Net Interest Margins and Monetary Policy

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Abstract

We show that the response of banks' net interest margin to a monetary policy shock is state-dependent. After a period of low Federal Funds rates, a contractionary monetary policy shock leads to a significant rise in net interest margins. In contrast, after a period of high Federal Funds rates, a contractionary monetary policy shock leads to a fall in net interest margins. The response of aggregate economic activity displays a similar state-dependency: real GDP, aggregate real consumption, and real investment fall much more sharply when a contractionary policy occurs after a period of low Federal Funds rates compared to a period of high Federal Funds rates. We develop a banking model in which the fraction of households that are attentive to deposit interest rates depends on the level of the interest rate. This fraction varies over time because of social interactions. We embed our banking model in a DSGE model where the aggregate marginal propensity to consume out of liquid wealth is high. The model accounts for the strong state-dependency in the response of the net interest margins and aggregate economic activity to a contractionary monetary policy shock.

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

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1 Introduction

We show that the response of banks' net interest margin (NIM) to a monetary policy shock is state-dependent. After 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, a contractionary monetary policy shock leads to a fall in NIM. The response of aggregate economic activity displays a similar state-dependency: real GDP, aggregate real consumption, and real investment fall much more sharply when a contractionary policy occurs after a period of low Federal Funds rates compared to a period of high Federal Funds rates.

We estimate that the cumulative effect of a monetary policy shock over three years after a prolonged period of low interest rates is an *increase* in NIM-related bank profits of roughly 92 billion dollars, which equals 0.33 percent of 2023 GDP. Suppose instead that the shock occurs after a prolonged period of high interest rates. Then, the corresponding impact on NIM-related profits is a *decrease* of 98.3 billion dollars, which represents 0.35 percent of 2023 GDP. In sum, the counterparts of Commercial Banks save 191 billion dollars in net interest paid if the shock occurs in the high state rather the low state. These savings represent 0.68 percent of 2023 GDP.

Suppose that bank profits accrue to people with a much lower marginal propensity to consume out of liquid wealth than those who receive interest income from banks. Then, the contraction in aggregate demand should, other things equal, be larger when a contractionary policy shock occurs after a prolonged period of low interest rates. So, in an economy with nominal rigidities, state-dependence in NIMs creates state-dependence in the response of aggregate economic activity to a monetary policy shock.

To explore this conjecture, we first develop a competitive banking model in which the fraction of households that are attentive to deposit interest rates depends on the interest rate. This fraction varies over time because of social dynamics arising from random encounters between attentive and inattentive households. Some inattentive households become attentive after meeting attentive households, who are more likely to discuss interest rates when these rates are high. Consequently, the number of attentive depositors increases with the interest rate, reducing future bank profitability. In a competitive environment, this anticipated decline in future profitability must be offset by higher current profitability, resulting in a wider spread between the Federal Funds rate and deposit rates and an increase in banks' NIM. This effect is particularly pronounced when interest rates are low because an increase in rates reduces the present value of future profits more significantly when rates are low than when they are high. We show that our partial equilibrium model accounts very well for the dynamic response of NIM to monetary policy shocks after prolonged periods of high and low interest rates.

We embed our banking model in a DSGE model where the aggregate marginal propensity to consume out-of-liquid wealth is high. In the model, state dependency in the response of deposit rates to a monetary policy shock interacts with households who have a high marginal propensity to consume out-of-liquid wealth. The net result is to induce state dependency in the way that monetary policy affects aggregate economic activity.

In reality, there are many types of households that have a high marginal propensity to consume out of liquid wealth. For example, many retired people derive a substantial part of their income from various types of bonds. Other examples include wealthy hand-to-mouth people of the sort emphasized by Kaplan, Moll, and Violante [2018], and low-income households who often face borrowing constraints (see, for example Bilbiie [2021], Auclert, Rognlie, and Straub [forthcoming] and Debortoli and Galí [2024] and the references therein).

Incorporating all of the sources of heterogeneity that have been stressed in the literature is beyond the scope of this paper. Instead, we focus on a parsimonious TANK model. The first household group consists 'permanent income' consumers who are not credit-constrained. Changes in deposit interest rates have a small impact on the consumption decisions of these households. The second household group consists of 'hand-to mouth consumers' who have a marginal propensity to consume equal to one.

To simplify, we assume that permanent income households are always attentive to interest rates on deposits. Hand-to-mouth households can be attentive or inattentive to deposit interest rates, with changes in attention determined by social dynamics.

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. Similarly, capital owners 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 this version of the paper, we present some preliminary findings about the quantitative properties of the DSGE model to establish that it can account for the state dependency in aggregate economic activity stemming fom state dependency in the response of NIM to monetary policy shocks. Going forward we intend to estimate the model parameters using Bayesian estimation methods as in Christiano, Trabandt, and Walentin [2011] and Christiano, Eichenbaum, and Trabandt [2016].

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 contains brief concluding remarks.

2 Literature review

Our paper contributes to three important strands of literature. The first is a large empirical and theoretical literature on the role of banks in the monetary transmission mechanism which includes 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] 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 Federal Funds rate rises. Our paper makes two significant contributions to this body of work. 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 marginal propensity to consume 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 incorporate social dynamics into a simple TANK model and show that these dynamics can create state-dependent responses of banking variables to monetary policy shocks.

The third related line of research is work on social dynamics which emphasizes the importance of social interactions in changing 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 to model changes in people's inattention. Our model is consistent with recent work by Pfäuti [2023] which shows that the public's attention to inflation doubles once inflation exceeds 4 percent.

3 Data

Our empirical analysis uses detailed data from the Consolidated Reports of Condition and Income (Call Reports) obtained from the FDIC[1]. These reports are filed quarterly by all national banks, state-member banks, insured state-nonmember 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

[1] See FDIC Website

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 net interest margin: (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 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.

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[2].

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.[3] 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 3 months before to the day before 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.'

Our second measure of a shock to monetary policy is based 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

[2]See FRB Updated Excess Bond Premium data.

[3]Bauer and Swanson (2022)Bauer and Swanson [2022] follows Nakamura and Steinsson (2018)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.

time t shock to monetary policy as the residual in a regression of the federal funds rate on contemporaneous and four lags of lagged Real GDP, the PCE price index, and four lags of the Excess Bond Premium.[4] For convenience, we refer to this measure of a monetary policy shock as the 'recursive shock measure.'

4 Empirical results

In this section, we investigate the state-dependent nature of how monetary policy affects loan rates, deposit rates, net interest rate margins, 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 on the value one when the average level of FFR in the previous six quarters is higher than a threshold value of $\bar{R}$ equal to 4%. The average value of the FFR is 1.47% (5.61%) when the average of the previous six quarters' FFR is less (greater) than 4.0%. [5]

4.1 Estimating the state-dependent response of outcome variables to a monetary policy shock

We consider the following local projection equation:

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

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. 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 FFR across the last six quarters is higher than $\bar{R} = 4\%$ and zero otherwise. We refer to the state when$\mathbb{I}_{\{R_{t-1,t-6}>\bar{R}\}} = 1$ as the 'high' state and the state when $\mathbb{I}_{\{R_{t-1,t-6}>\bar{R}\}} = 0$ as the 'low' 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} andMP_{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 denotes the time t 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 $\bar{R} = 4\%$. The coefficient $\beta_{1,h}$ captures the fixed effect of a high average value of past interest. The coefficient $\beta_{2,h}$ measures the

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

[5] 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%.

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 $\bar{R} = 4$. 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 $\mathbb{I}_{\{R_{t-1,t-6} > \bar{R}\}} = 1$.

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.[6]

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 rates and financial variables. We report the results of estimating regression (1) in which the dependent variable is either the log of FFR, NIM, the deposit expense rate, loan expense rate, Core NIM, the time deposit rate minus the saving deposit rate, and time deposits as a fraction of saving deposits.

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 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 that occurs in high and low states.

Figure 1 reports our results for FFR. Two key results are worth noting. First, for both shock measures, a contractionary monetary policy shock induces a persistent increase in the federal funds rate for roughly two years. Second, there is relatively little evidence of state dependence in the response of the federal funds rate. These results are robust to which of the shock measures that we use.

Figure 2 reports our results for NIM. Three results emerge. First, if we do not allow for state dependence, NIM falls by a modest amount after a contractionary monetary policy shock. The fall is not statistically significant for the recursive shock measure but is statistically significant for the Bauer-Swanson shock measure. 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 roughly equal to 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 maximal decline roughly equal to about 15 or 21 basis points, depending on the shock measure. Third, the fourth

[6] Confidence Intervals are constructed assuming zero correlation between $\beta_{0,h}$and $\beta_{2,h}$.

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.

