP, the log of consumption, the log of investment, the log of the inflation rate, and the real value of the stock market. Figures 8 - 9 - follow the same structure as Figures 2 - 7.

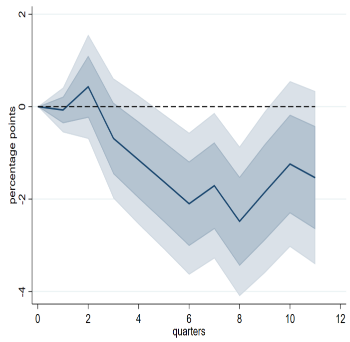
Figure 9: ***Real Gross Domestic Product, response to a monetary policy shock***

Panel A: Choleski-style Identification

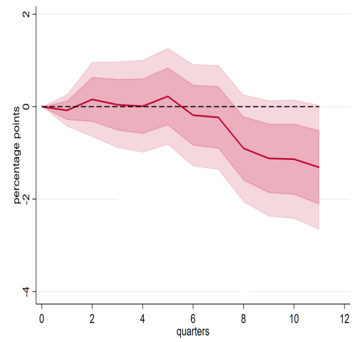
No State-Dependence **Allowing for State Dependence**



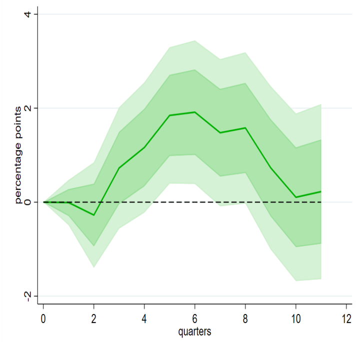
(a) Baseline Response



(b) Response in low rate state



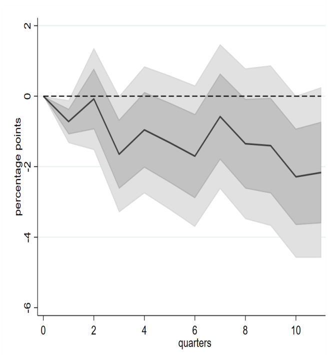
(c) Response in high rate state



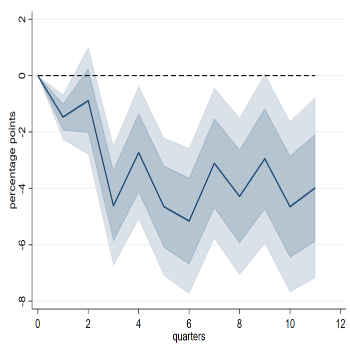
(d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

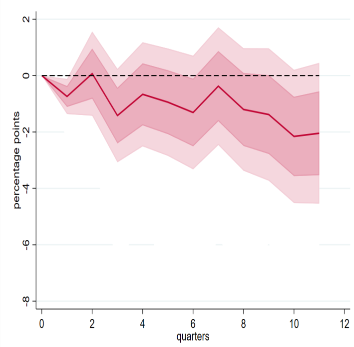
No State-Dependence **Allowing for State Dependence**



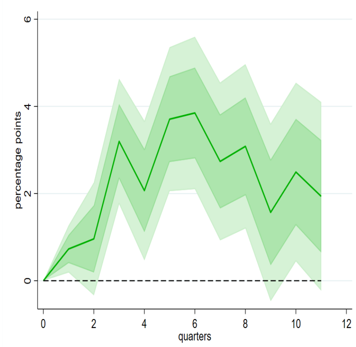
(e) Baseline Response



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

Note: Solid Lines in the first three columns depict point estimates of the response of Real GDP to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

Figure 9 shows that the response of real GDP to a contractionary monetary policy shock exhibits strong state dependence. Two features are worth noting. First, for both shock measures, a contractionary monetary policy shock induces a persistent decrease in real GDP lasting approximately two years. Second, there is strong evidence of state dependence in the response of real GDP, which declines more when the shock occurs in the low interest rate state. The difference in real GDP's response when the shock occurs in the low and high interest rate states is statistically significant for both shock measures. Figure 9 shows that a similar pattern holds for consumption and investment.

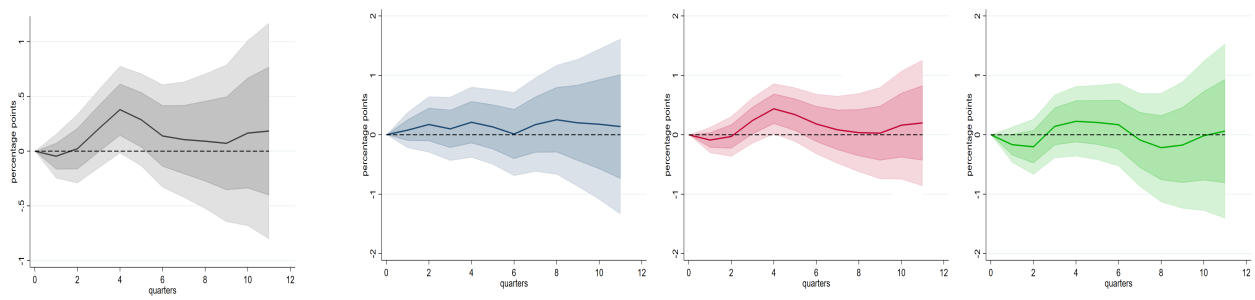
Figure 10 displays the effect of a monetary policy shock on the log of the personal consumption expenditures

(PCE) price index. Interestingly, there is no evidence that the response of this price index's is state-dependent. Regardless of whether the shock occurs in the low or the high interest rate state, a contractionary shock does not induce a statistically significant change in the price level.

Figure 10: ***Log of PCE prices, response to a monetary policy shock***

Panel A: Choleski-style Identification

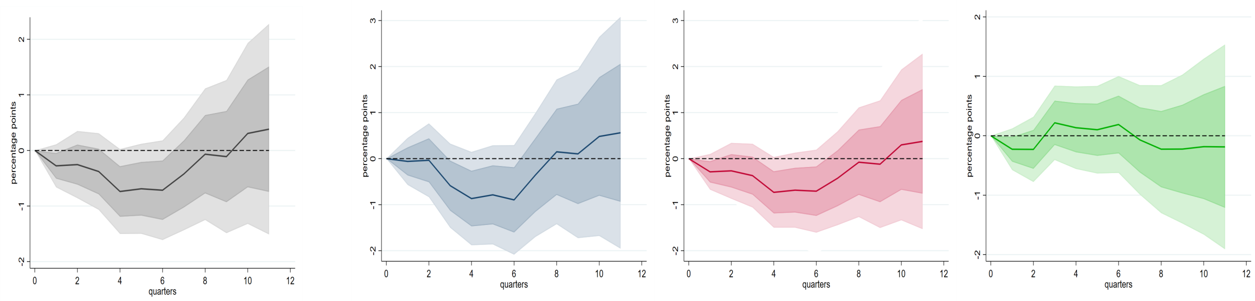
No State-Dependence **Allowing for State Dependence**



(a) Baseline Response (b) Response in low rate state (c) Response in high rate state (d) Difference, low vs high state

Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence **Allowing for State Dependence**



(e) Baseline Response (f) Response in low rate state (g) Response in high rate state (h) Difference Low vs High

Note: Solid Lines in the first three columns depict point estimates of the response of log of Personal Consumption Expenditure Price Index (PCEPI) to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the point estimates in the third and second columns. The shaded areas depict the 68% (darker) and 95% (lighter) confidence intervals.

In sum, for both shock measures, the response of aggregate economic activity and inflation to a contractionary monetary policy shock is consistent with the conventional view. The shock induces persistent declines in real GDP, consumption, and investment. It does not cause a statistically significant change in the aggregate price level. However, in contrast to the conventional view, the effect of a monetary policy shock is state-dependent. A contractionary monetary shock induces a substantially larger decline in economic activity after a period of low interest rates. This state dependence mirrors our findings about state dependence in the response of NIM and related financial indicators to a contractionary monetary policy shock.

4.4 Connecting Financial Variable and Economic Activity Results

It is useful to quantify the differential impact of a monetary policy shock on NIM in the high and low- interest-rate states. Suppose we begin in the low-interest-rate state. Then, the cumulative effect of the recursive and Bauer and Swanson monetary policy shock over three years is an *increase* in NIM-related bank profits (the change in NIM times Commercial Banks' total bank assets) of approximately 95 and 92 billion dollars, respectively. Conversely, if the shock occurs in the high interest rate state, the corresponding impact on NIM-related profits is a *decrease* of 64 and 98 billion dollars, depending on the shock measure. In summary, banks' counterparties save between 150 and 191 billion dollars in net interest payments when the shock occurs in the high interest rate state rather than the low interest rate state.

There is substantial empirical evidence that the MPC out of liquid wealth is high, ranging from 0.20 and 0.60 (see, for example, Carroll et al. [2017]and Ganong et al. [2023]). Assuming an MPC out of liquid wealth of 0.40, there's a differential swing in aggregate demand of 60 to 75 billion dollars arising from state dependence on wealth.

We focus on the recursive policy shock to estimate the effect of changes in stock market wealth on consumption because the standard errors of the point estimates obtained using the Bauer-Swanson shock measure are very large.

Twelve quarters after a 100 basis point contractionary monetary policy shock occurring in the low-interest-rate state, the S&P 500 declines by approximately 10 percent. The market capitalization of the S&P 500 was around 28 trillion dollars at the end of 2019. So, this decline translates to a reduction in wealth of approximately 2.8 trillion dollars.

After 12 quarters, the S&P 500 declines by approximately 4 percent after a 100 basis point contractionary monetary policy shock in the high interest rate state. This decrease corresponds to a reduction in wealth of roughly 1.2 trillion dollars. Based on estimates by Di Maggio et al. [2020]andChodorow-Reich et al. [2021], the marginal propensity to consume (MPC) out of stock market wealth is approximately 3 percent. Using this estimate, the differential decline in demand amounts to 48 billion dollars.

The previous calculations imply a total differential swing in aggregate demand between a policy shock that occurs in the low and high interest rate state of about 120 billion dollars. To put this number in perspective, the analogous cumulative difference in the GDP contraction over 12 quarters is roughly 130 billion dollars.

Suppose that bank profits accrue to people with a much lower MPC out of liquid wealth than those who receive interest income from banks. In this case, the contraction in aggregate demand would likely be larger, all else equal, when a contractionary monetary policy shock occurs in the low interest rate state. We explore this conjecture in two steps. In Section 4, we develop a partial equilibrium banking model to explain our main NIM findings. Section 5 integrates this banking model into a medium-scale model to analyze the state-dependent effects of a monetary policy shock on aggregate economic activity.

5 Partial Equilibrium Model

In this section, we study a simple competitive banking model that accounts for the key empirical facts about the effect of a monetary policy shock on NIM.

In the first subsection, we study a model that does not allow for social dynamics. The key features of this model are that (i) some households are attentive, and others are inattentive to the interest rate they earn on bank deposits, and (ii) banks recognize this variation and consider it when valuing household deposits. We adopt a matching framework in which competitive banks invest resources to attract attentive and inattentive households. In the second subsection, we study the social dynamics that govern changes in the fraction of attentive and inattentive households. We incorporate these social dynamics into our banking model in the third subsection. To keep the analysis as transparent as possible, we assume that the price level is fixed so inflation is zero. We relax this assumption in the general equilibrium model.

5.1 A Simple Competitive Banking Model

To isolate the role of the key mechanisms in our model, we abstract from non-competitive behavior by banks. The forces that we emphasize–the impact of interest rates on social dynamics and the joint effect of social dynamics and interest rates on the present value of future profits–would also be present in models of monopolistic competition with free entry.

5.1.1 Deposits

The economy has two types of households. The first group is attentive to the interest rates they earn on bank deposits. The second group is inattentive to the interest rates offered by banks. The first and second groups represent a fraction a_t and i_t of the population, respectively, where

$$a_t + i_t = 1.$$

For simplicity, we assume that each household has one dollar of deposits.

There is a continuum of banks with measure one. . A fraction δ of dollar deposits leave their bank every period due to exogenous factors.. So, there are δa_t and δi_t dollars belonging to attentive and inattentive customers seeking a new bank at time t. We assume that $\delta \in (0, 1)$.

Banks can identify which depositors are attentive and inattentive and can invest resources to attract the two types of depositors. It costs $\tau_j v_j$ dollars to attract v_j dollars of type j deposits, $j = a, i$. It is natural to assume that it is more costly to attract inattentive depositors than attentive ones, i.e. $\tau_i > \tau_a$. The reason is that inattentive depositors are less likely to notice bank offers.

Matches, m_{at}, between banks and deposits of attentive households form according to the technology,

$$m_{at} = \mu \left(\delta a_t\right)^{\varsigma} v_{at}^{1-\varsigma},$$

where $\mu > 0$, and $\varsigma \in (0,1)$. The matching function for deposits belonging to inattentive customers is,

$$m_{it} = \mu \left(\delta i_t\right)^{\varsigma} v_{it}^{1-\varsigma}.$$

The probability that a bank receives one dollar of deposits belonging to an attentive or inattentive household is $p_{at} = \mu \left(\delta a_t\right)^{\varsigma} v_{at}^{1-\varsigma}/v_{at}$ and $p_{it} = \mu \left(\delta i_t\right)^{\varsigma} v_{it}^{1-\varsigma}/v_{it}$, respectively.

In equilibrium, all deposits find a match,

$$\delta a_t = \mu \left(\delta a_t\right)^{\varsigma} v_{at}^{1-\varsigma} \quad \text{and} \quad \delta i_t = \mu \left(\delta i_t\right)^{\varsigma} v_{it}^{1-\varsigma}. \tag{2}$$

Solving for v_{at} and v_{it} we obtain,

$$v_{at} = \mu^{-1/(1-\varsigma)} \delta a_t \quad \text{and} \quad v_{it} = \mu^{-1/(1-\varsigma)} \delta i_t.$$

The household's opportunity cost of funds within the period is zero, so they are willing to accept any non-negative interest rate offered by banks. The time t gross interest on deposits owned by attentive and inattentive customers is R_{at} and R_{it}, respectively. These interest rates are generally non-negative because banks value deposits and compete to attract them.