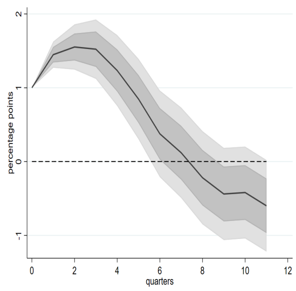
Federal Funds Rate (FFR)

Figure 1: ***Federal Funds Rate, response to a monetary policy shock***

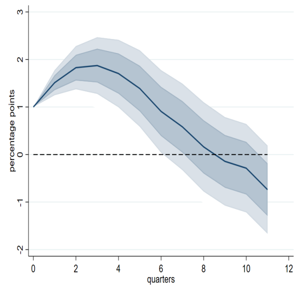
Panel A: Choleski-style Identification

No State-Dependence

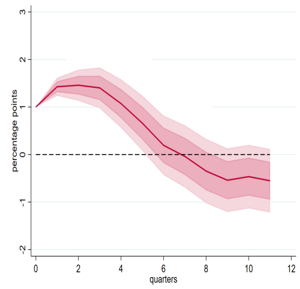
Allowing for State Dependence



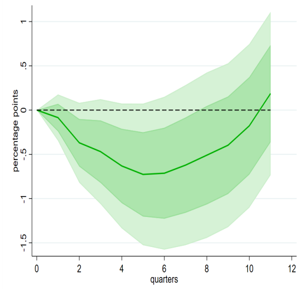
(a) Baseline Response



(b) Response in low rate state



(c) Response in high rate state

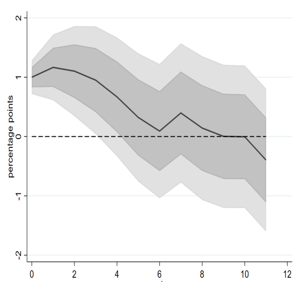


(d) Difference, low vs high state

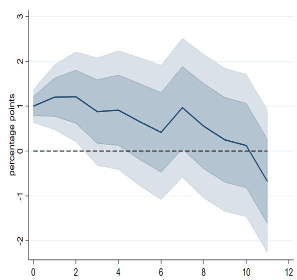
Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence

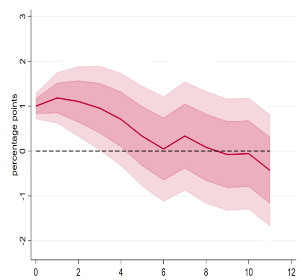
Allowing for State Dependence



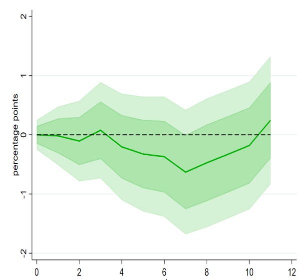
(e) Baseline Response



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

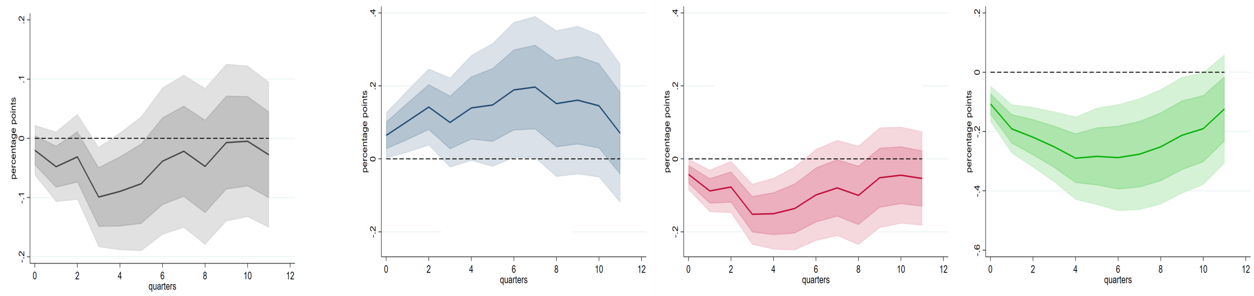
Note: Solid Lines in the first three columns depict point estimates of the response of Federal Funds Rate to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the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

Net Interest Margin

Figure 2: ***Net Interest Margin, response to a monetary policy shock***

Panel A: Choleski-style Identification

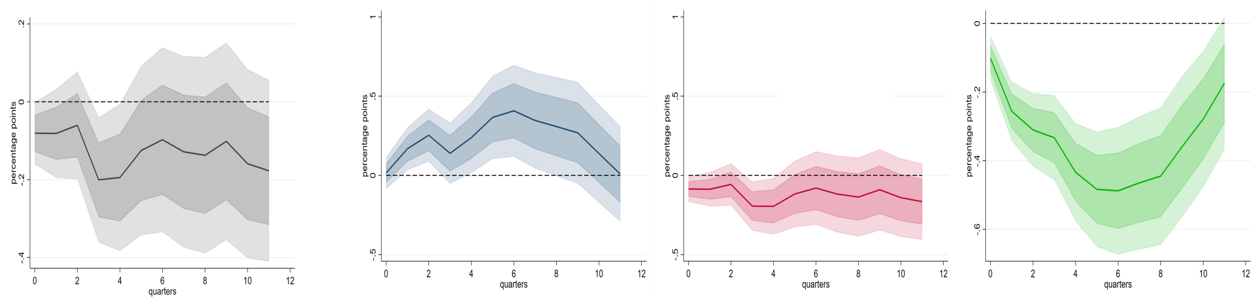
No State-Dependence | **Allowing for State Dependence**



(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 Net Interest Margin 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.

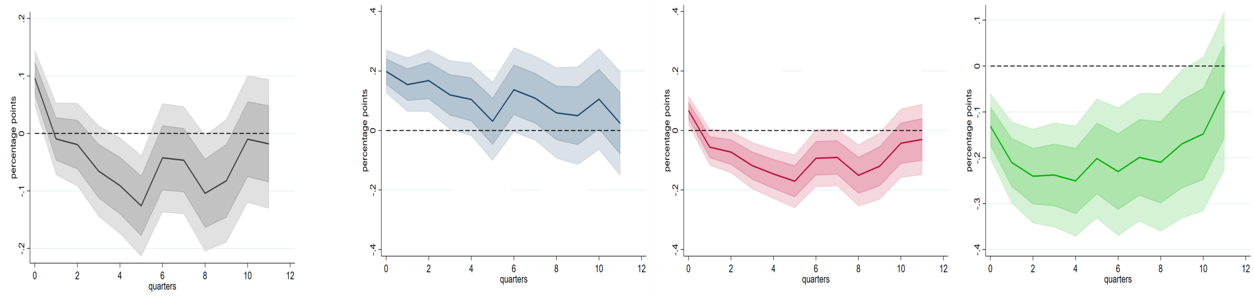
Figure 3 shows how core NIM (the difference between the average loan interest income rate and the average deposit interest expense rate) responds to a monetary policy shock. Columns 2 and 3 show that for both shock measures, core NIM rises when the shock occurs in the low state but falls when the shock occurs in the high state. The peak rises roughly 20 to 28 basis points, depending on the shock measure. The peak declines are roughly 17 and 21 basis points, depending on the shock measure. Column 4 shows that the difference between the response rates is negative. In all cases, these effects are statistically significant.

Core Net Interest Margin

Figure 3: ***Core Net Interest Margin, response to a monetary policy shock***

Panel A: Choleski-style Identification

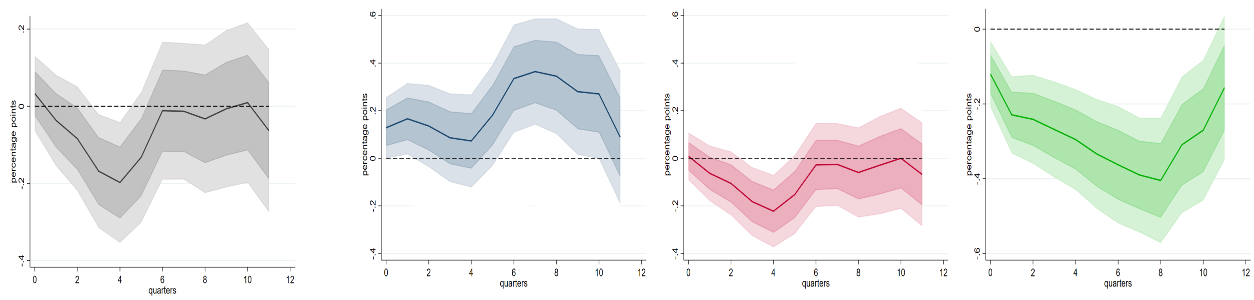
No State-Dependence | **Allowing for State Dependence**



(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 Net Interest Margin 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 turn to an analysis of the underlying determinants of the response of core NIM to a monetary policy shock. Figures 4 and 5 report results for the deposit expense rate and the loan income rate. Note that regardless of whether we are in the low or the high state, a contractionary policy shock (however measured) induces a rise in these rates(see columns 2 and 3 of Figure 4 and 5). The rise in both rates is smaller when the policy shock occurs in the low state than when the shock occurs in the high state (see column 4). The statistical significance of the difference depends on which rate and shock measure we consider. Passthrough is neither immediate nor complete for the loan or deposit interest rate. The deposit interest rate tends to react more in the high state than the low state. However, the difference is only significant with the Bauer and Swanson shock measure. In contrast, the difference between the response of the loan interest rate in the high and low state is not statistically different for either shock measure.

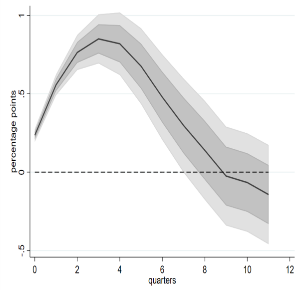
Deposit Expense Rate

Figure 4: ***Deposit Expense Rate, response to a monetary policy shock***

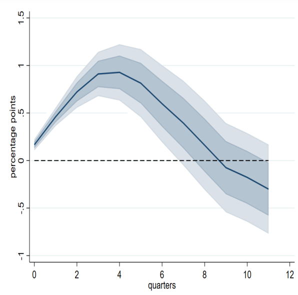
Panel A: Choleski-style Identification

No State-Dependence

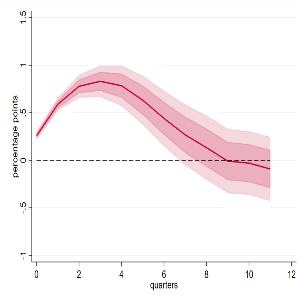
Allowing for State Dependence



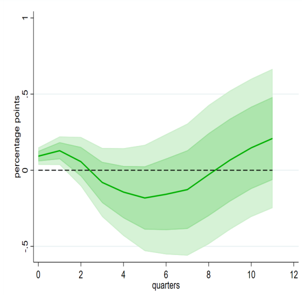
(a) Baseline Response



(b) Response in low rate state



(c) Response in high rate state

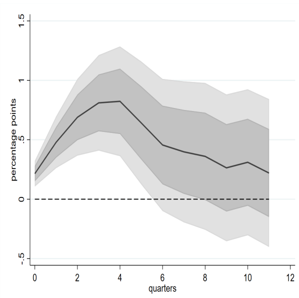


(d) Difference, low vs high state

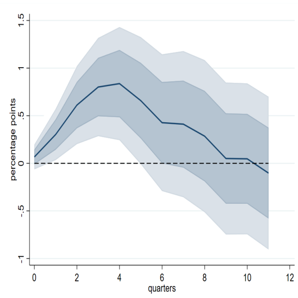
Panel B: High Frequency Bauer and Swanson (2023) Identification

No State-Dependence

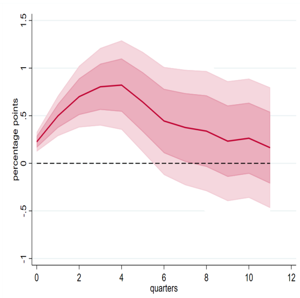
Allowing for State Dependence



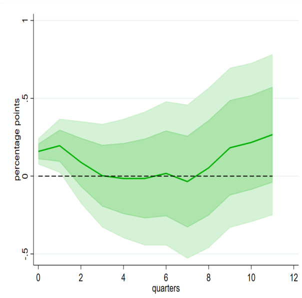
(e) Baseline Response



(f) Response in low rate state



(g) Response in high rate state



(h) Difference Low vs High

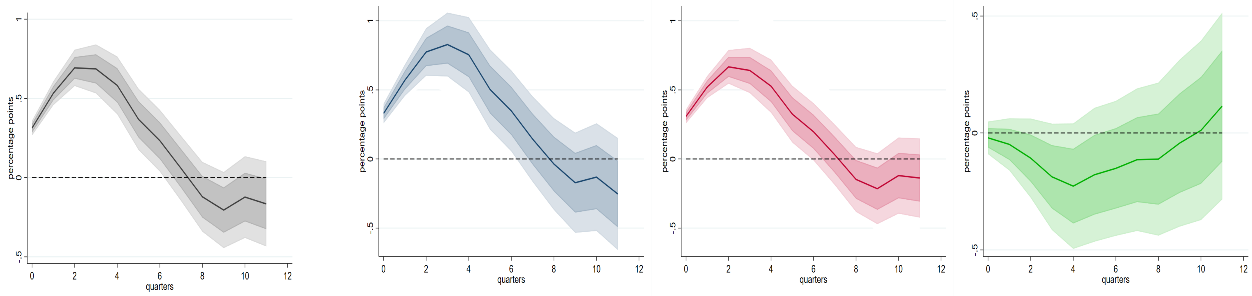
Note: Solid Lines in the first three columns depict point estimates of the response of Deposit Expense Rate to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between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

Loan Income Rate

Figure 5: ***Loan Income Rate, response to a monetary policy shock***

Panel A: Choleski-style Identification

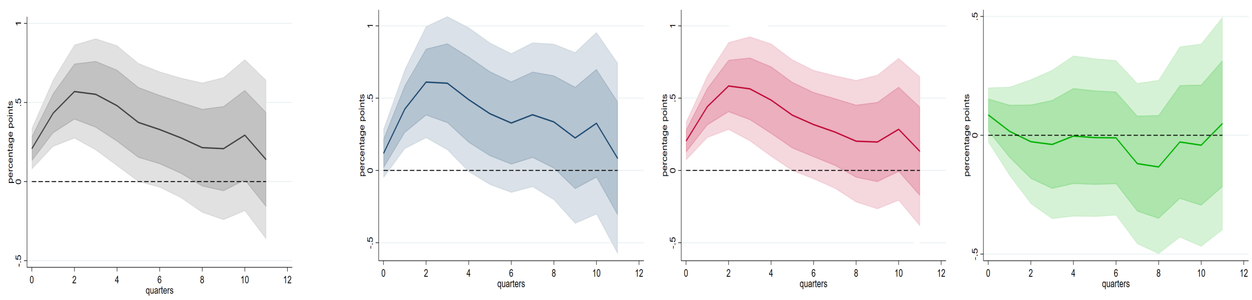
No State-Dependence **Allowing for State Dependence**



(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.

We now decompose the movements in Core NIM into intensive and extensive margins. By the former, we mean changes in the interest rates on savings and time deposits. By the latter, we mean changes in the ratio of time deposits to saving deposits.

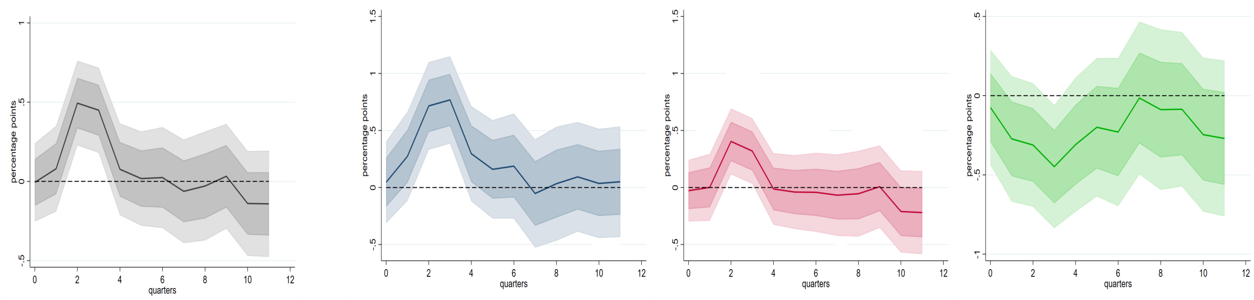
The spread between the interest rate on time and savings deposits also rises but somewhat less dramatically (see Figure 6). So, movements in the intensive margin play a role in moving Core NIM.

Time Deposits rate minus Saving Deposit Rate

Figure 6: ***Time Deposit Rate minus Saving Deposit Rate, response to a monetary policy shock***

Panel A: Choleski-style Identification

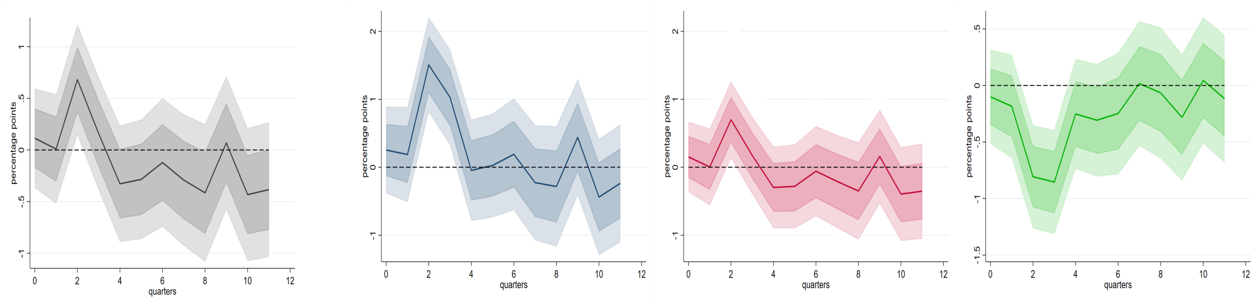
No State-Dependence **Allowing for State Dependence**



(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.