In equilibrium, banks' total cost of acquiring deposits is

$$\delta \mu^{-1/(1-\varsigma)} \left(\tau_a a_t + \tau_i i_t\right).$$

5.1.2 Loans and the Value of Deposits

The monetary authority sets the policy rate, R_t, which coincides with the inter-bank borrowing and lending rate. We think of R_t as the gross Federal Funds rate. Banks extend loans to firms to meet their working capital needs. The marginal cost of lending one dollar is constant and equal to ε^l. Since banks are perfectly competitive, the equilibrium lending rate, R_t^l, is

$$R_t^l = R_t + \varepsilon^l. \tag{3}$$

The value to a bank of a dollar deposit from an attentive household is

$$V_{a,t} = R_t - R_{at} + \frac{1-\delta}{R_t} V_{a,t+1}. \tag{4}$$

Here, R_{at} is the gross interest rate banks pay to attentive depositors, and $R_t - R_{at}$ is the time t spread or profit per dollar of deposits owned by an attentive household that banks earn. The continuation value of the dollar of deposits, $V_{a,t+1}$, is discounted at rate R_t and multiplied by $(1-\delta)$ to account for the fraction δ of depositors that leave the bank.

The value to a bank of a dollar deposit from an inattentive household is

$$V_{i,t} = R_t - R_{it} + \frac{1-\delta}{R_t} V_{i,t+1}. \tag{5}$$

Here, R_{it} is the gross interest rate banks pay to inattentive depositors, and $R_t - R_{it}$ is the spread on a dollar of deposits owned by an inattentive customer. The logic underlying this expression (5) is analogous to the one underlying (4)

The zero profit condition implies that, in equilibrium, the cost of attracting a dollar belonging to an attentive or inattentive depositor equals the probability of obtaining that dollar of deposit multiplied by its value to the bank,

$$\tau_a = \frac{\mu \left(\delta a_t\right)^{\varsigma} v_{at}^{1-\varsigma}}{v_{at}} V_{a,t},$$

$$\tau_i = \frac{\mu \left(\delta i_t\right)^{\varsigma} v_{it}^{1-\varsigma}}{v_{it}} V_{i,t}.$$

In conjunction with (2), these conditions imply,

$$\tau_a = \mu^{1/(1-\varsigma)} V_{a,t} \text{ and } \tau_i = \mu^{1/(1-\varsigma)} V_{i,t}. \tag{6}$$

To gain intuition into the model's properties, suppose that R_t is constant over time. Then the value of a dollar of deposits belonging to attentive and inattentive households is given by,

$$V_a = \frac{R}{R-1+\delta} \left(R - R_a\right),$$

$$V_i = \frac{R}{R-1+\delta} \left(R - R_i\right).$$

Using the equilibrium conditions (6), we obtain the following expressions for interest rate spreads,

$$R - R_a = \frac{\tau_a}{\mu^{1/(1-\varsigma)}} \left(1 - \frac{1-\delta}{R}\right), \tag{7}$$

$$R - R_i = \frac{\tau_i}{\mu^{1/(1-\varsigma)}} \left(1 - \frac{1-\delta}{R}\right). \tag{8}$$

These spreads have three properties worth highlighting. First, the spreads increase with R,

$$\frac{d\left(R - R_j\right)}{dR} = \frac{\tau_j}{\mu^{1/(1-\varsigma)}} (1-\delta) R^{-2} > 0.$$

The intuition is as follows. Future profits are discounted by R. When R rises, the present value of the future profits from a deposit decreases. Since banks earn zero profits in equilibrium, current spreads must increase to compensate for this discounting effect. We refer to this effect as the present-value effect. Second, in response to a change in R, interest rate spreads increase more when interest rates are low than when interest rates are high. To illustrate why this result holds, consider an annuity that pays y in every period. The present value of this annuity is y/R. The change in this present value when R rises is $-R^{-2}y$, which is lower when R is high. Third, since $\tau_i > \tau_a$, when R rises, the spread earned by the bank on deposits owned by inattentive households increases more than the corresponding spread for attentive depositors.

The bank's NIM (nim_t) is given by,

$$nim_t = R_t + \varepsilon^l - (a_t R_{at} + i_t R_{it}),$$

where $R_t + \varepsilon^l$ is income from lending and $a_t R_{at} + i_t R_{it}$ is interest on deposits. We can rewrite nim_t is terms of deposit spreads as,

$$nim_t = \varepsilon^l + a_t (R_t - R_{at}) + i_t (R_t - R_{it}).$$

Using the expressions for interest rate spreads in steady state, (7)-(8), we obtain,

$$nim = \varepsilon^l + \frac{\tau_i - a(\tau_i - \tau_a)}{\mu^{1/(1-\varsigma)}} \left(1 - \frac{1-\delta}{R}\right). \tag{9}$$

Equation (9) has two key implications. First, nim_t is a decreasing function of the fraction of attentive households in the economy. The reason is that the interest rate spread that banks earn is lower for attentive households. Second, higher interest rates increase nim. This result is based on the present-value effect: current spreads rise to offset a higher discount rate on future bank profits.

Bank profits, π_t^b are given by,

$$\pi_t^b = R_t + \varepsilon^l - (a_t R_{at} + i_t R_{it}) - \varepsilon^l - \delta\mu^{-1/(1-\varsigma)} (a_t \tau_a + i_t \tau_i).$$

The interpretation of the last two terms in this expression is as follows. The term ε^l represents the operational costs from lending, and $\delta\mu^{-1/(1-\varsigma)} (a_t \tau_a + i_t \tau_i)$ are the costs of customer acquisition. Banks make zero profits in a present value sense, but make positive profits on a period-by-period basis. These profits are the returns on prior investments to acquire deposits.

5.2 Social Dynamics

A conventional way to model inattention is to assume that the cost of paying attention is heterogeneous across depositors. However, this approach does not generate state dependence. A given basis point change yields the same benefit to a depositor, whether we start from a low or a high interest rate environment. So depositors would react in a similar way to the change in the interest in both environments–their reaction is not state-dependent.

For this reason, we introduce social dynamics that change the number of attentive and inattentive people over time. In particular, we consider changes in the fraction of inattentive households that arise from social interactions between attentive and inattentive households. We assume that these meetings are random. Inattentive households can become attentive when they interact with attentive households. Critically, the rate at which these switches in the state of attentiveness occur is an increasing function of the policy rate.

The laws of motion for the number of inattentive and attentive households are given by:

$$i_{t+1} = i_t(1-\kappa_i) - \omega(R_t)a_t i_t(1-\kappa_i) + \kappa_a a_t, \tag{10}$$

and

$$a_{t+1} = a_t(1-\kappa_a) + \omega(R_t)a_t i_t(1-\kappa_i) + \kappa_i i_t. \tag{11}$$

There are two types of transitions between attention states: exogenous and endogenous ones that are a function of the interest rate. The exogenous interactions occur at the end of the period. A fraction κ_a of the households who were attentive at the beginning of the period become inattentive. A fraction fraction κ_i of the households that remain inattentive after social interactions become attentive.

The endogenous interactions occur at the beginning of the period. There are $a_t i_t$ pairwise meetings between attentive and inattentive households. During these meetings, some inattentive households become attentive by learning about interest rate offers through conversations with attentive households. The conversion rate, $\omega(R_t)$, is an increasing function of the annualized quarterly net interest rate. We assume that this function takes a simple quadratic form:

$$\omega(R_t) = \chi\left(4R_t - 4\right)^2.$$

This function reflects the idea that attentive depositors are more likely to discuss the interest rates they earn on their deposits when interest rates are high. An important effect of the function $\omega(R_t)$ on our results is that it yields a low (high) level of attentive depositors when interest rates have been low (high) for an extended period.

The number of inattentive households who become attentive in period t is:

$$\omega(R_t)a_t i_t + \left[i_t - \omega(R_t)a_t i_t\right]\kappa_i = \omega(R_t)a_t i_t(1-\kappa_i) + i_t\kappa_i,$$

So, the probability that an inattentive household becomes attentive is $\omega(R_t)a_t(1-\kappa_i) + \kappa_i$.

The change in the number of attentive depositors, $a_{t+1} - a_t$ varies with the current level of attentive depositors,

$$\frac{d\left(a_{t+1} - a_t\right)}{da_t} = \omega(R_t)(1-2a_t)(1-\kappa_i) - \left(\kappa_i + \kappa_a\right).$$

The first term represents changes in a_t due to social interactions. This term is positive when $R_t > 1$ is high and $a_t < 0.5$ since, under these conditions, a high number of inattentive households become attentive. The second term is negative for two reasons. First, when a_t is higher, more attentive households become inattentive ($\kappa_a a_t$). Second, when a_t is higher, fewer inattentive become attentive ($\kappa_i(1-a_t)$).

The strength of the social interactions related to R_t is maximal when $a_t = 0.5$. When a_t is low, social interactions aren't very powerful because there aren't many attentive households that can interact with inattentive households.

When a_t is high, social interactions aren't very powerful because there aren't many inattentive households that can be converted into attentive households.

Steady State Suppose the Federal Funds rate is constant and equal to zero ($R = 1$). In this setting, attentive households do not discuss interest rates in their social interactions, and the steady state proportion of attentive households depends only on the exogenous rates at which households change their attention state

$$a = \frac{1}{1 + \kappa_a/\kappa_i}.$$

Suppose instead the Federal Funds rate is constant at a strictly positive level ($R > 1$). Then the steady state level of a is given by the quadratic equation

$$0 = -a\kappa_a + \omega(R)a\,(1-a)\,(1-\kappa_i) + \kappa_i\,(1-a)\,.$$

The positive solution to this equation is

$$a = \frac{\omega(R)(1-\kappa_i) - \kappa_a - \kappa_i + \sqrt{\left[\omega(R)(1-\kappa_i) - \kappa_a - \kappa_i\right]^2 + 4\omega(R)(1-\kappa_i)\kappa_i}}{2\omega(R)(1-\kappa_i)}.$$

A key property of the function $\omega(R_t)$ is that it leads to a low (high) level of attentive depositors when interest rates have been low (high) for an extended period.

5.3 Banking with Social Dynamics

In an economy with social dynamics, the value to a bank of a dollar deposit from an attentive household is

$$V_{a,t} = R_t - R_{at} + \frac{1-\delta}{R_t}\left[\kappa_a V_{i,t+1} + (1-\kappa_a)\,V_{a,t+1}\right].$$

Recall that a fraction δ of deposits leaves the bank, so the continuation value is multiplied by $1-\delta$. This continuation value takes into account the possibility that an attentive household may become inattentive (and hence more valuable to the bank). This switch happens with probability κ_a.

The value to a bank of a dollar deposit from an inattentive consumer is given by

$$V_{i,t} = R_t - R_{it} + \frac{1-\delta}{R_t}\left(\left[\omega(R_t)a_t(1-\kappa_i) + \kappa_i\right]V_{a,t+1} + \left\{1 - \left[\omega(R_t)a_t(1-\kappa_i) + \kappa_i\right]\right\}V_{i,t+1}\right).$$

The continuation value takes into account the probability that an inattentive household becomes a less valuable, attentive household ($\omega(R_t)a_t(1-\kappa_i) + \kappa_i$).

Recall that in equilibrium, equation (6) holds: the investment necessary to attract a dollar of deposits of type j is equal to the probability of succeeding times the value of this deposit to the bank,

$$\tau_j = \mu^{1/(1-\varsigma)}V_{j,t}.$$

Using this result we obtain

$$\frac{\tau_a}{\mu^{1/(1-\varsigma)}} = R_t - R_{at} + \frac{1-\delta}{R_t}\left[\kappa_a \frac{\tau_i}{\mu^{1/(1-\varsigma)}} + (1-\kappa_a)\frac{\tau_a}{\mu^{1/(1-\varsigma)}}\right],$$

and

$$\frac{\tau_i}{\mu^{1/(1-\varsigma)}} = R_t - R_{it} + \frac{1-\delta}{R_t}\left(\left\{[\omega(R_t)a_t(1-\kappa_i)+\kappa_i]\frac{\tau_a}{\mu^{1/(1-\varsigma)}} + \{1-[\omega(R_t)a_t(1-\kappa_i)+\kappa_i]\}\frac{\tau_i}{\mu^{1/(1-\varsigma)}}\right\}\right),$$

The interest rate spread for attentive depositors is:

$$R_t - R_{at} = \frac{\tau_a}{\mu^{1/(1-\varsigma)}} - \frac{1-\delta}{R_t}\left(\kappa_a \frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}} + \frac{\tau_a}{\mu^{1/(1-\varsigma)}}\right).$$

This spread is lower than in a version of the model without social dynamics (see equation (7)). The reason is that attentive depositors are more valuable to the bank because, with probability κ_a, they become inattentive in the future. It follows from the zero profit condition (6) that the current spread must be lower than in a model without social dynamics.

The interest rate spread for inattentive depositors is:

$$R_t - R_{it} = \frac{\tau_i}{\mu^{1/(1-\varsigma)}} - \frac{1-\delta}{R_t}\left\{\frac{\tau_i}{\mu^{1/(1-\varsigma)}} - [\omega(R_t)a_t(1-\kappa_i)+\kappa_i]\frac{\tau_i-\tau_a}{\mu^{1/(1-\varsigma)}}\right\}.$$

This spread is higher than in a model without social dynamics (see equation (8)). The reason is that, with probability $\omega(R_t)a_t(1-\kappa_i)+\kappa_i$, inattentive depositors become attentive in the future, so current spreads must be higher to compensate for the expected future profitability decline. This effect is stronger when the number of attentive households is high because inattentive households are more likely to encounter attentive households and become attentive. The effect is also stronger when interest rates are higher because the conversion rate, $\omega(R_t)$, is higher, i.e., the probability that an inattentive household becomes attentive increases.

Recall that nim_t is given by,

$$nim_t = R_t + \varepsilon^l - (a_t R_{at} + i_t R_{it}).$$

Replacing R_{at} and R_{it} we obtain.

$$\begin{aligned} nim_t \quad = \quad & \varepsilon^l + a_t\left[\frac{\tau_a}{\mu^{1/(1-\varsigma)}} - \frac{1-\delta}{R_t}\left(\kappa_a\frac{\tau_i-\tau_a}{\mu^{1/(1-\varsigma)}} + \frac{\tau_a}{\mu^{1/(1-\varsigma)}}\right)\right] \\ & +(1-a_t)\left(\frac{\tau_i}{\mu^{1/(1-\varsigma)}} - \frac{1-\delta}{R_t}\left\{\frac{\tau_i}{\mu^{1/(1-\varsigma)}} - [\omega(R_t)a_t(1-\kappa_i)+\kappa_i]\frac{\tau_i-\tau_a}{\mu^{1/(1-\varsigma)}}\right\}\right). \end{aligned}$$

We can rewrite nim_t as

$$nim_t = \varepsilon^l + \frac{a_t\tau_a + (1-a_t)\tau_i}{\mu^{1/(1-\varsigma)}}\left(1 - \frac{1-\delta}{R_t}\right) + \frac{1-\delta}{R_t}\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\left(a_{t+1} - a_t\right). \tag{12}$$

The first two terms in this expression equal the value of nim_t in an economy without social interactions. We describe the intuition for those terms after equation (9). The third term captures the impact of social interactions on nim_t. An increase in the number of attentive depositors, $a_{t+1} - a_t$, increases nim_t because the equilibrium spread on inattentive depositors rises to compensate for the higher probability that inattentive depositors will become attentive.

The impact of a change in a_t on nim_t is given by

$$\frac{dnim_t}{da_t} = \frac{\tau_a - \tau_i}{\mu^{1/(1-\varsigma)}}\left(1 - \frac{1-\delta}{R_t}\right) + \frac{1-\delta}{R_t}\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\left(\frac{da_{t+1}}{da_t} - 1\right),$$

where

$$\frac{da_{t+1}}{da_t} = 1 - (\kappa_i + \kappa_a) + \omega(R_t)(1 - 2a_t)(1 - \kappa_i).$$

Combining these two equations, we obtain,

$$\frac{dnim_t}{da_t} = -\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\left(1 - \frac{1-\delta}{R_t}\right) + \frac{1-\delta}{R_t}\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\left[\omega(R_t)(1 - 2a_t)(1 - \kappa_i) - (\kappa_i + \kappa_a)\right].$$

A change in a_t has two effects. The first effect is negative: an increase in a_t lowers the average interest rate spread because the spread on attentive households' deposits is smaller than those from inattentive households. The second effect plays an important role in allowing the model to generate state dependence in nim_t. This effect is positive when $a_t < 0.5$ and R_t is high. In this case, many inattentive households will become attentive. Those conversions imply that inattentive customers will generate lower profits in the future. The zero profit condition implies that current margins must rise to compensate for that effect.

The marginal impact of R_t on nim_t is given by

$$\frac{dnim_t}{dR_t} = \frac{a_t\tau_a + (1-a_t)\tau_i}{\mu^{1/(1-\varsigma)}}(1-\delta)R_t^{-2} - R_t^{-2}(1-\delta)\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\left(a_{t+1} - a_t\right) + \frac{1-\delta}{R_t}\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\frac{da_{t+1}}{dR_t},$$

where

$$\frac{da_{t+1}}{dR_t} = \omega'(R_t)a_t(1-a_t)(1-\kappa_i) = 32\chi(R_t - 1)a_t(1-a_t)(1-\kappa_i).$$

There are three effects to consider. The first effect is positive and stems from the change in the discount rate associated with a rise in R_t. This effect is also present in an economy without social dynamics: a rise in the interest rate reduces the present value of future profits. The zero profit condition implies that current interest rate spreads must rise to offset this impact. The second effect is negative. When interest rates rise, banks discount more heavily the future losses that occur when some inattentive depositors become attentive. The present value of these losses declines when R_t increases. So the spread on inattentive deposits has to increase by less in the present to compensate. That effect decreases nim_t. The third effect is positive. Recall that $\omega(R_t)$ is increasing in R_t. So, higher interest rates raise the rate at which inattentive households become attentive due to social interactions. This effect reduces future profits from inattentive households. The zero profit condition implies that the current interest rate spread on inattentive consumers must rise to compensate for that effect.

Combing the two expressions above, using the law of motion for attentive households and re-arranging yields:

$$\frac{dnim_t}{dR_t} = \frac{(1-\delta)(\tau_i - \tau_a)}{\mu^{1/(1-\varsigma)} R_t^2} \left[\left\{ \frac{\tau_i}{\tau_i - \tau_a} - a_t \right\} + \left\{ (\kappa_i + \kappa_a) a_t - \kappa_i \right\} + \left\{ 16\chi(1-\kappa_i)(R_t - 1)(R_t + 1) a_t (1 - a_t) \right\} \right].$$

The term in the first braces denotes the effect of a rise in R_t when there are no social dynamics. The terms in the second and third braces denote the exogenous and endogenous social dynamics effect, respectively.

Model estimation We partition the parameters of our model into two sets. The first set consists of parameters chosen a priori. The second set is estimated using Bayesian methods. The parameters that are set a priori are listed in Table 2.

Table 2: Parameter values set a priori

Parameter	Parameter value	Description
ϵ_l	0.0075	Cost per dollar of making loans
R_L	1.014	Gross annual interest rate, low interest rate state
R_H	1.056	Gross annual interest rate, high interest rate state

We set $\epsilon_l = 0.0075$ so that the model is consistent with the average annual core NIM over our sample period, four percent. We set $R_L = 1.014$ in the low interest rate steady state and $R_H = 1.056$ in the high interest rate steady state. These values correspond to the average values of the Federal Funds rate below and above the four percent threshold, respectively. We assume that social dynamics take place multiple times per day. The total number of interactions per quarter is 200. Economic interactions occur at the end of the quarter.

We estimate the following parameters: χ,κ_a,κ_i,δ,$\tau_a/\mu^{\frac{1}{1-\varsigma}}$,$\tau_i/\mu^{\frac{1}{1-\varsigma}}$. In the equilibrium equations, the parameters τ_a, τ_i, μ, and ς only appear as the ratios $\tau_a/\mu^{\frac{1}{1-\varsigma}}$, $\tau_i/\mu^{\frac{1}{1-\varsigma}}$, which is why we estimate those ratios rather than the individual parameters.

We assume the economy begins in either the low or high nominal interest rate state. Conditional on that choice, we feed in sequences for the nominal interest rate, R_t, corresponding to the Choleski-based impulse response functions of the policy rate from Section 4.

The vector ψ denotes the point estimates of the impulse responses of nim_t in the high and low interest rate state discussed in Section 4. Our estimation procedure uses the first 12 quarters of the empirical impulse responses of nim_t. We denote our empirical estimates of ψ by the 24x1 vector $\hat{\psi}$.

The estimation procedure is the same as in Christiano et al. [2010]. To explain this procedure, suppose that the structural model is true. Denote the true values of the model parameters by θ_0. Let $\psi(\theta)$ denote the mapping from values of the model parameters to the model-based impulse responses of NIM in the high and low interest rate states. Classical asymptotic sampling theory implies that when the number of observations, T, is large,

$$\sqrt{T}\left(\hat{\psi}-\psi\left(\theta_0\right)\right) \overset{a}{\sim} N\left(0, W\left(\theta_0\right)\right).$$

It is convenient to express the asymptotic distribution of $\hat{\psi}$ as

$$\hat{\psi} \overset{a}{\sim} N\left(\psi\left(\theta_0\right), V\right). \tag{13}$$

Here, V is a consistent estimate of the precision matrix $W\left(\theta_0\right)/T$. FollowingChristiano et al. [2010], we assume V is a diagonal matrix. In our case, the diagonal elements of that matrix are the estimated variances of the impulse responses of nim_t in the high- and low-interest-rate states.

We specify priors for θ and then compute the posterior distribution for θ given $\hat{\psi}$ using Bayes' rule. This computation requires the likelihood of $\hat{\psi}$ given θ. Our asymptotically valid approximation of this likelihood is implied by (13):

$$f\left(\hat{\psi}|\theta, V\right)=(2\pi)^{-\frac{N}{2}}|V|^{-\frac{1}{2}}\exp\left[-0.5\left(\hat{\psi}-\psi(\theta)\right)' V^{-1}\left(\hat{\psi}-\psi(\theta)\right)\right]. \tag{14}$$

The value of θ that maximizes this function is an approximate maximum likelihood estimator of θ. It is approximate for two reasons. First, the central limit theorem underlying (13) only holds exactly as $T\to\infty$. Second, our proxy for V is guaranteed to be correct only for $T\to\infty$.

The Bayesian posterior of θ conditional on $\hat{\psi}$ and V is:

$$f\left(\theta|\hat{\psi}, V\right)=\frac{f\left(\hat{\psi}|\theta, V\right)p(\theta)}{f\left(\hat{\psi}|V\right)}. \tag{15}$$

In practice, we impose an additional constraint, also known as an endogenous prior: when estimating the model, we only consider parameter values θ such that (i) the spreads $R_t-R_{i,t}$, $R_t-R_{a,t}$ are always non-negative; (ii) $R_{i,t}$ and $R_{a,t}$ in the high interest rate state are higher than in the low interest rate state; and (iii) $\tau_i>\tau_a$.

The function $p(\theta)$ denotes the prior distribution of θ, and $f\left(\hat{\psi}|V\right)$ denotes the marginal density of $\hat{\psi}$:

$$f\left(\hat{\psi}|V\right)=\int f\left(\hat{\psi}|\theta, V\right)p(\theta)\,d\theta.$$

Because the denominator is not a function of θ, we can compute the mode of the posterior distribution of θ by maximizing the value of the numerator in (15). We compute the posterior distribution of the parameters using a standard Monte Carlo Markov chain (MCMC) algorithm.

We assume uniform priors $U(0,100)$ for $\tau_a/\mu^{\frac{1}{1-\varsigma}}$ and $\tau_i/\mu^{\frac{1}{1-\varsigma}}$ and $U(0,1)$ priors for κ_a,κ_i and δ. We assume a gamma prior for χ with shape parameters (2,1).[9]

[9] We encountered numerical problems when we worked with a uniform prior for χ. The gamma distribution allows for dispersed priors (see Figure 11) while avoiding numerical problems by placing low probability on extreme values of χ.

Figure 11 depicts the prior and posterior distributions for the estimated parameters. The black dashed and blue solid lines correspond to the prior and posterior distributions. The vertical dotted lines depict the joint posterior modes of the parameters. The data are very informative about model parameters. Table 3 reports the mean and 95 percent probability intervals for the priors and posterior distributions of the estimated parameters.

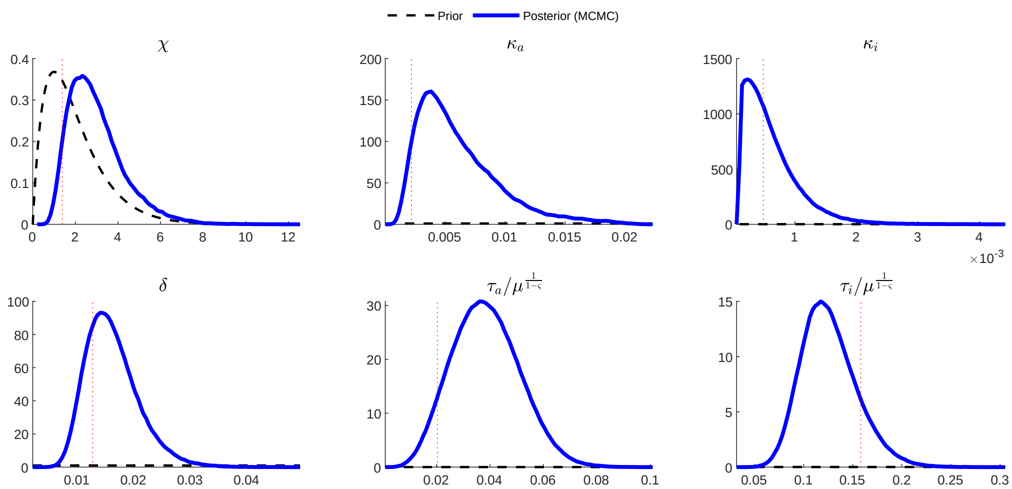


Figure 11: Priors and Posteriors of Estimated Parameters.

Table 3: Priors and Posteriors of Parameters.

Parameter	Prior Distribution	Posterior Distribution
	D, Mean, [2.5-97.5%]	Mode, [2.5-97.5%]
Social dynamics interaction parameter, χ	G, 2.0, [0.051 7.37]	1.3880, [0.947 5.619]
Rate at which attentive become inattentive, κ_a	U, 0.5, [0.025 0.975]	0.0022, [0.001 0.013]
Rate at which inattentive become attentive, κ_i	U, 0.5, [0.025 0.975]	0.0005, [0.000 0.015]
Fraction of depositors who leave banks, δ	U, 0.5, [0.025 0.975]	0.0127, [0.008 0.026]
Cost of attracting attentive depositors, $\tau_a/\mu^{\frac{1}{1-\varsigma}}$	U, 50 , [2.5 97.5]	0.0197, [0.015 0.063]
Cost of attracting inattentive depositors, $\tau_i/\mu^{\frac{1}{1-\varsigma}}$	U, 50 , [2.5 97.5]	0.1602, [0.075 0.183]

Notes: The posterior mode and parameter distributions are based on a standard MCMC algorithm with 10.5 million draws (3 chains, about 15 percent of draws used for burn-in, draw acceptance rates about 0.2). U denotes the prior for the uniform distribution for which the mean is reported instead of the mode. G denotes the Gamma (2,1) distribution.