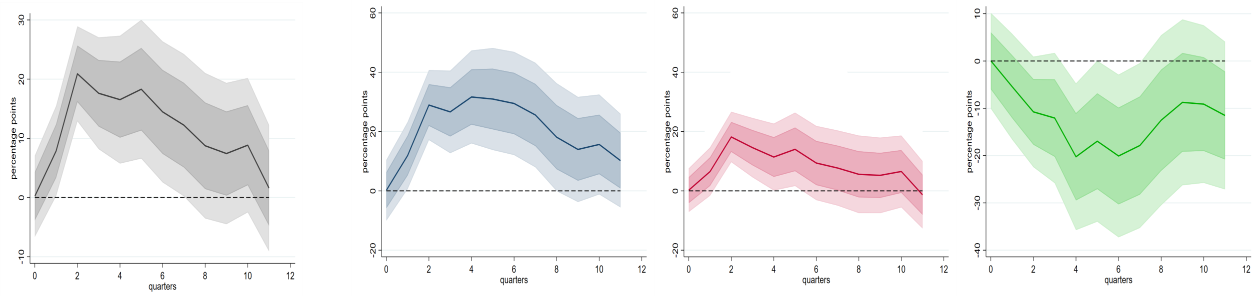
The extensive margin plays a larger role than the intensive margin in moving Core NIM. Figures 7 show that a contractionary monetary policy shock induces a switch from savings deposits to time deposits. The point estimates of movements along the intensive and extensive are consistent with state dependence, with the statistical significance varying by the shock measure. Overall, there is less evidence of state dependence on the extensive margin than the intensive margin. However, the fact that the extensive margin moves when the interest rate rises exacerbates the impact of state dependence in the intensive margin on the response of core NIM to a policy shock.

Time Deposits as a fraction of Saving Deposits

Figure 7: ***Time Deposits as a fraction of Saving Deposits (Outstanding Amounts), response to a monetary policy shock***

Panel A: Choleski-style Identification

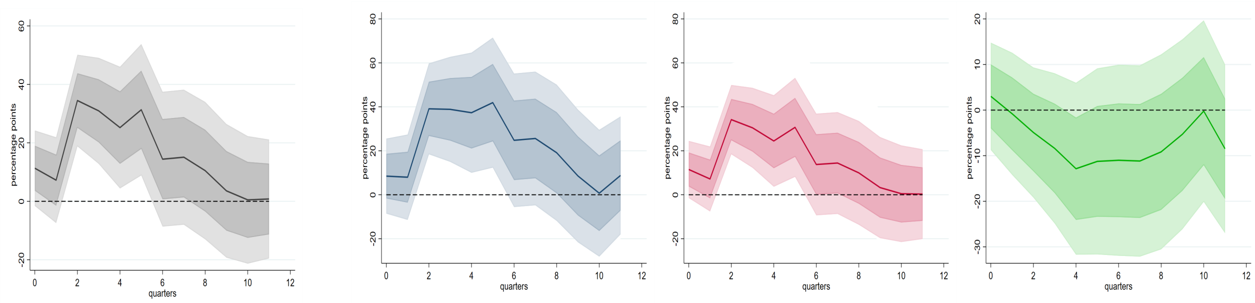
No State-Dependence **Allowing for State Dependence**



(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 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.

4.3 Aggregate Economic Activity and Inflation

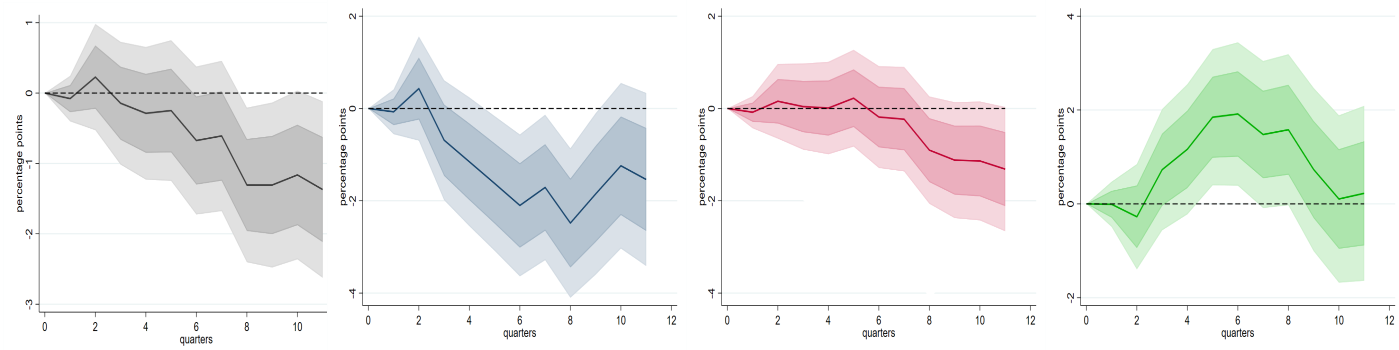
In this subsection, we investigate the state-dependent effects of a monetary policy shock on aggregate economic activity and inflation. We report the results of estimating regression (1) in which the dependent variable is either the log of the log Real GDP, log Consumption, log Investment, and the log of the inflation rate. Figures 8 - 11 are organized in the same way as Figures 1 - 7.

Real GDP

Figure 8: ***Real Gross Domestic Product, response to a monetary policy shock***

Panel A: Choleski-style Identification

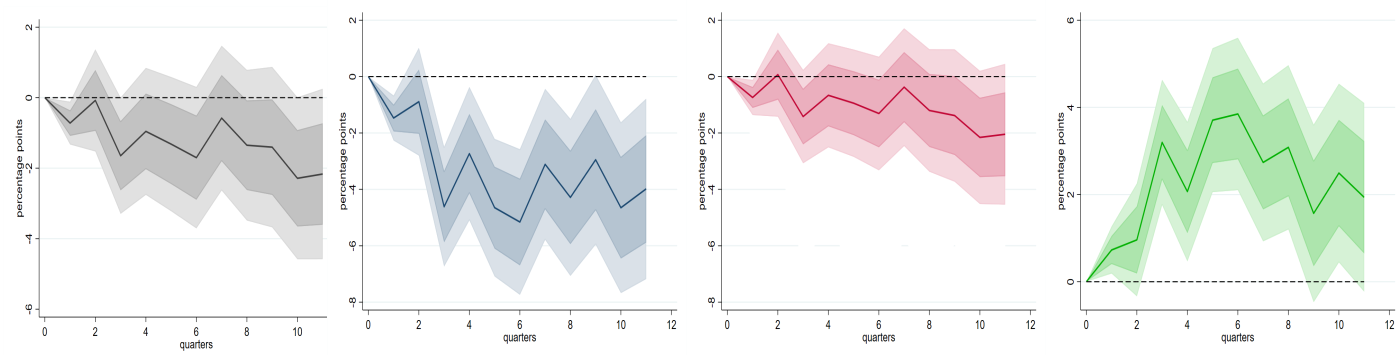
No State-Dependence **Allowing for State Dependence**



(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.

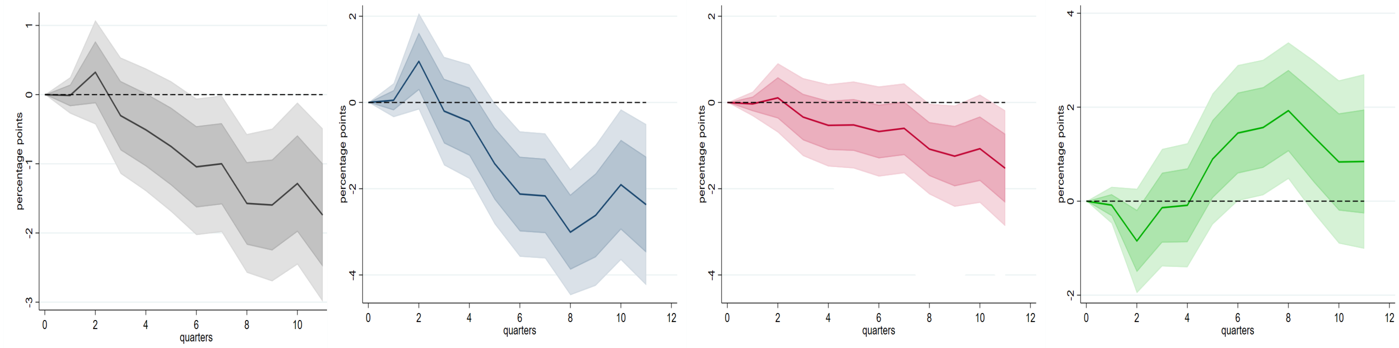
Figure 8 shows that the response of real GDP to a contractionary monetary policy shock exhibits strong state dependence. There are three key results. First, for both shock measures, a contractionary monetary policy shock induces a persistent decrease in real GDP for roughly two years. Interestingly, the decline is larger when we work with the Bauer and Swanson shock measure. Second, there is strong evidence of state dependence in the response of the real GDP. Specifically, the decline in real GDP is larger when the shock occurs in the low state than when the shock occurs in the high state. Third, the difference in real GDP's response when the shock occurs in the low and high states is statistically significant for both shock measures. Figures 9 and 10 show that the same findings hold for real consumption and investment.

Real Consumption

Figure 9: ***Real Personal Consumption Expenditure, response to a monetary policy shock***

Panel A: Choleski-style Identification

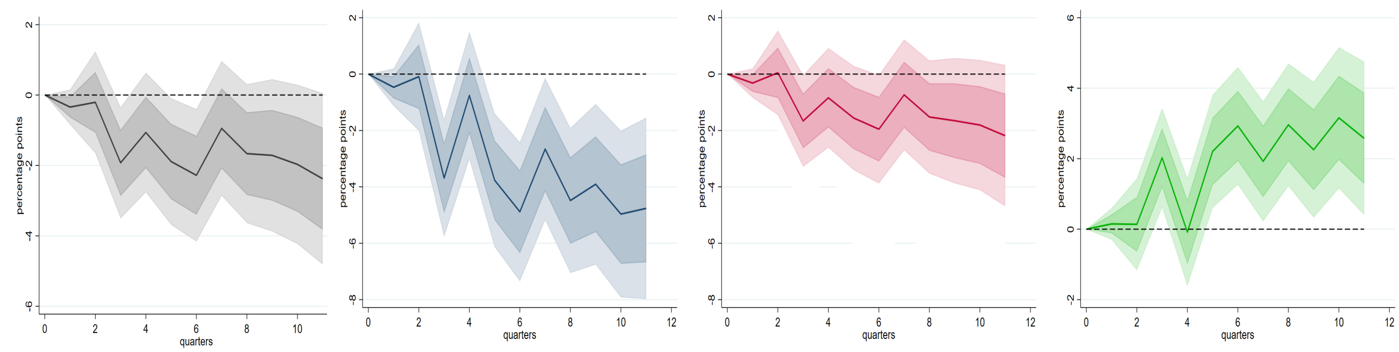
No State-Dependence **Allowing for State Dependence**



(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

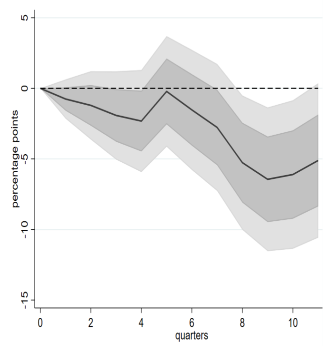
Note: Solid Lines in the first three columns depict point estimates of the response of Real Consumption to a 100 b.p. contractionary shock to monetary policy. Shaded areas depict 68% (darker) and 95% (lighter) confidence intervals. The solid line in the fourth column depict the difference between the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

Real Investment

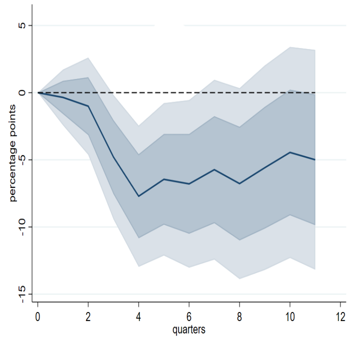
Figure 10: ***Real Private Investment, response to a monetary policy shock***

Panel A: Choleski-style Identification

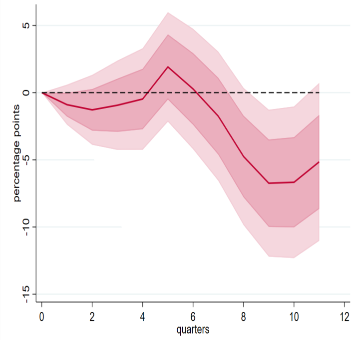
No State-Dependence **Allowing for State Dependence**



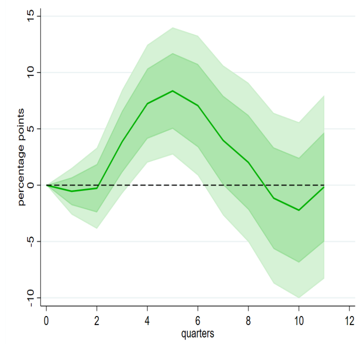
(a) Baseline Response



(b) Response in low rate state



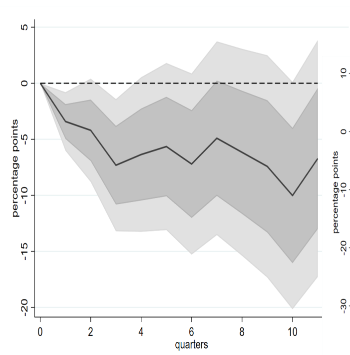
(c) Response in high rate state



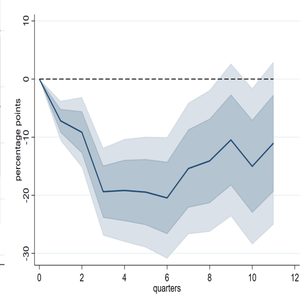
(d) Difference, low vs high state

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

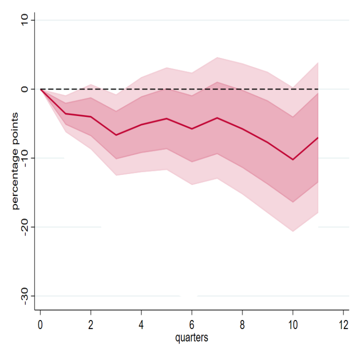
No State-Dependence **Allowing for State Dependence**



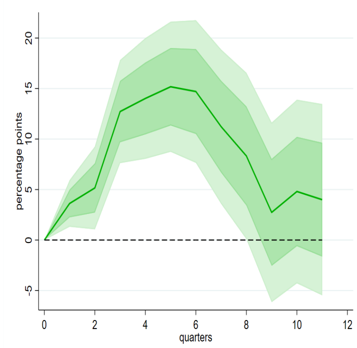
(e) Baseline Response



(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 Investment 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.

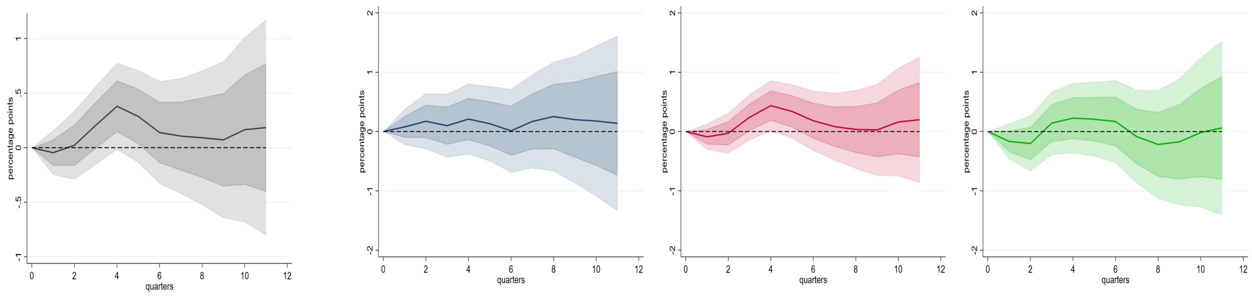
Figure 11 displays the effect of the policy shock measures on the log of the personal consumption expenditures price index. Interestingly, there is no evidence that the response of this variable is state-dependent. Regardless of whether the the shock occurs in the low or the high state, a contractionary does not induce a statistically significant change in the price level.