Our estimated parameters imply that deposits are sticky: only 1.27 percent leave banks per period. As emphasized by Drechsler, Savov, and Schnabl [2017, 2018, 2021] and others, the stickiness of deposits is a key determinant of banks' franchise values.

To illustrate the properties of the estimated model, we compute the equilibrium response of nim_t to a temporary increase in the policy rate with parameter values set to their posterior modes. The economy is initially in the steady state corresponding to either the low or the high interest rate. We consider the dynamic response of nim_t to a temporary rise in interest rates.

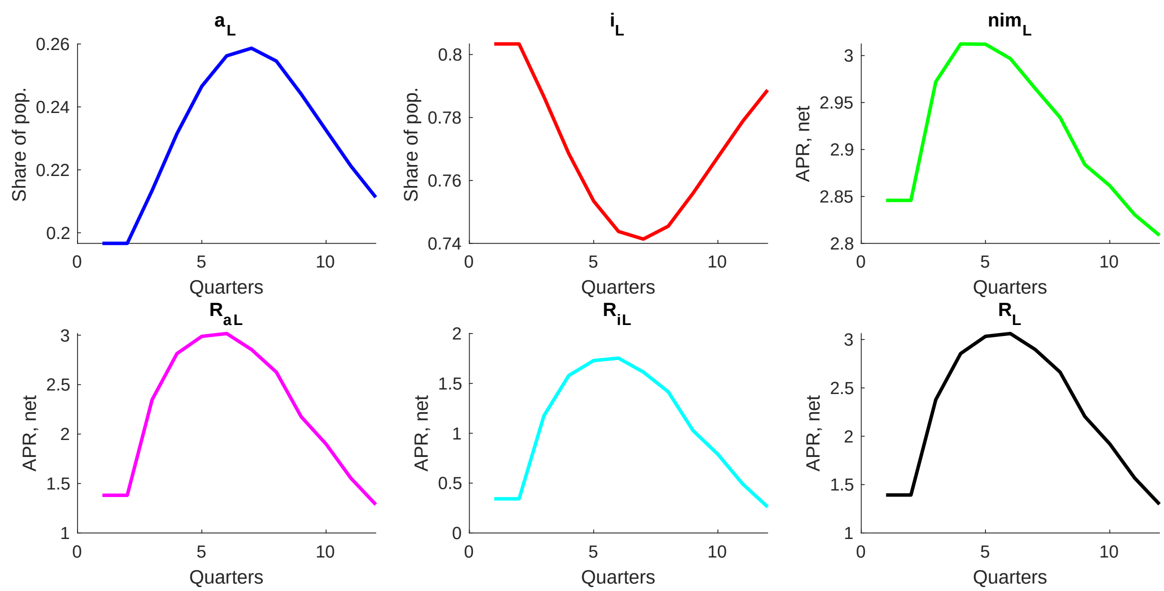
Our estimated parameter values imply that the fraction of attentive depositors in the low-interest-rate steady state is low (about 20 percent). In this scenario, inattentive depositors are unlikely to transition to being attentive in the future. So banks do not need to charge them higher spreads in the present to break even. In equilibrium, the interest rate spread for inattentive depositors is low.

In contrast, in the steady state with $R = 1.056$, the fraction of attentive depositors is high (about 55 percent). In this scenario, inattentive depositors are less valuable because the strong social dynamics make it likely that inattentive depositors will interact with attentive depositors and become attentive. In equilibrium, this effect results in a higher interest rate spread for inattentive depositors. Because inattentive depositors are more likely to become attentive in the future, banks have to charge them higher spreads in the present to break even.

The interest rate shocks are the first nine elements of the estimated impulse response function of the Federal Funds rate to a 100 basis points policy shock (see Figure 1).

Figures 12 and 13 illustrate the responses of various aggregates to a rise in R, starting from the low and high interest rates, respectively.

Figure 12: Dynamic response to monetary policy shock in low-interest-rate state.



Consider first the responses when the initial interest rate is low. In this case, the number of attentive households is small, and social dynamics play a limited role. When interest rates rise, the present value effect dominates, causing nim_t to rise. In contrast, when the initial interest rate is high, the present value effect is weaker and the social dynamics effect is more pronounced, leading to a decline in nim_t.

Figure 13: Dynamic response to monetary policy shock in high-interest-rate state.

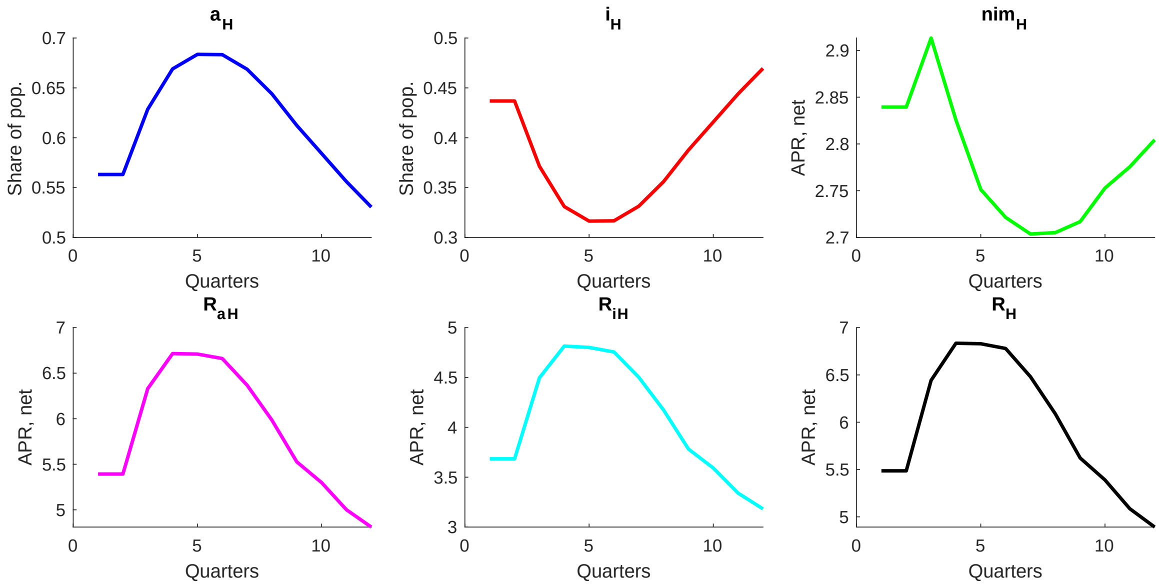
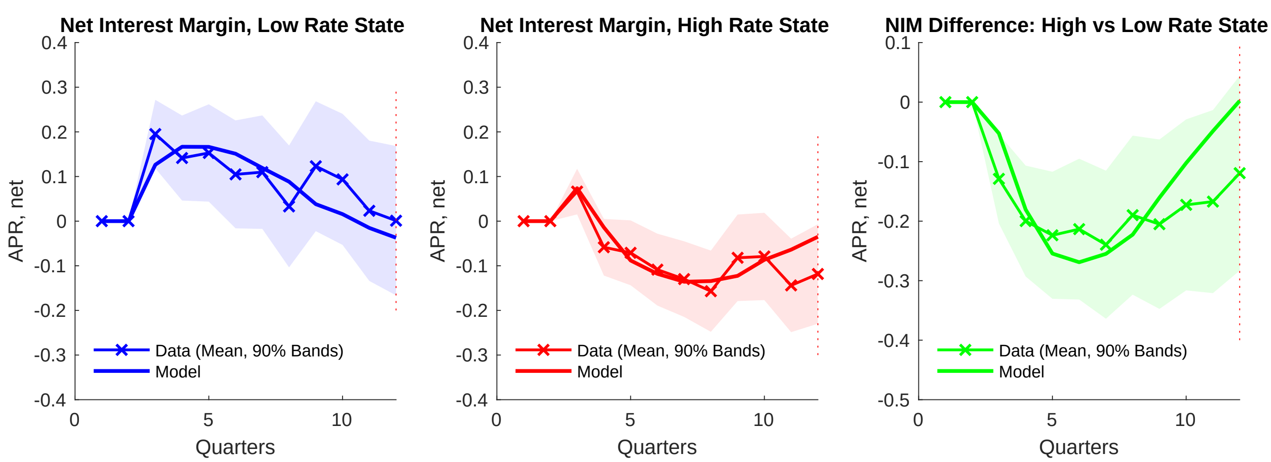


Figure 14 shows the responses of nim_t in the high and low interest rate states and the differences between those responses when we evaluate the model at the estimated posterior mode parameters. The figure compares the model-based responses with their empirical counterparts, which are derived using the recursive monetary policy shock measure. The key finding is that the model does a good job of accounting for the empirical responses. Indeed, taking sampling uncertainty into account, the null hypothesis that the response functions are identical cannot be rejected.

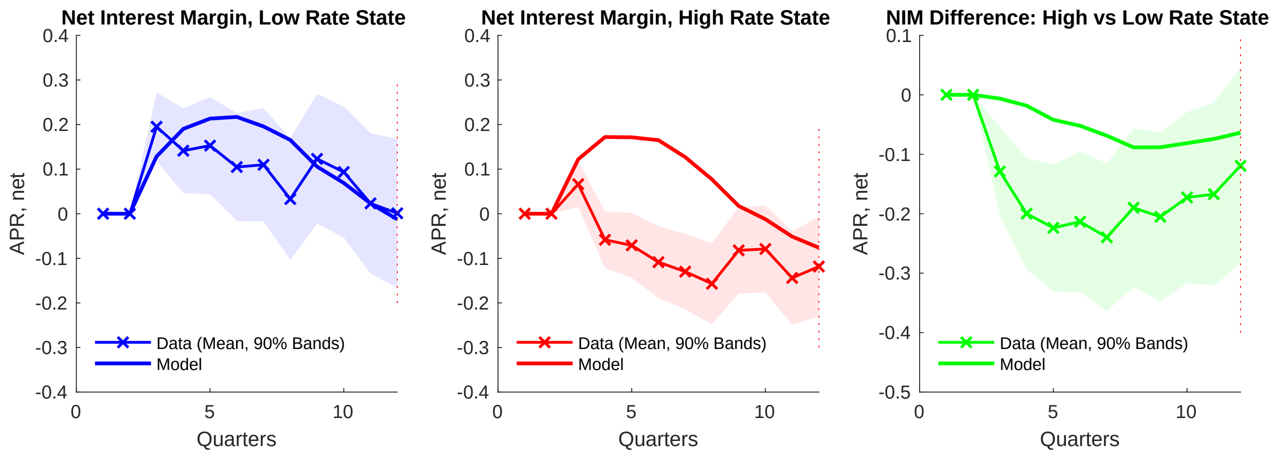
Figure 14: Dynamic response to monetary policy shock: NIM



Note: This figure compares the theoretical impulse response functions from the estimated partial equilibrium banking model with their empirical counterparts discussed in Section 3. Solid lines represent the model-generated IRFs, while solid lines with "x" markers indicate the corresponding empirical IRFs. The shaded areas denote the 90 percent confidence intervals for the empirical IRFs.

Figure 15 shows the responses of nim_t in the high and low interest rate states as well as the differences between these responses when the model is evaluated using the estimated posterior mode parameters, except for χ which we set to zero. This counterfactual simulation isolates the importance of endogenous social dynamics for the response of nim_t to a monetary policy shock. Without endogenous social dynamics, the model fails to replicate the empirical responses, primarily because it cannot generate the observed decline in nim_t following a monetary policy shock in the high interest rate state.

Figure 15: Counterfactual simulation: NIM response to monetary policy shock without endogenous social dynamics ($\chi = 0$).



Note: This figure compares the theoretical impulse response functions generated from the estimated partial equilibrium banking model without endogenous social interactions ($\chi = 0$), to their empirical counterparts discussed in Section 3. Solid lines represent the model IRFs, while solid lines with "x" markers indicate the corresponding empirical IRFs. The shaded areas denote the 90 percent confidence intervals for the empirical IRFs.

6 Banking in a General Equilibrium Model

This section describes a general equilibrium model that incorporates our banking model. The model captures the interaction between the state-dependent passthrough of policy rate changes to deposit rates and the presence of households with a high MPC out of liquid wealth. This interaction generates state dependence in the transmission of monetary policy to aggregate economic activity.

In reality, many types of households have a high MPC out of liquid wealth. For example, many retirees rely heavily on income from bonds. Other examples include wealthy hand-to-mouth consumers of the sort emphasized by e.g. Kaplan et al. [2018] and low-income households who often face binding borrowing constraints (see, for example, Bilbiie [2021], Auclert et al. [forthcoming], and Debortoli and Galí [2024] as well as the references therein).

Incorporating all of the sources of heterogeneity emphasized in the literature is beyond the scope of this paper. Instead, we focus on a parsimonious model that highlights the interactions between the state-dependent passthrough of bank deposit rates to changes in the Federal Funds rate and the presence of households with a high MPC out of liquid wealth. We assume that borrowing constraints are not binding for one group of households, referred to as permanent income (PI) consumers. Another group of households consists of hand-to-mouth (HTM) consumers. To simplify, we assume PI households are always attentive, while HTM households transition between attentive and inattentive states based on the social dynamics outlined in the partial equilibrium model.

Importantly, given our timing conventions, households earn interest on their wages, allowing them to increase consumption when deposit rates rise. This effect is particularly significant for hand-to-mouth households. Firms finance their wage and capital rental payments by borrowing from banks at the beginning of the period. Households supply labor and deposit wage payments in banks at the beginning of the period. Capital owners also deposit their rents in banks at the beginning of the period. So, all households can increase consumption when deposit interest rates rise. In other dimensions, the model is a simple variant of the DSGE model discussed in Christiano, Eichenbaum, and Evans [2005].

In subsection 5.1, we describe the households, firms, and banks in the economy and define the equilibrium. Subsection 5.2 describes our choices of parameters and the properties of the model. Subsection 5.3 presents our main results. Finally, subsection 5.4 explores the sensitivity of our results to allowing for sticky wages and prices.

6.1 Model Description

We model the production sector of the economy as in Christiano et al. [2005].