Log of PCE Prices

Figure 11: ***Log of PCE prices, response to a monetary policy shock***

Panel A: Choleski-style Identification

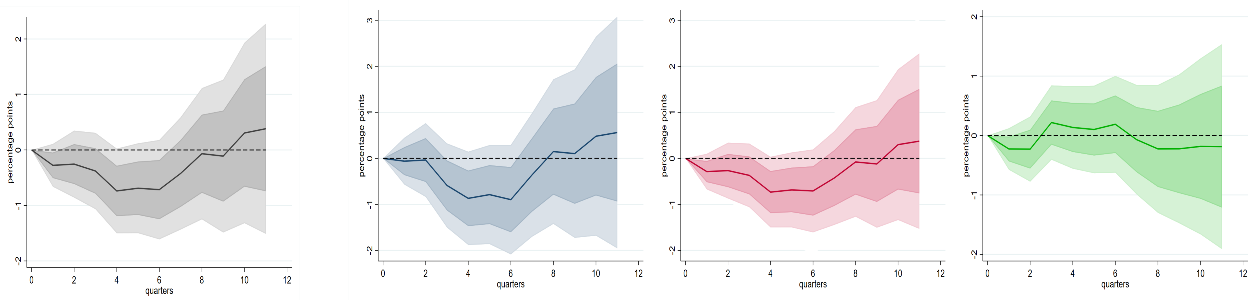
No State-Dependence **Allowing for State Dependence**



(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 decline in the aggregate price level. In contrast to the conventional view, the effect of a monetary policy shock is state-dependent. It induces a substantially larger decline in economic activity after a period of low policy rates. This state-dependent effect parallels our findings about state dependence in the response of NIM and associated financial indicators to a contractionary monetary policy shock.

4.4 Connecting the 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 roughly 95 and 92 billion dollars, respectively. These increases amount to 0.34% and 0.33% of 2023 GDP. Suppose instead that the shock occurs in the high-interest-rate state. Then, the corresponding impact on NIM-related profits is a *decrease* of 64 and 98 billion dollars, depending on the shock measure, which amounts to 0.23% and 0.35% of 2023 GDP. In sum, Commercial Banks' counterparts save 15 and 191 billion dollars in net interest paid if the shock occurs in the high state rather the low state. These savings correspond to 0.57% or 0.68% of 2023 GDP.

Suppose that bank profits accrue to people with a much lower marginal propensity to consume out of liquid wealth than those who receive interest income from banks. Then, the contraction in aggregate demand should, other things equal, be larger when a contractionary policy shock occurs in the low state. We explore this conjecture in two parts. In section 4, we construct a partial equilibrium banking model to account for our main NIM results. In section 5, we embed the banking model in a medium-scale TANK model to account for 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 the financial variables discussed in the previous section.

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. In the third subsection, we incorporate these social dynamics into our banking model.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. Every period, a fraction δ of dollar deposits leave their bank 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 $\mu \left(\delta a_t\right)^{\varsigma} v_{at}^{1-\varsigma}/v_{at}$ and $\mu \left(\delta i_t\right)^{\varsigma} v_{it}^{1-\varsigma}/v_{it}$, respectively.

In equilibrium, all deposits find a match,

$$v_{at} = \delta a_t \quad \text{and} \quad v_{it} = \delta i_t. \tag{2}$$

The reason is that household's opportunity cost of funds within the period is zero, so households accept any non-negative interest rate offered by banks. To simplify our analysis, we assume that deposit markets are perfectly competitive. 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 deposits are valuable to banks and they compete for deposits.

In equilibrium, the total cost of deposit acquisition by banks is

$$\delta\left(\tau_a a_t + \tau_i i_t\right).$$

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^l, is

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

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,

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

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

In conjunction with (2), these conditions imply,

$$\tau_a = \mu V_{a,t} \text{ and } \tau_i = \mu V_{i,t}. \tag{6}$$

If R_t is constant over time, then the value of a dollar of deposits belonging to attentive and inattentive households is given by,

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

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

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

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

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

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

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

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 this effect in a simple way, 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. So, attentive depositors benefit more from a rise in the Federal Funds rate than inattentive ones.

The bank's net interest margin (nim_t) is given by,

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

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,

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

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

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

Equation (9) has two key implications. First, nim_t decreases with the fraction of attentive households in the economy. The reason is that the interest rate spread earned by banks 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,

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

The interpretation of the last two terms in this expression is as follows. The term ε^l represents the operational costs from lending and $\delta\left(a_t \tau_a + i_t \tau_i\right)$ are the costs of customer acquisition. Banks make zero profits in a present value sense but they make positive profits on a period by period basis. These profits are the returns on prior investments on deposit acquisition.

5.2 Social dynamics

We now consider changes in the fraction of households that is inattentive 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 interest rate.

The laws of motion for the number of inattentive and attentive households is 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 in the sense that they are a function of the interest rate. The endogenous interactions occur in 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 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 exogenous interactions occur at the end of the period. A fraction κ_a of the households who were attentive in the beginning of the period become inattentive. A fraction fraction κ_i of the households that remain inattentive after social interaction become attentive.

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

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

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

The number of attentive households who become inattentive is $\kappa_a a_t$, so the probability that an attentive becomes inattentive is κ_a.

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

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

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

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

A key implication 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,

$$\tau_j = \mu V_{j,t}.$$

Using this result we obtain

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

and

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

The interest rate spread for attentive depositors is:

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

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 decline.

The interest rate spread for inattentive depositors is:

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

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, raising the probability that an inattentive household becomes attentive.

Recall that nim_t is given by,

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

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

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

We can rewrite nim_t as

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

The first two terms in this expression equal the value of nim_t in an economy without social interactions. The intuition for those terms is described 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

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

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,

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

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 deposits of attentive households is smaller than the spread on deposits 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

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

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:

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

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.

We now discuss the quantitative properties of our model. We use the parameter values listed in Table 1.

Table 1: Parameter values

Parameter	Parameter value	Description
κ_i	0.0008	Rate at which inattentive become attentive
κ_a	0.0029	Rate at which attentive become inattentive
χ	1.2173	Social dynamics interaction parameter
τ_a/μ	0.0123	Cost of attracting attentive depositors/matching function parameter
τ_i/μ	0.1333	Cost of attracting inattentive depositors/matching function parameter
δ	0.0237	Fraction of depositors who leave banks for exogenous reasons
R_L	1.015	Gross annual interest rate, low interest rate state
R_H	1.056	Gross annual interest rate, high interest rate state
ϵ_l	0.005	Cost per dollar of making loans
T_q	200	Frequency of social interactions in a quarter of time

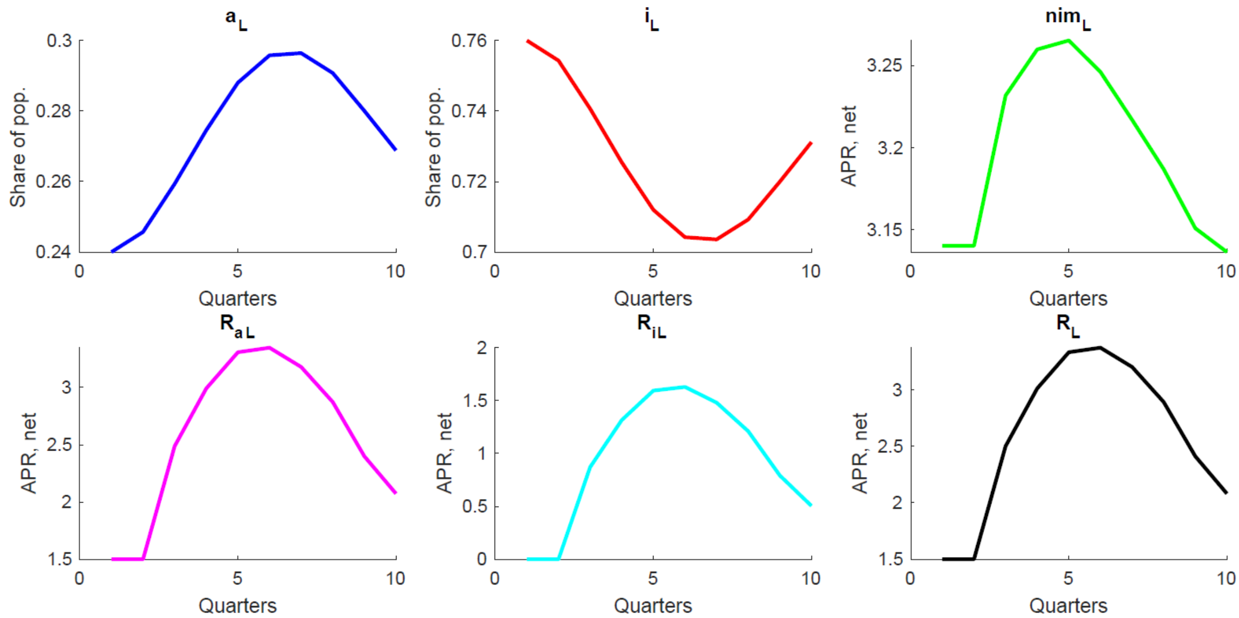
We calibrate our banking model parameters to jointly deliver that (i) $R_{i,t}, R_{a,t}$are never lower than one, i.e. deposits rates never get negative after a monetary policy shock in either of the two states considered (ii) the spreads $R_t - R_{i,t}, R_t - R_{a,t}$ are also always non-negative and (iii) the theoretical impulse responses of core net interest margins to a 100 b.p. monetary policy shock are as close as possible to their empirical counterparts presented in Section 3. We set $\epsilon_l = 0.005$ so that the difference between the lending rate to firms and the Federal Funds rate is two percent per annum (see equation 3). Finally, we set $\chi = 1.2173$ and $\delta = 0.0237$ corresponding to an annualized value of 0.9085 so that so that financial variables' dynamic model responses roughly coincide with the point estimates of the Bauer and Swanson [2022] reported above. In a future version of the paper we will estimate the parameters of the model

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 set $T_q = 200$ so that households have multiple social interactions per day.