Final good producers A representative, perfectly competitive firm produces a final homogeneous good, Y_t, using the technology:

$$Y_t = \left(\int_0^1 Y_{jt}^{\frac{1}{\gamma}} dj \right)^{\gamma}, \gamma > 1. \tag{16}$$

The variable Y_{jt} denotes the quantity of intermediate input j used by the firm.

Profit maximization implies the following demand schedule for intermediate products:

$$Y_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\frac{\gamma}{\gamma-1}} Y_t. \tag{17}$$

Here, P_{jt} denotes the price of intermediate input j in units of the final good.

The price of output is given by:

$$P_t = \left(\int_0^1 P_{jt}^{-\frac{1}{\gamma-1}} dj \right)^{-(\gamma-1)}.$$

The final good, Y_t, can be used to produce either consumption goods or investment goods.

Intermediate goods producers Intermediate good j is produced by a monopolist using labor, N_{jt}, and capital services, K_{jt}, according to the production function:

$$Y_{jt} = (K_{jt})^{\alpha} N_{jt}^{1-\alpha}. \tag{18}$$

Here, K_{jt} and N_{jt} denote the total amount of capital services and hours worked purchased by firm i, respectively. The intermediate goods firm is a monopolist in the product market and is competitive in factor markets. As in Christiano et al. [2005], we assume that to produce in period t the retailer must borrow the nominal wage bill, $W_t N_{jt}$

plus the nominal capital service bill, $R_t^k K_{jt}$ from banks at the beginning of the period. These loans are provided at the gross interest rate R_t^l. The retailer repays the loan at the end of period t after receiving sales revenues.

The firm's real marginal cost is $s_{jt} = \partial S_{jt}/\partial Y_{jt}$ where $S_{jt} = min_{K_{jt},N_{jt}} R_t^l [r_t^k K_{jt} + w_t N_{jt}]$ and Y_{jt} is given by (18). Given our assumptions, the real marginal cost for firm j is

$$s_{jt} = \frac{R_t^l \left(r_t^k\right)^\alpha w_t^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha}}.$$

The profits of intermediate-good producer j at time t are:

$$\pi_{jt} = P_{jt} Y_{jt} - P_t s_{jt} Y_{jt}.$$

The j^{th} retailer sets its price, P_{jt} subject to the demand curve, (17) (2.4), and the following Calvo sticky-price friction:

$$P_{jt} = \begin{cases} \Pi^\iota P_{j,t-1} & \text{with probability 1-}\xi, \\ \widetilde{P}_t & \text{with probability } \xi. \end{cases} \tag{19}$$

When $\iota = 1$, prices are indexed to steady state inflation and, as a result, there is no price dispersion in the steady state. When $\iota = 0$ there is no indexation so there is price dispersion in the steady state.

Here, $\widetilde{P}_t$ denotes the price set by the fraction $1 - \xi$ of producers who can re-optimize at time t. Our notation reflects the well-known result that, in models like ours, all firms that can re-optimize their price at time t choose the same price. We assume these producers make their price decision before observing the monetary policy shock realized during the current period.

All of the intermediate good firms are owned by the representative 'permanent income' household. We denote the time $t+k$ value of a dollar of dividend that these households receive by v_{t+k}. The firm chooses its optimal time-t price, $\tilde{P}_t$, to maximize:

$$\max_{\tilde{P}_t} E_t \sum_{k=0}^{\infty} (\xi\beta)^k \lambda_{t+k}^b \left(\tilde{P}_t Y_{j,t+k} - P_{t+k} s_{j,t+k} Y_{j,t+k}\right),$$

subject to the demand curve (17). We describe the first-order conditions for optimal price setting in the Appendix. [10]

Wage determination Christiano et al. [2016] show that estimated versions of three models of wage determination produce nearly identical implications for macroeconomic aggregates: the search and matching matching model of labor in Hall and Milgrom [2008],the Calvo-style sticky wage model by Erceg et al. [2000] , and a reduced-form specification of real wages incorporating inertia. Following Christiano et al. [2016], we adopt the following simple real wage rule:

$$ln\left(\frac{w_t}{w}\right) = \vartheta_1 ln\left(\frac{w_{t-1}}{w}\right) + \vartheta_2 ln\left(\frac{N_t}{N}\right).$$

[10] The variable v_{t+j} is the Lagrange multiplier of the household problem associated with the nominal budget constraint.

The nominal wage is given by

$$W_t = w_t P_t.$$

Employment is demand determined and the three types of households vary their work in proportion to their steady state values in order to satisfy labor demand. For now, we assume that $\vartheta = 0.99$. We compute steady state values using a version of the model with flexible wages and prices.

Labor demand equals labor supply,

$$N_t = \phi N_t^P + a_t^H N_{a,t}^H + i_t^H N_{i,t}^H.$$

We assume that labor is distributed among households according to allocation rules that ensure the total labor supply matches the total labor demand,

$$N_{a,t}^H = \frac{N_a^H}{N} N_t,$$

$$N_{i,t}^H = \frac{N_i^H}{N} N_t.$$

Given the labor allocation rules for attentive and inattentive hand-to-mouth households, combined with the definition of aggregate labor provided above yields an implicit rule for the allocation of labor for PIH households.

Households The population consists of two types of households, each comprising a continuum of identical members. A fraction ϕ of the economy is made up of hand-to-mouth households, while the remaining fraction $(1-\phi)$ consists of permanent income households.

Hand-to-mouth households

The index j indicates whether a household is inattentive or attentive. The superscript H denotes a variable specific to hand-to-mouth households. Households of type $j = \{i, a\}$ maximize

$$E_t \sum_{l=0}^{\infty} \beta^t \left\{ \ln(C_{j,t+l}^H - bC_{j,t+l-1}^H) - \psi \frac{(N_{j,t+l}^H)^{1+\eta}}{1+\eta} \right\},$$

subject to the budget constraint

$$P_t C_{jt}^H = \left(W_t N_{jt}^H - D_{jt}^H\right) + D_{jt}^H R_{jt},$$

where D_{jt}^H are deposits of hand-to-mouth households type j. These deposits cannot exceed the funds that the households receive at the beginning of the period

$$D_{jt}^H \leq W_t N_{jt}^H. \tag{20}$$

Firms deposit the household wages, $W_t N_{jt}^H$ at the beginning of the period. Households consume at the end of the period so there is no opportunity cost associated with depositing the funds received in the beginning of the period. Given that $R_{jt} \geq 1$, the constraint (20) holds with equality. We can write the resulting resource constraint as,

$$P_t C_{jt}^H = R_{jt} W_t N_{jt}^H.$$

As discussed below, nominal wages are initially at their steady state and then adjust gradually in response to monetary policy shocks. With employment determined by demand and the budget constraint binding, the preferences of hand-to-mouth households are irrelevant. In other words, hand-to-mouth households consume all their income and make no intertemporal consumption choices.

Hand-to-mouth households play an important role in our model because they amplify the impact of changes in interest rates on consumption and aggregate activity. This impact is much smaller in an economy populated by permanent income households like the ones we describe below.

Permanent income households

The representative permanent income households owns the firms in the economy and the stock of capital. In each period, the household decides how much to consume, how much physical capital to accumulate, how many units of capital services to supply, and how much cash to deposit with a bank. For simplicity, we assume that all of these households are attentive. Our results are not very sensitive to this assumption. Permanent income households smooth their consumption over time, so changes in their interest income have a small impact on current consumption.

Permanent income households maximizes their lifetime utility:

$$U_t = E_t \sum_{l=0}^{\infty} \beta^t \left\{ \ln(C_{t+l}^P - bC_{t+l-1}^P) - \psi \frac{(N_{t+l}^P)^{1+\eta}}{1+\eta} \right\}, \tag{21}$$

subject to the budget constraint:

$$P_t \left(C_t^P + I_t \right) + B_{t+1} - R_{t-1} B_t + \Psi_t = \left(W_t N_t^P + R_t^K u_t \bar{K}_t - D_t^P \right) + D_t^P R_{a,t} + \int_0^1 \pi_{jt} dj + \pi_t^b, \tag{22}$$

where D_t^P are deposits that PIH households make at the start of the period. These deposits cannot exceed the funds that the household receives at the beginning of the period

$$D_t^P \leq W_t N_t^P + R_t^K u_t \bar{K}_t. \tag{23}$$

Since households consume at the end of the period, the opportunity cost of holding bank deposits is zero. Households seek to maximize the value of D_t^P, so equation 23 is binding. We can write the resulting resource constraint as

$$P_t \left(C_t^P + I_t \right) + B_{t+1} - R_{t-1} B_t + \Psi_t = R_{at} \left(W_t N_t^P + R_t^K u_t \bar{K}_t \right) + \int_0^1 \pi_{jt} dj + \pi_t^b,$$

The variable $\bar{K}_t$ the beginning of period physical capital stock, Ψ_t denotes nominal lump-sum taxes, $\int_0^1 \pi_{jt} dj$ are the nominal profits from monopolistically competitive firms, and π_t^b are total banking profits. The variable I_t denotes household capital investment. The variable u_t denotes the utilization rate of capital, which we assume is set by the household. Capital services, K_t, depends on the physical stock of capital and the rate of capital utilization according to $K_t = u_t \bar{K}_t$ so that $R_t^K u_t \bar{K}_t$ represents the household's earnings from supplying capital services.

The timing of asset investments is as follows. At the beginning of the period, households receive wage payments and rental income from firms, which they can deposit into bank accounts. These accounts earn an interest rate R_{at} within the period. By the end of the period the proceeds from these deposits become available for consumption, investment in capital, or investment in bonds that yield an interest rate R_t.

The capital rate of depreciation depends on the rate of utilization, u_t, according to the following equation

$$\Delta(u_t) = \sigma_0 + \sigma_1(u_t - 1) + \frac{\sigma_2}{2}(u_t - 1)^2.$$

We choose values for the parameters σ_1 and σ_2 so that u_t is equal to one in the steady state.

The law of motion for the stock of physical capital owned by the permanent income household is:

$$\bar{K}_{t+1} = [1 - \Delta(u_t)]\,\bar{K}_t + F(I_t, I_{t-1}). \tag{24}$$

The function F(.) summarizes the technology that transforms current and past investments into installed capital for use in the following period. As in Christiano et al. [2005] this function is given by[11]

$$F(I_t, I_{t-1}) = \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t,$$

where

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{s_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2.$$

Timing It is useful to specify the timing of transactions. At the beginning of each period, firms borrow from banks to cover their wage bill and capital rental costs. Banks issue checks to the firms, which are then used to pay households. Households deposit these funds back into the banks. By the end of the period, banks recover the loans extended to firms, along with interest at a rate of $R^l - 1$. Banks then pay households their deposits, plus interest calculated at rates $R_{at} - 1$ and $R_{it} - 1$ for attentive and inattentive depositors, respectively.

Social dynamics To simplify, we assume that PIH households are always attentive.[12] Only HTM households change between attentive and inattentive states. The total number of attentive, a_t, are given by,

$$a_t = a_t^H + \phi,$$

where a_t^h are the number of attentive HTM households. There are i_t^h households who are inattentive, all of whom are hand to mouth.

[11] See Eberly et al. [2012] for empirical evidence in favor of this investment adjustment cost specification.

[12] Allowing the PIH to switch between attention states complicates the model while generating small quantitative effects. The reason is that the changes in consumption resulting from shifts in attention states are the annuitized value of the difference in deposit interest income between attentive and inattentive depositors.

$$a_t^H + i_t^H + \phi = 1,$$

$$a_{t+1} = \phi + a_t^H(1-\kappa_a) + \omega(R_t)(\phi + a_t^H)i_t^H(1-\kappa_i) + \kappa_i i_t^H, \tag{25}$$

$$a_t = a_t^H + \phi.$$

So

$$a_{t+1}^H = a_t^H(1-\kappa_a) + \omega(R_t)(\phi + a_t^H)i_t^H(1-\kappa_i) + \kappa_i i_t^H. \tag{26}$$

Also

$$i_{t+1}^H = 0 + i_t^H(1-\kappa_i) - \omega(R_t)(\phi + a_t^H)i_t^H(1-\kappa_i) + \kappa_a a_t^H. \tag{27}$$

We can rewrite as

$$a_{t+1}^H = a_t^H(1-\kappa_a) + \omega(R_t)(\phi + a_t^H)(1-\phi-a_t^H)(1-\kappa_i) + \kappa_i(1-\phi-a_t^H). \tag{28}$$

The number of attentive depositors that become inattentive is $\kappa_a a_t^H$. The probability that an attentive depositor becomes inattentive is:

$$\kappa_a \frac{a_t^H}{\phi + a_t^H}.$$

The number of inattentive depositors who become attentive,

$$\omega(R_t)(\phi + a_t^H)i_t^H(1-\kappa_i) + \kappa_i i_t^H.$$

Probability that an inattentive depositor becomes attentive,

$$\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i.$$

Banking The nominal value to a bank of a deposit from an attentive household that represents one unit of output (i.e. P_t dollars) is

$$V_{at} = P_t\left(R_t - R_{at}\right) + E_t \frac{1-\delta}{R_t}\left[\kappa_a \upsilon_t V_{i,t+1} + \left(1-\kappa_a \upsilon_t\right) V_{a,t+1}\right],$$

where

$$\upsilon_t = \frac{a_t^H D_{at}^H}{\phi D_t^p + a_t^H D_{at}^H}.$$

The probability of a dollar of deposits becomes inattentive is lower when there are PIH households ($\phi > 0$) because these households never become inattentive. The probability υ_t takes this composition effect into account.

The term $E_t (1-\delta)/R_t$ embodies the idea that banks are owned by PIH households and future proceeds are discounted at the nominal interest rate. Using the PIH household Euler equation to substitute out for R_t yields a standard stochastic discount factor in the expression above.

The nominal value to a bank of a deposit from an inattentive household that represents one unit of output (i.e, P_t dollars) is

$$V_{it} = P_t (R_t - R_{it}) + E_t \frac{1-\delta}{R_t} \left(\left[\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i \right] V_{a,t+1} + \left\{ 1 - \left[\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i \right] \right\} V_{i,t+1} \right),$$

since all inattentive deposits are from hand-to-mouth households there are no composition effects.

The free entry conditions are

$$\tau_a = \mu^{1/(1-\varsigma)} \frac{V_{at}}{P_t},$$

$$\tau_i = \mu^{1/(1-\varsigma)} \frac{V_{it}}{P_t},$$

where τ_a and τ_i are the real cost of attracting attentive and inattentive depositors.

Using this result we obtain

$$\frac{\tau_a}{\mu^{1/(1-\varsigma)}} = R_t - R_{at} + E_t \frac{1-\delta}{R_t/\Pi_{t+1}} \left[\kappa_a \upsilon_t \frac{\tau_i}{\mu^{1/(1-\varsigma)}} + (1 - \kappa_a \upsilon_t) \frac{\tau_a}{\mu^{1/(1-\varsigma)}} \right],$$

and

$$\frac{\tau_i}{\mu^{1/(1-\varsigma)}} = R_t - R_{it} + E_t \frac{1-\delta}{R_t/\Pi_{t+1}} \left(\left\{ \left[\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i \right] \frac{\tau_a}{\mu^{1/(1-\varsigma)}} + \left\{ 1 - \left[\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i \right] \right\} \frac{\tau_i}{\mu^{1/(1-\varsigma)}} \right\} \right).$$

The interest rate spread for attentive depositors is:

$$R_t - R_{at} = \frac{\tau_a}{\mu^{1/(1-\varsigma)}} - E_t \frac{1-\delta}{R_t/\Pi_{t+1}} \left[\frac{\tau_a}{\mu^{1/(1-\varsigma)}} + \kappa_a \upsilon_t \frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}} \right].$$

The interest rate spread for inattentive depositors is:

$$R_t - R_{it} = \frac{\tau_i}{\mu^{1/(1-\varsigma)}} - E_t \frac{1-\delta}{R_t/\Pi_{t+1}} \left(\left\{ \frac{\tau_i}{\mu^{1/(1-\varsigma)}} - \left[\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i \right] \frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}} \right\} \right).$$

Banks's net interest income is given by,

$$\left(R_t + \varepsilon^l \right) \left(\phi D_t^p + a_t^H D_{at}^H + i_t^H D_{it}^H \right) - \left[\left(\phi D_t^p + a_t^H D_{at}^H \right) R_{at} + i_t^H D_{i,t}^H R_{it} \right].$$

To compute nim_t we divide this expression by total assets, $\phi D_t^p + a_t^H D_{a,t}^H + i_t^H D_{i,t}^H$, to obtain,

$$nim_t = \varepsilon^l + \frac{\phi D_t^p + a_t^H D_{at}^H}{\phi D_t^p + a_t^H D_{at}^H + i_t^H D_{it}^H}\left(R_t - R_{at}\right) + \frac{i_t^H D_{it}^H}{\phi D_t^p + a_t^H D_{at}^H + i_t^H D_{it}^H}(R_t - R_{it}).$$

In equilibrium,

$$v_{at} = \frac{\delta}{\mu^{1/(1-\varsigma)}}\left(\phi D_t^p + a_t^H D_{at}^H\right),$$

$$v_{it} = \frac{\delta}{\mu^{1/(1-\varsigma)}}\left(i_t^H D_{it}^H\right).$$

Nominal banking profits are,

$$\begin{aligned}\pi_t^b &= \left(R_t + \varepsilon^l\right)\left(\phi D_t^p + a_t^H D_{at}^H + i_t^H D_{it}^H\right) - \left[\left(\phi D_t^p + a_t^H D_{at}^H\right) R_{at} + i_t^H D_{it}^H R_{it}\right] \\ &\quad -\varepsilon^l\left(\phi D_t^p + a_t^H D_{at}^H + i_t^H D_{it}^H\right) - \delta\left[\frac{\tau_a}{\mu^{1/(1-\varsigma)}}\left(\phi D_t^p + a_t^H D_{at}^H\right) + \frac{\tau_i}{\mu^{1/(1-\varsigma)}} i_t^H D_{it}^H\right].\end{aligned}$$

The first term represents lending revenue, the second term is interest paid by banks on deposits, the third term are the operational costs associated with lending, and the final term are the costs on deposit acquisition.

Re-arranging this expression we obtain,

$$\pi_t^b = \left(\phi D_t^p + a_t^H D_{at}^H\right)\left(R_t - R_{at} - \delta\frac{\tau_a}{\mu^{1/(1-\varsigma)}}\right) + i_t^H D_{it}^H\left(R_t - R_{it} - \delta\frac{\tau_i}{\mu^{1/(1-\varsigma)}}\right).$$

Monetary policy The monetary authority controls the nominal interest rate, R_t. In normal times it chooses R_t according to a Taylor-type rule:

$$\ln(R_t) = \rho\ln(R_{t-1}) + (1-\rho)\ln(R) + (1-\rho)\left[\theta_\pi ln\left(\frac{\Pi_t}{\bar{\Pi}}\right) + \theta_y ln\left(\frac{GDP_t}{GDP}\right)\right] + \varepsilon_t, \tag{29}$$

where ε_t is an iid shock with zero mean and standard deviation σ^r, $\theta_\pi > 1$ and $\theta_y \geqq 0$. The variables $\bar{\Pi}$, and R are the target level of inflation and the corresponding steady-state value of the nominal interest rate, respectively. The parameter ρ controls the degree of persistence in the policy rate. GDP_t is given by

$$GDP_t = C_t + I_t + G_t.$$

Fiscal policy Real government spending, G, is constant over time. Nominal government spending is financed with nominal lump-sum taxes, Ψ. To simplify, we assume that only PIH households pay taxes.

Aggregate resource constraint The aggregate resource constraint is given by:

$$Y_t = C_t + I_t + G_t + \tilde{v}_{at}\tau_a + \tilde{v}_{it}\tau_i + \varepsilon^l\left(w_t N_t + r_t^K u_t \bar{K}_t\right),$$

where $\tilde{v}_{at}\tau_a$ and $\tilde{v}_{it}\tau_i$ are the real costs incurred by banks to attract attentive and inattentive depositors, respectively. The term $\varepsilon^l\left(w_t N_t + r_t^K u_t \bar{K}_t\right)$ represents the resource costs incurred by banks when making loans.

6.2 Model Estimation

We estimate several of the general equilibrium parameters. To do so, we proceed as follows. We partition the parameters of our model into two sets. The first set consists of parameters chosen a priori. With one exception, the second set is estimated using the Bayesian procedure applied to the partial equilibrium model.[13]

The parameters that are set a priori are listed in Table 4.

Table 4: Parameter values set a priori

Parameter	Parameter value	Description
ϵ_l	0.0075	Cost per dollar of making loans
R_L	1.014	Gross annual nominal interest rate, low nominal interest rate state
R_H	1.056	Gross annual nominal interest rate, high nominal interest rate state
r	1.014	Gross annual real interest rate, low and high nominal interest rate states
β	$1/r$	Discount factor
κ_i	5.4410×10^{-4}	Rate at which inattentive become attentive
ξ	0.95	Price stickiness parameter
γ	1.1	Gross steady state price markup
σ_0	0.025	Depreciation function parameter
σ_1	0.0285	Depreciation function parameter
σ_2	0.001	Depreciation function parameter
α	$1/3$	Capital share in production
η	1	Curvature disutility of labor
ψ	1	Slope disutility of labor
g/y	0.2	Steady state government consumption to output ratio
ι	1	Price indexation to steady state inflation
ρ	0.75	Persistence coefficient interest rate rule
θ_π	1.5	Inflation coefficient interest rate rule
θ_y	0.125	Output coefficient interest rate rule

We set ϵ_l to the same value as in the partial equilibrium model, 0.0075. We set $R_L = 1.014$ in the low interest rate steady state and $R_H = 1.056$ in the high interest rate steady state. These values correspond to the average values of the Federal Funds rate below and above the four percent threshold, respectively.

We set the annualized steady state real interest rate in the high and low nominal interest rate states, r, to 1.4 percent. We set the discount factor to 1/1.014. We set κ_i to the posterior mode parameter value in the partial equilibrium model.[14]

We set the price stickiness parameter ξ to 0.95. This value implies a slope of the linearized NK Phillips curve of 0.003. This slope is roughly consistent with post-1990 sample estimates by Del Negro et al. [2020] and Hazell et al. [2022]. We set the steady state gross price markup γ to 1.1 as in e.g. Harding, Lindé and Trabandt [2022, 2023]. Our results are robust to the choice of γ.

Consider nest the parameters σ_0, σ_1, and σ_2. We set σ_0 so that the capital depreciation rate in the low nominal

[13]The exception is that we allow the interest rate faced by inattentive households in the low interest rate state to be slightly negative, with a lower bound of -1.5 percent per annum. Doing so improves the model fit in the high interest rate state. We interpret negative interest rates on deposits as reflecting fees charged by banks.

[14]We encounter numerical difficulties when we attempt to estimate this parameter.

interest rate steady state is 2.5 percent per quarter. We set σ_1 such that the capital utilization rate, u, in the low nominal interest rate steady state is equal to one. Consistent with Christiano et al. [2005], we set σ_2 to 0.001. This value implies that it is relatively inexpensive to vary the capital utilization rate.

Consistent with the literature, we set the capital share in production α to 1/3 and the share of government consumption to output in steady state to 0.2. Consistent with Christiano et al. [2005], we assume quadratic disutility of labor, so η is equal to one. We also set the parameter ψ, which affects the disutility of labor, equal to one.

We set the price indexation parameter ι to one so that there is no price dispersion in steady state in either the low or the high nominal interest rate steady states. Finally, we set the parameters of the monetary policy rule ρ, θ_π and θ_y to 0.75, 1.5 and 0.125, respectively. These values are consistent with the empirical NK literature.

When solving the model, we assume that social dynamics take place on a daily basis but economic interactions occur at the end of the quarter. We assume that the total number of interactions per quarter is 200 implying that households have multiple social interactions per day.

We estimate the following parameters: χ,κ_a,δ,$\tau_a/\mu^{\frac{1}{1-\varsigma}}$,$\tau_i/\mu^{\frac{1}{1-\varsigma}}$,$\phi$,$b$,$s_I$,$\vartheta_1$ and ϑ_2. In the equilibrium equations, the parameters τ_a, τ_i, μ and ς only appear as the ratios $\tau_a/\mu^{\frac{1}{1-\varsigma}}$, $\tau_i/\mu^{\frac{1}{1-\varsigma}}$ which is why we estimate those ratios rather than the individual parameters.

In our estimation we assume that the economy begins either in the low or high nominal interest rate state. Conditional on that state, we feed in sequences for the nominal interest rate R_t corresponding to the Choleski-based estimated impulse response functions of the policy rate (see Section 4).

We estimate model parameters by matching data and model-based impulse response functions for the following variables: real GDP per capita, real consumption per capita, real investment per capita, real hourly wage, and net interest rate margin.

Our computational approach is as follows. We consider two steady states corresponding to a low (R_L) and high (R_H) nominal interest rate. The real interest rate is the same in both steady states. Our specification for R_L and R_H implies two different values for steady state inflation. To simulate the effect of a monetary policy shock we feed in paths for R_L and R_H equal to estimated impulse response of the Federal Funds rate to a Choleski-based monetary policy shock for 12 quarters.[15] After this period, the interest rate path is governed by the Taylor rule.

Recall there are 200 hundred social interactions per quarter in the model. We linearly interpolate the quarterly interest rates to obtain 200 intraquarter interest rates. The later are used to compute paths for a^L and a^H. Economic decisions are made at the end of each quarter using the 200th value of a^L and a^H. Using the Fair and Taylor (1983) procedure, we solve two versions of the nonlinear model, corresponding to the high and low steady state interest rate. This procedure yields two sets of impulse response functions.

Since we are working with the Cholesky monetary shock measure, we impose the restriction that model real

[15]These paths can be interpreted as resulting from a particular sequence of shocks to the Taylor rule.

quarterly aggregates do not respond to beginning of period monetary policy shocks.

6.3 Results Baseline

Table 5 reports the priors and posteriors of our estimated parameters.

Table 5: Priors and Posteriors of Parameters.

Parameter	Prior Distribution	Posterior Distribution
	D, Mean, [2.5-97.5%]	Mode, [2.5-97.5%]
Social dynamics interaction parameter, χ	G, 2.0, [0.0506 7.3777]	1.8870, [0.9409 5.0424]
Rate at which attentive become inattentive, κ_a	U, 0.025, [0.000 0.049]	0.0060, [0.0025 0.0217]
Fraction of depositors who leave banks, δ	U, 0.025, [0.000 0.049]	0.0223, [0.0182 0.0489]
Cost of attracting attentive depositors, $\tau_a/\mu^{\frac{1}{1-\varsigma}}$	U, 0.05, [0.000 0.0975]	0.0161, [0.0078 0.0405]
Cost of attracting inattentive depositors, $\tau_i/\mu^{\frac{1}{1-\varsigma}}$	U, 0.50 , [0.025 0.975]	0.2691, [0.1225 0.2954]
Share of PIH households, ϕ	U, 0.45, [0.010 0.8775]	0.4972, [0.3273 0.6683]
Consumption habit persistence, b	U, 0.75, [0.615 0.926]	0.8357, [0.6943 0.8658]
Investment adjustment costs, s_I	U, 10.0, [0.103 19.50]	4.9627, [3.3158 17.165]
Real wage rule, persistence, ϑ_1	U, 0.80, [0.615 0.965]	0.9635, [0.7489 0.9901]
Real wage rule, labor demand, ϑ_2	U, 0.50, [0.025 0.975]	0.1083, [0.0522 0.3037]

Notes: The posterior mode and parameter distributions are based on a standard MCMC algorithm with a total of 500.000 draws (1 chain, 50.000 draws used for burn-in, draw acceptance rate about 0.25). U denotes the prior for the uniform distribution for which the mean is reported instead of the mode. G denotes the Gamma (2,1) distribution.