To illustrate the properties of the model, we compute the equilibrium response of nim_t to a temporary rise in the policy rate. We begin from two steady states corresponding to a low interest rate, $R = 1.015$, and a high interest rate, $R = 1.056$. We then consider the dynamics response of nim_t to a temporary rise in interest rates, beginning in these two steady states. The interest rate shocks are the first nine estimates of the impulse response function of the Federal Funds rate to a 100 basis points policy shock depicted in Figure 1.

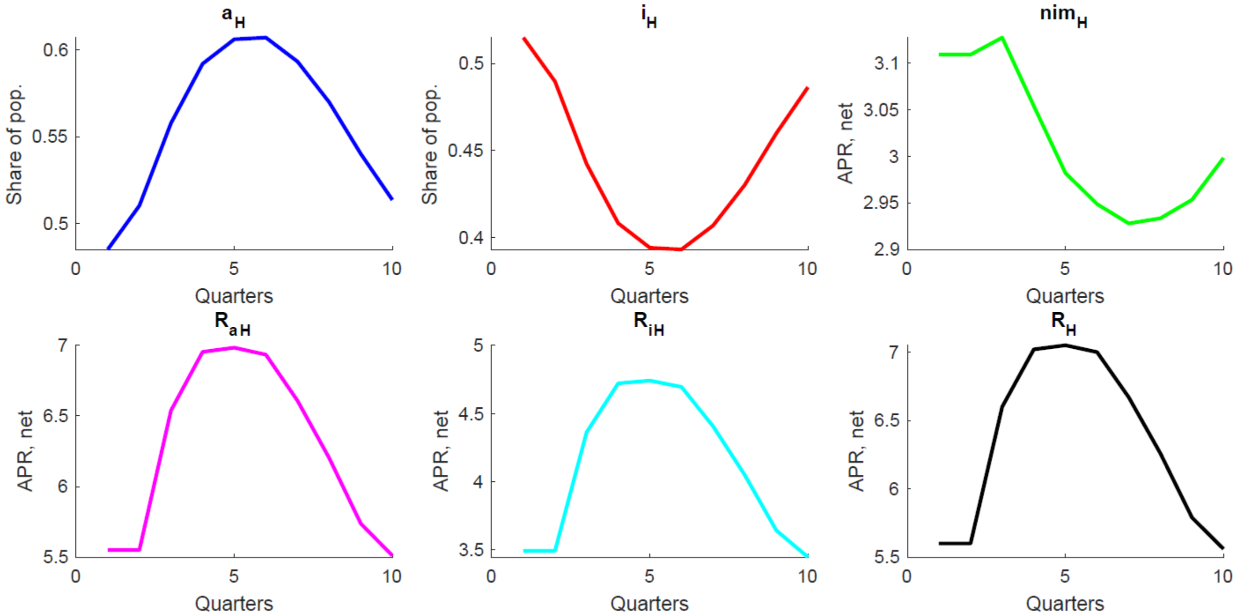
Figures 12 and 13 illustrate the responses of various aggregates to a rise in R, starting from the low and high level of interest rates, respectively.

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



Consider first the responses when the initial interest rate is low. Three interesting features of Figure 12 are worth noting. First, a rise in R_t leads to a substantial increase in the fraction of attentive households. Second, deposit rates rise but by less than the interest rate on loans. The latter is equal to the increase in the Federal Funds rate. Third, the policy shock induces a substantial increase in nim_t. The intuition for the previous results can be summarized as follows. First, the present value effect is stronger when R_t is low, i.e., there is a larger decline in the present value of future profits that a current rise in interest rate spreads must offset. Second, there is a high level of inattentive depositors, a substantial fraction of which will become attentive in the future. Recall that those types of customers will be less profitable for the bank in the future. Since there many such customers, this effect creates substantial upward pressure on current nim_t to ensure zero profits in equilibrium.

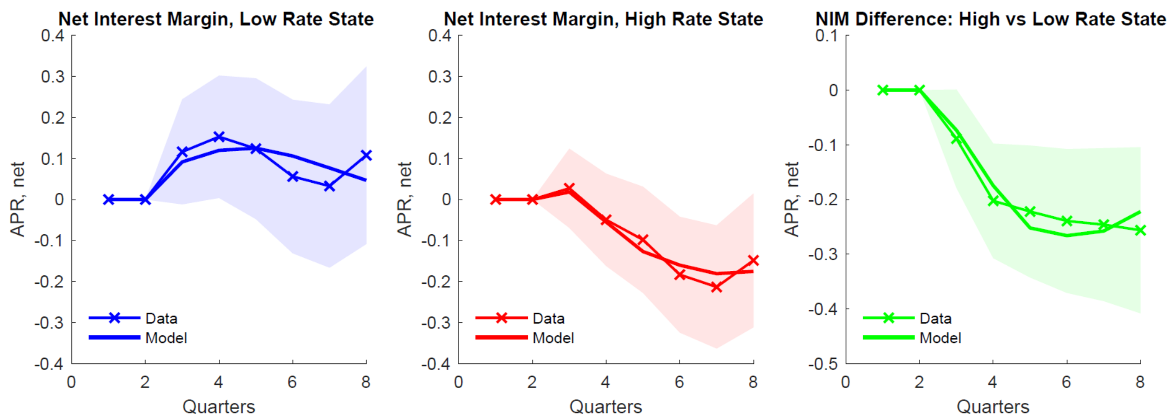
Figure 13: Dynamic response to monetary policy shock in high-interest-rate state.



Next, consider the responses when the initial interest rate is high. Three interesting features of Figure 13 are worth noting. First, the initial share of inattentive households is low. So, a rise in R_t does not lead to a substantial decline in the share of inattentive households and a corresponding increase in the share of attentive households. Second, the rise in the interest rate paid to attentive households is very large. Since nim_t is dominated by the high share of attentive households, nim_t does not react much to a change in the fe deral funds rate. The intuition behind these results can be summarized as follows. First, as discussed above, the impact of a rise in interest rates on the present value of future profits is weaker when R_t is high. Second, since most depositors are attentive, banks have few inattentive depositors who will turn attentive in the future. So, a small number of customers will become attentive in the future. Recall that those types of customers are less profitable for the bank in the future, creating upward pressure on current nim_t to counteract that effect. Since there are few such customers, the rise in nim_t that's required to have \zero profits in equilibrium is small.

Finally, Figure 14 shows the level responses of nim_t in the high and low interest rate states as well as the differences between those responses. We plot the model-based responses along with the empirical counterparts obtained using the Bauer and Swanson (2023) 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 one cannot reject the null hypothesis that the response functions are the same.

Figure 14: Dynamic response to monetary policy shock: Net Interest Margin



Note: This figure compares the theoretical impulse response functions generated from the partial equilibrium banking model to their empirical counterpars presented in section 3. Solid lines display the model IRFs. Solid Lines with "x" markers display the corresponding empirical IRFs. Shaded areas represent the 90% confidence bands of the empirical IRFs.

6 Banking in a general equilibrium model TANK model

In this section, we describe a general equilibrium model which embodies our banking model. In the model, state-dependent pass of policy rate changes to deposit rates interact with the presence of households who have a high marginal propensity to consume out of liquid wealth. The net result is to induce state dependency in the way that monetary policy affects aggregate economic activity.

In reality, there are many types of households who have a high marginal propensity to consume out of liquid wealth. For example, many retirees derive a substantial part of their income from various types of bonds. Other examples, include wealthy hand-to-mouth consumers of the sort emphasized by Kaplan et al. [2018], XXXX and poor 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 stressed in the literature is beyond the scope of this paper. Instead, we focus on a parsimonious TANK model that captures the interactions between the state-dependent passthrough of bank deposit rates to changes in the Federal Funds rate and the presence of some households with a high marginal propensity to consume out of liquid wealth. We assume that borrowing constraints are not binding for one group households in the model. We refer to these households as permanent income consumers (PI). Another class of households are hand-to mouth consumers. To simplify, we assume that permanent income households are always attentive. Hand-to-mouth households transit between attentive and inattentive states according to the social dynamics described in the partial equilirbrium model.