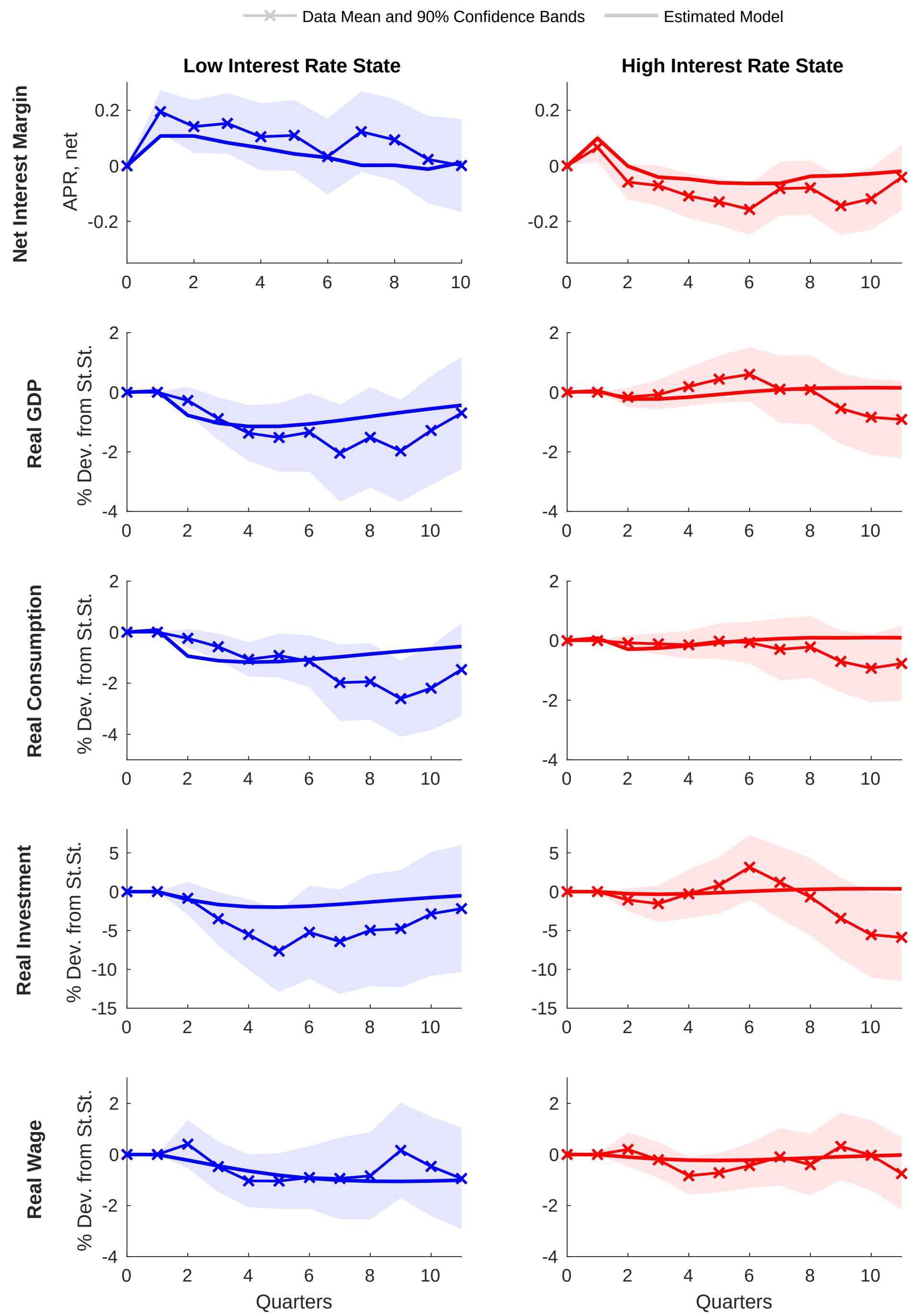
The point estimates of the banking parameters are broadly similar to those obtained when we estimate the partial equilibrium model. The point estimates of the habit formation parameter, b, and the investment adjustment cost parameter s_I are broadly consistent with those used in the literature, see e.g. Christiano et al. [2005] and Smets and Wouters [2007]. The point estimate for ϕ is consistent with the literature reviewed by Carroll et al. [2017]. Consistent with the data the wage rule parameters imply a very inertial response of the wage rate to monetary policy shocks (see, for example, Christiano et al. [2015]).

Figure 16 displays the model-based impulse responses of nim_t and various macroeconomic aggregates to a monetary policy shock along with the estimated counterparts from Section 4.

The first key result is that the response of NIM is state dependent. In the low interest rate scenario, a monetary shock increases NIM. In contrast, NIM decreases in the high interest rate scenario. The intuition for these results is the same as in the partial equilibrium model.

The second key result is that the magnitude of the responses to a monetary policy shock is state dependent for all variables except wages and the Federal Funds rate. The peak decline in aggregate output is roughly twice as large in the low interest rate scenario compared to the high rate scenario. Consumption and investment display a similar pattern of state dependence. The response of real wages to a monetary policy shock is muted regardless of which steady state we start from.

Figure 16: Estimated General equilibrium model. Impulse responses to a monetary policy shock of 100 b.p. annualized. NIM, real GDP, real consumption, real investment and real wages: data vs. model. Units in deviation from steady state or data baseline, respectively.



Note: This figure compares the theoretical impulse response functions (IRFs) generated from the estimated general equilibrium banking model with their empirical counterparts discussed in Section 3. Solid lines represent the model-generated IRFs. Solid lines with "x" markers depict the corresponding empirical IRFs. The shaded areas represent the 90 percent confidence bands for the empirical IRFs.

7 Conclusion

We show that the impact of monetary shocks on the economy depends on whether the shocks occur after periods of low or high nominal interest rates. This state dependence is evident in banks' net interest margins and in key macroeconomic variables, such as GDP, consumption, and investment.

These facts cannot be explained by a model in which households are inattentive due to the costs of paying attention. The reason is that a given change in interest rates provides the same benefit to a depositor, regardless of whether the initial interest rate is high or low. So depositors should respond similarly to interest rate changes in both environments, i.e. their reactions are not state dependent.

We explain our empirical findings using an estimated nonlinear NK general equilibrium model with a banking sector. The model has two key characteristics. First, some depositors are inattentive to interest rates earned on deposits. Second, the fraction of inattentive depositors changes because of social dynamics. Inattentive depositors may become attentive after interaction with attentive depositors. These interactions are more likely when interest rates are high. The state dependence in deposit interest rates affects the broader economy because there are households with a high propensity to consume out of liquid wealth.

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8 Appendix

Intermediate goods producers To compute marginal cost, s_{jt}, we solve the following problem,

$$S_{jt} = min_{K_{jt},N_{jt}} R_t^l [r_t^k K_{jt} + w_t N_{jt}]$$

subject to

$$Y_{jt} = (K_{jt})^\alpha N_{jt}^{1-\alpha}.$$

The first-order conditions for this problem are,

$$R_t^l r_t^K = s_{jt} \alpha (K_{jt})^{\alpha-1} N_{jt}^{1-\alpha},$$

$$R_t^l w_t = s_{jt}(1-\alpha)(K_{jt})^\alpha N_{jt}^{-\alpha}.$$

Combining,

$$\frac{r_t^K}{w_t} = \frac{\alpha N_{jt}}{(1-\alpha) K_{jt}}$$

We can now compute the j^{th} firm's real marginal cost, s_{jt},

$$s_{jt} = \frac{R_t^l \left(r_t^K\right)^\alpha w_t^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha}}$$

The profits of intermediate-good producer j at time t are:

$$\pi_{jt} = P_{jt} Y_{jt} - P_t s_{jt} Y_{jt}.$$

The first-order conditions for optimal price setting are:

$$\begin{aligned}
Z_{1,t} &= \gamma s_t \lambda_t^b P_t Y_t + \beta \xi E_t \left(\frac{\Pi^\iota}{\Pi_{t+1}}\right)^{\frac{\gamma}{1-\gamma}} Z_{1,t+1} \\
Z_{2,t} &= \lambda_t^b P_t Y_t + \beta \xi E_t \left(\frac{\Pi^\iota}{\Pi_{t+1}}\right)^{\frac{1}{1-\gamma}} Z_{2,t+1} \\
Z_{1,t} &= Z_{2,t} \left(\frac{1-\xi\left(\frac{\Pi^\iota}{\Pi_t}\right)^{\frac{1}{1-\gamma}}}{1-\xi}\right)^{(1-\gamma)}.
\end{aligned}$$

The inverse price dispersion term is given by:

$$\breve{p}_t = \left[(1-\xi)\left(\frac{1-\xi\left(\frac{\Pi^\iota}{\Pi_t}\right)^{\frac{1}{1-\gamma}}}{1-\xi}\right)^\gamma + \xi \frac{\left(\frac{\Pi^\iota}{\Pi_t}\right)^{\frac{\gamma}{1-\gamma}}}{\breve{p}_{t-1}}\right]^{-1}.$$

Households *Hand-to-mouth households*

Their labor supply is demand determined, so their consumption is given by

$$P_t C^H_{jt} = R_{jt} W_t N^H_{jt}.$$

To implement the labor allocation rules above, we need to compute the steady state hours worked for these households in a version of the model with flexible prices and wages,

$$E_t \sum_{l=0}^{\infty} \beta^t \left\{ \ln(C^H_{j,t+l} - bC^H_{j,t+l-1}) - \psi \frac{(N^H_{j,t+l})^{1+\eta}}{1+\eta} \right\}$$

$$P_t C^H_{jt} = R_{jt} W_t N^H_{jt}.$$

The first-order conditions are,

$$\frac{1}{C^H_{j,t} - bC^H_{j,t-1}} - E_t \frac{\beta b}{C^H_{j,t+1} - bC^H_{j,t}} = \lambda^H_t P_t,$$

$$\psi (N^H_{jt})^\eta = \lambda^H_t R_{jt} W_t$$

where λ^H_t is the Lagrange multiplier associated with the budget constraint.

Permanent income households

$$U_t = E_t \sum_{l=0}^{\infty} \beta^l \left\{ \ln(C^P_{t+l} - bC^P_{t+l-1}) - \psi \frac{(N^P_{t+l})^{1+\eta}}{1+\eta} \right\}, \tag{30}$$

subject to

$$P_t \left(C^P_t + I_t \right) + B_{t+1} - R_{t-1} B_t + \Psi_t = \left(W_t N^P_t + R^K_t u_t \bar{K}_t - D^P_t \right) + D^P_t R_{at} + \Phi_t, \tag{31}$$

$$\sigma_0 + \sigma_1 (u_t - 1) + \frac{\sigma_2}{2} (u_t - 1)^2 - \Delta(u_t) = 0,$$

$$[1 - \Delta(u_t)] \bar{K}_t + \left[1 - \frac{s_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t - \bar{K}_{t+1} = 0. \tag{32}$$

It is useful to compute

$$\Delta'(u_t) = \sigma_1 + \sigma_2 (u_t - 1).$$

We first need to compute the steady state where they choose their labor supply.

FOC

$$\psi (N^P_t)^\eta = \lambda^P_t R_{jt} W_t.$$

Next, we need to compute all other FOCs:

$$\frac{1}{C_t^P - bC_{t-1}^P} - E_t \frac{\beta b}{C_{t+1}^P - bC_t^P} = \lambda_t^P P_t$$

$$\lambda_t^P = E_t \beta R_t \lambda_{t+1}^P$$

$$-\lambda_t^K + \beta E_t \lambda_{t+1}^K \left[1 - \delta(u_{t+1})\right] + \beta E_t \lambda_{t+1}^P R_{a,t+1} R_{t+1}^K u_{t+1} = 0,$$

$$-\lambda_t^P P_t + \lambda_t^K \left[1 - \frac{s_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] - \lambda_t^K s_I \left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}} + \beta E_t \lambda_{t+1}^K s_I \left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2 = 0,$$

$$\lambda_t^P R_{a,t} R_t^K - \lambda_t^K \left[\sigma_1 + \sigma_2(u_t - 1)\right] = 0$$

Aggregate consumption

Aggregate consumption, C_t, is the average of the consumption of HTM attentive, inattentive, and PIH households weighted by their weight in the population,

$$C_t = \phi C_t^P + a_t^H C_{at}^H + i_t^H C_{it}^H.$$

Aggregate resource constraint The aggregate resource constraint is given by:

$$Y_t = \breve{p}_t \left(u_t \bar{K}_t\right)^{\alpha} N_t^{1-\alpha} = C_t + I_t + G_t + \tilde{v}_{at}\tau_a + \tilde{v}_{it}\tau_i + \varepsilon^l \left(w_t N_t + r_t^K u_t \bar{K}_t\right).$$

where $\widetilde{v}_{at}\tau_a + \tilde{v}_{it}\tau_i$ are the costs incurred by banks to attract attentive and inattentive depositors, respectively.

Equilibrium equations After scaling nominal variables we can write the equilibrium equations as follows

$$a_{t+1}^H = a_t^H(1 - \kappa_a) + \omega(R_t)(\phi + a_t^H)(1 - \phi - a_t^H)(1 - \kappa_i) + \kappa_i(1 - \phi - a_t^H)$$

$$\omega(R_t) = \chi\left(4R_t - 4\right)^2$$

$$a_t^H + i_t^H + \phi = 1$$

$$a_t = a_t^H + \phi$$

$$Y_t = C_t + I_t + G_t + \tilde{v}_{at}\tau_a + \tilde{v}_{it}\tau_i + \varepsilon^l \left(w_t N_t + r_t^K u_t \bar{K}_t\right)$$

$$Y_t = \breve{p}_t \left(u_t \bar{K}_t \right)^{\alpha} N_t^{1-\alpha}$$

$$C_t = \phi C_t^P + a_t^H C_{at}^H + i_t^H C_{it}^H$$

$$N_t = \phi N_t^P + a_t^H N_{at}^H + i_t^H N_{it}^H$$

$$\lambda_t^K = \beta E_t \lambda_{t+1}^K \left[1 - \Delta(u_{t+1}) \right] + \beta E_t \widetilde{\lambda}_{t+1}^P R_{a,t+1} r_{t+1}^K u_{t+1}$$

$$\tilde{\lambda}_t^P = \beta E_t \frac{R_t}{\Pi_{t+1}} \tilde{\lambda}_{t+1}^P$$

$$-\widetilde{\lambda}_t^P + \lambda_t^K \left[1 - \frac{s_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] - \lambda_t^K s_I \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} + \beta E_t \lambda_{t+1}^K s_I \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 = 0$$

$$\widetilde{\lambda}_t^P R_{at} r_t^K - \lambda_t^K \left[\sigma_1 + \sigma_2 (u_t - 1) \right] = 0$$

$$\frac{1}{C_t^P - b C_{t-1}^P} - E_t \frac{\beta b}{C_{t+1}^P - b C_t^P} = \widetilde{\lambda}_t^P$$

$$\bar{K}_{t+1} = \left[1 - \Delta(u_t) \right] \bar{K}_t + \left[1 - \frac{s_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t$$

$$\Delta(u_t) = \sigma_0 + \sigma_1 (u_t - 1) + \frac{\sigma_2}{2} (u_t - 1)^2$$

$$C_{at}^H = R_{at} w_t N_{at}^H$$

$$C_{it}^H = R_{it} w_t N_{it}^H$$

$$\breve{p}_t = \left[(1-\xi) \left(\frac{1 - \xi \left(\frac{\Pi^{\iota}}{\Pi_t} \right)^{\frac{1}{1-\gamma}}}{1-\xi} \right)^{\gamma} + \xi \frac{\left(\frac{\Pi^{\iota}}{\Pi_t} \right)^{\frac{\gamma}{1-\gamma}}}{\breve{p}_{t-1}} \right]^{-1}$$

$$
\begin{aligned}
Z_{1t} &= \gamma s_t \widetilde{\lambda}_t^P Y_t + \beta \xi E_t \left(\frac{\Pi^{\iota}}{\Pi_{t+1}} \right)^{\frac{\gamma}{1-\gamma}} Z_{1,t+1} \\
Z_{2t} &= \widetilde{\lambda}_t^P Y_t + \beta \xi E_t \left(\frac{\Pi^{\iota}}{\Pi_{t+1}} \right)^{\frac{1}{1-\gamma}} Z_{2,t+1} \\
Z_{1t} &= Z_{2t} \left(\frac{1 - \xi \left(\frac{\Pi^{\iota}}{\Pi_t} \right)^{\frac{1}{1-\gamma}}}{1-\xi} \right)^{(1-\gamma)}
\end{aligned}
$$

$$
s_t = \frac{R_t^l \left(r_t^K \right)^{\alpha} w_t^{1-\alpha}}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}}
$$

$$
\frac{r_t^K}{w_t} = \frac{\alpha N_t}{(1-\alpha) u_t \bar{K}_t}
$$

$$
GDP_t = C_t + I_t + G_t
$$

$$
\ln(R_t) = (1-\rho)\ln(R) + \rho \ln(R_{t-1}) + (1-\rho) \left[\theta_{\pi} \ln \left(\frac{\Pi_t}{\bar{\Pi}} \right) + \theta_y \ln \left(\frac{GDP_t}{GDP} \right) \right] + \varepsilon_t
$$

$$
\tau_a \widetilde{v}_{at} = \frac{\delta \tau_a}{\mu^{1/(1-\varsigma)}} \phi d_t^P + \frac{\delta \tau_a}{\mu^{1/(1-\varsigma)}} a_t^H d_{at}^H
$$

$$
\tau_i \widetilde{v}_{it} = \frac{\delta \tau_i}{\mu^{1/(1-\varsigma)}} i_t^H d_{it}^H
$$

$$
nim_t = \varepsilon^l + \frac{\phi d_t^P + a_t^H d_{at}^H}{\phi d_t^P + a_t^H d_{at}^H + i_t^H d_{it}^H} (R_t - R_{at}) + \frac{i_t^H d_{it}^H}{\phi d_t^P + a_t^H d_{at}^H + i_t^H d_{it}^H} (R_t - R_{it})
$$

$$
d_t^P = w_t N_t^P + r_t^K u_t \bar{K}_t
$$

$$
d_{at}^H = w_t N_{at}^H
$$

$$
d_{it}^H = w_t N_{it}^H
$$

$$
R_t - R_{it} = \frac{\tau_i}{\mu^{1/(1-\varsigma)}} - E_t \frac{1-\delta}{R_t/\Pi_{t+1}} \left[\frac{\tau_i}{\mu^{1/(1-\varsigma)}} - \left(\omega(R_t)(\phi + a_t^H)(1-\kappa_i) + \kappa_i \right) \frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}} \right]
$$

$$
R_t - R_{at} = \frac{\tau_a}{\mu^{1/(1-\varsigma)}} - E_t \frac{1-\delta}{R_t/\Pi_{t+1}} \left[\frac{\tau_a}{\mu^{1/(1-\varsigma)}} + \kappa_a \upsilon_t \frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}} \right]
$$

$$\upsilon_t = \frac{a_t^H d_{at}^H}{\phi d_t^P + a_t^H d_{at}^H}$$

$$R_t^l = R_t + \varepsilon^l$$

$$G_t = G$$

With flexible prices and wages, we have the following equations for labor supply and the equilibrium wage:

$$\psi (N_t^P)^\eta = \left(\frac{1}{C_t^P - bC_{t-1}^P} - E_t \frac{\beta b}{C_{t+1}^P - bC_t^P} \right) R_{at} w_t$$

$$\psi (N_{at}^H)^\eta = \left(\frac{1}{C_{a,t}^H - bC_{a,t-1}^H} - E_t \frac{\beta b}{C_{a,t+1}^H - bC_{a,t}^H} \right) R_{at} w_t$$

$$\psi (N_{it}^H)^\eta = \left(\frac{1}{C_{i,t}^H - bC_{i,t-1}^H} - E_t \frac{\beta b}{C_{i,t+1}^H - bC_{i,t}^H} \right) R_{it} w_t$$

With sticky prices and wages, the above equations for labor supply and the equilibrium wage are replaced by

$$N_{at}^H = \frac{N_a^H}{N} N_t$$

$$N_{it}^H = \frac{N_i^H}{N} N_t$$

$$ln \left(\frac{w_t}{w} \right) = \vartheta_1 ln \left(\frac{w_{t-1}}{w} \right) + \vartheta_2 ln \left(\frac{N_t}{N} \right).$$

Above, we have made use of the following expressions:

$$\widetilde{\lambda}_t^P = \lambda_t^P P_t$$

$$\widetilde{v}_{jt} = \frac{v_{jt}}{P_t}$$

$$W_t = w_t P_t$$

$$d_t^p = \frac{D_t^p}{P_t}$$

$$d_{at}^H = \frac{D_{at}^H}{P_t}$$

$$d_{it}^H = \frac{D_{it}^H}{P_t}$$

We have a system of 39 equations in 39 variables:

$$Y_t, C_t, I_t, G_t, \bar{K}_t, GDP_t, N_t, \tau_a \widetilde{\upsilon}_{at}, \tau_i \widetilde{\upsilon}_{it}, \breve{p}_t$$

$$C_t^P, C_{at}^H, C_{it}^H, N_t^P, N_{at}^H, N_{it}^H, u_t, w_t, Z_{1t}, Z_{2t}$$

$$\lambda_t^K, \widetilde{\lambda}_t^P, \Delta(u_t), r_t^K, \Pi_t, s_t, R_{at}, R_{it}, R_t^l, R_t$$

$$nim_t, \upsilon_t, a_t, i_t^H, a_t^H, d_t^P, d_{at}^H, d_{it}^H, \omega(R_t)$$

Steady state Fix a value for the nominal interest rate, R, in steady state. Then,

$$\omega(R) = \chi \left(4R - 4\right)^2$$

The law of motion for a^H can be written as:

$$\left(a^H\right)^2 \omega(R)(1-\kappa_i) - a^H \left[\omega(R)(1-\kappa_i)\left(1-2\phi\right) - \kappa_a - \kappa_i\right] - (1-\phi)\left[\phi\omega(R)(1-\kappa_i) + \kappa_i\right] = 0$$

Solving yields:

$$a^H = \frac{\omega(R)(1-\kappa_i)\left(1-2\phi\right) - \kappa_a - \kappa_i \pm \sqrt{\left[\omega(R)(1-\kappa_i)\left(1-2\phi\right) - \kappa_a - \kappa_i\right]^2 + 4\left(1-\phi\right)\omega(R)(1-\kappa_i)\left[\phi\omega(R)(1-\kappa_i) + \kappa_i\right]}}{2\omega(R)(1-\kappa_i)}$$

Proceed with the positive solution for a^H. Then,

$$i^H = 1 - \phi - a^H$$

$$a = a^H + \phi$$

$$\Pi = \beta R$$

$$R^l = R + \varepsilon^l$$

$$R_i = R - \frac{\tau_i}{\mu^{1/(1-\varsigma)}} + \frac{1-\delta}{R/\Pi}\left[\frac{\tau_i}{\mu^{1/(1-\varsigma)}} - \left(\omega(R)(\phi + a^H)(1-\kappa_i) + \kappa_i\right)\frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\right]$$

$$\breve{p} = \frac{1 - \xi \Pi^{\gamma \frac{\iota - 1}{1-\gamma}}}{(1-\xi)\left(\frac{1-\xi \Pi^{\frac{\iota-1}{1-\gamma}}}{1-\xi}\right)^{\gamma}}$$

$$s \quad = \tfrac{1}{\gamma} \quad \frac{1 - \beta\xi\Pi^{\gamma\frac{\iota-1}{1-\gamma}}}{1-\beta\xi\Pi^{\frac{\iota-1}{1-\gamma}}}\left(\frac{1-\xi\Pi^{\frac{\iota-1}{1-\gamma}}}{1-\xi}\right)^{(1-\gamma)}$$

Guess a value for υ_t between 0 and 1. Then:

$$R_a = R - \frac{\tau_a}{\mu^{1/(1-\varsigma)}} + \frac{1-\delta}{R/\Pi}\left[\frac{\tau_a}{\mu^{1/(1-\varsigma)}} + \kappa_a \upsilon \frac{\tau_i - \tau_a}{\mu^{1/(1-\varsigma)}}\right]$$

Guess a value for r^k. Then:

$$u = \frac{R_a r^K - \sigma_1}{\sigma_2} + 1$$

Rig parameters $\sigma_0, \sigma_1, \sigma_2$ later on. Also:

$$\Delta(u) = \sigma_0 + \sigma_1(u-1) + \frac{\sigma_2}{2}(u-1)^2$$

$$w = \left[\frac{s\alpha^{\alpha}(1-\alpha)^{1-\alpha}}{R^l\left(r^K\right)^{\alpha}}\right]^{\frac{1}{1-\alpha}}$$

$$N_a^H = \left[\frac{1-\beta b}{\psi\,(1-b)}\right]^{\frac{1}{1+\eta}}$$

$$N_i^H = \left[\frac{1-\beta b}{\psi\,(1-b)}\right]^{\frac{1}{1+\eta}}$$

$$C_a^H = R_a w N_a^H$$

$$C_i^H = R_i w N_i^H$$

$$d_a^H = w N_a^H$$

$$d_i^H = w N_i^H$$

$$d^P = \frac{(1-\upsilon)\, a^H d_a^H}{\upsilon \phi}$$

$$\tau_a \widetilde{v}_a = \delta \frac{\tau_a}{\mu^{1/(1-\varsigma)}} \phi d^P + \delta \frac{\tau_a}{\mu^{1/(1-\varsigma)}} a^H d_a^H$$

$$\tau_i \widetilde{v}_i = \delta \frac{\tau_i}{\mu^{1/(1-\varsigma)}} i^H d_i^H$$

Guess a value for N^P. Then:

$$N = \phi N^P + a^H N_a^H + i^H N_i^H$$

$$\bar{K} = \frac{\alpha N w}{(1-\alpha) u r^K}$$

$$Y = \breve{p} \left(u \bar{K} \right)^{\alpha} N^{1-\alpha}$$

$$I = \Delta(u) \bar{K}$$

$$C^P = \frac{1-\beta b}{(1-b)\, \psi (N^P)^{\eta}} R_a w$$

$$C = \phi C^P + a^H C_a^H + i^H C_i^H$$

$$\widetilde{\lambda}^P = \frac{1-\beta b}{(1-b)\, C^P}$$

$$\lambda^K = \widetilde{\lambda}^P$$

Finally,

$$Z_1 = \frac{\gamma s \widetilde{\lambda}^P Y}{1 - \beta \xi \Pi^{\gamma \frac{\iota - 1}{1-\gamma}}}$$

$$Z_2 = \frac{\widetilde{\lambda}^P Y}{1 - \beta \xi \Pi^{\frac{\iota - 1}{1-\gamma}}}$$

$$nim = \varepsilon^l + \frac{\phi d^P + a^H d_a^H}{\phi d^P + a^H d_a^H + i^H d_i^H} (R - R_a) + \frac{i^H d_i^H}{\phi d^P + a^H d_a^H + i^H d_i^H} (R - R_i)$$

Set G such that G/GDP equals a desired value from the data. Then:

$$GDP = \frac{C + I}{1 - \frac{G}{GDP}}$$

$$G = \frac{G}{GDP} GDP$$

Adjust the three guesses for υ, r^k and N^P so that the following three equations hold with equality:

$$1 = \beta \left[1 - \Delta(u)\right] + \beta R_a r^K u$$

$$d^P = wN^P + r^K u\bar{K}$$

$$Y = C + I + G + \tilde{\upsilon}_a \tau_a + \tilde{\upsilon}_i \tau_i + \varepsilon^l \left(wN + r^K u\bar{K}\right)$$