Importantly, given our timing conventions, households earn interest-income on their wages. So households can increase consumption using the extra income produced by from rises in deposit rates. This effect is particularly significant for hand-to mouth households.

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 contains our main results. Finally, in subsection 5.4 we discuss the sensitivity of our results to allowing for sticky wages as well as sticky prices.

6.1 Model Description

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

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

$$Y_t = \left(\int_0^1 Y_{i,t}^{\frac{1}{\gamma}} di \right)^{\gamma}, \gamma > 1. \tag{13}$$

The variable $Y_{i,t}$ denotes the quantity of intermediate input i used by the firm.

Profit maximization implies the following demand schedule for intermediate products:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\frac{\gamma}{\gamma-1}} Y_t. \tag{14}$$

Here, $P_{i,t}$ denotes the price of intermediate input i in units of the final good.

The price of output is given by:

$$P_t = \left(\int_0^1 P_{i,t}^{-\frac{1}{\gamma-1}} di \right)^{-(\gamma-1)}.$$

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

Intermediate goods producers Intermediate good i is produced by a monopolist using labor, $N_{i,t}$, and capital services, $K_{i,t}$, according to the technology:

$$Y_{i,t} = (K_{i,t})^{\alpha} N_{i,t}^{1-\alpha}. \tag{15}$$

Here $K_{i,t}$ and $N_{i,t}$ denotes the total amount of capital services and hours worked purchased by firm i. 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, $W_t N_{i,t}$ plus the nominal capital service bill, $R_t^k K_{i,t}$ from banks at the beginning of the period. The gross interest rate on those loans is 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 $s_{i,t} = \frac{\partial S_{i,t}}{\partial Y_{it}}$ where $S_{i,t} = min_{K_{i,t},N_{it}} R_t^l [r_t^k K_{i,t} + w_t N_{it}]$ and $Y_{i,t}$ is given by (15). Given our assumptions, the i^{th} firm's real marginal cost is

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

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

$$\pi_{i,t} = P_{i,t} Y_{i,t} - P_t s_{i,t} Y_{i,t}.$$

The i^{th} retailer sets its price, $P_{i,t}$ subject to the demand curve, (14) (2.4), and the following Calvo sticky-price friction:

$$P_{i,t} = \left\{ \begin{array}{cc} \Pi^{\iota} P_{j,t-1} & \text{with probability 1-}\xi \\ \widetilde{P}_t & \text{with probability } \xi \end{array} \right\} \tag{16}$$

When $\iota = 1$, prices are indexed to steady state inflation and, as a result, there is no price dispersion from steady state. When $\iota = 0$ there is no indexation and 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 current period realization of the monetary policy shock.

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

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

subject to the demand curve (14). We describe the first-order conditions for optimal price setting in the Appendix. [7]

Wage determination Christiano et al. [2016] show that estimated versions of three models of wage determination have virtually identical implications for macroeconomic aggregates: the search and matching matching model of labor in Hall and Milgrom [2008], Erceg et al. [2000] of Calvo-style sticky wages, and a reduced-form specification of real wages embodying inertia. To minimize notation, we adopt the last model and assume that after a shock, real wages evolve according to

$$w_t = \vartheta w_{t-1} + (1 - \vartheta) w + (1 - \vartheta) \frac{N_t}{N},$$

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 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,

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

$$N^H_{a,t} = \frac{a^H}{a^H_t}\frac{N^H_a}{N}N_t,$$

$$N^H_{i,t} = \frac{i^H}{i^H_t}\frac{N^H_i}{N}N_t,$$

Given the equilibrium equation for the labor market, these equations imply,

$$N^P_t = \frac{N^P}{N}N_t.$$

Households People are organized into two types of households, each of which has a continuum of identical members. The economy has a fraction ϕ of hand to mouth households and a fraction $(1-\phi)$ of permanent income households.

Hand-to-mouth households

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

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

subject to the budget constraint

$$P_t C^H_{j,t} = \left(W_t N^H_{j,t} - D^H_{j,t}\right) + D^H_{j,t} R_{j,t},$$

where $D^H_{j,t}$ 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

$$D^H_{j,t} \leq W_t N^H_{j,t}. \tag{17}$$

Firms deposit the household wages, $W_t N^H_{j,t}$ 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 $R_{j,t} \geq 1$, the constraint (17) holds with equality. We can write the resulting resource constraint as,

$$P_t C^H_{j,t} = R_{j,t} W_t N^H_{j,t}.$$

As discussed below, nominal wages are initially at their steady state and then adjust slowly in response to monetary policy shocks. Since employment is demand determined and the budget constraint holds with equality, the preferences of the hand-to-mouth households are irrelevant. Put differently, hand-to-mouth households consume 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:

$$U_t = E_t \sum_{l=0}^{\infty} \beta^t \left\{ \ln(C_{t+l}^P - bC_{t+l-1}^P) - \psi \frac{(N_{t+l}^P)^{1+\eta}}{1+\eta} \right\}, \tag{18}$$

subject to the budget constraint:

$$P_t \left(C_t^P + I_t\right) + B_{t+1} - R_{t-1}B_t + \Psi_t = \left(W_t N_t^P + R_t^K u_t \bar{K}_t - D_t^P\right) + D_t^P R_{a,t} + \int_0^1 \pi_i di + \pi_t^b, \tag{19}$$

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

$$D_t^P \leq W_t N_t^P + R_t^K u_t \bar{K}_t. \tag{20}$$

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 20 is binding. We can write the resulting resource constraint as

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

The variable $\bar{K}_t$ the beginning of period physical capital stock, Ψ_t denotes nominal lump-sum taxes, $\int_0^1 \pi_i di$ 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 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:

$$\bar{K}_{t+1} = [1 - \Delta(u_t)]\,\bar{K}_t + F(I_t, I_{t-1}). \tag{21}$$

The function F(.) summarizes the technology that transforms current and past investments into installed capital for use in the following period. As in CEE (2005)Christiano et al. [2005] this function is given by[8]

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

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 start of the period, firms borrow from banks their wage bill and capital rental costs. Banks issue firms checks which they use to pay the households. Households, in turn, deposit these funds back into the banks. By the end of the period, banks receive the funds they lent to the firms plus interest at a rate $R^l - 1$. They pay households their deposits plus interest, calculated at a rate $R_{a,t} - 1$ and $R_{i,t} - 1$ for attentive and inattentive depositors, respectively.

Social dynamics To simplify, we assume that PIH households are always attentive.[9] 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.

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

$$a_{t+1} = \phi + a_t^H(1 - \kappa_a) + \omega(R_t)(\phi + a_t^H)i_t^H(1 - \kappa_i) + \kappa_i i_t^H, \tag{22}$$

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

So

$$a_{t+1}^H = a_t^H(1 - \kappa_a) + \omega(R_t)(\phi + a_t^H)i_t^H(1 - \kappa_i) + \kappa_i i_t^H. \tag{23}$$

Also

[8] See Eberly et al. [2012] for empirical evidence in favor of this class of investment adjustment costs.

[9] Allowing the PIH to switch between attention states complicates the model while generating small quantitative effects. The reason is that the changes in consumption associated with changes in the state of attention are the anuity value times the difference between the deposit rates for attentive and inattentive depositors.

$$i_{t+1}^{H}=0+i_{t}^{H}(1-\kappa_{i})-\omega(R_{t})(\phi+a_{t}^{H})i_{t}^{H}(1-\kappa_{i})+\kappa_{a}a_{t}^{H}. \tag{24}$$

We can rewrite as

$$a_{t+1}^{H}=a_{t}^{H}(1-\kappa_{a})+\omega(R_{t})(\phi+a_{t}^{H})(1-\phi-a_{t}^{H})(1-\kappa_{i})+\kappa_{i}(1-\phi-a_{t}^{H}). \tag{25}$$

The number of attentive that become inattentive, $\kappa_a a_t^H$. Probability that an attentive becomes inattentive is:

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

The number of inattentive 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 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

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

where

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

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

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

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

The free entry condition is

$$\tau_j=\mu\frac{V_{j,t}}{P_t},$$

where τ_j is the real cost of attracting depositors of type j.

Using this result we obtain

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

and

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

The interest rate spread for attentive depositors is:

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

The interest rate spread for inattentive depositors is:

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

Banks's net interest income is given by,

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

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,

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

In equilibrium,

$$\upsilon_{at} = \delta \left(\phi D_t^p + a_t^H D_{a,t}^H\right),$$

Nominal banking profits are,

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

$$-\varepsilon^l \left(\phi D_t^p + a_t^H D_{a,t}^H + i_t^H D_{i,t}^H\right) - \left[\tau_a \delta \left(\phi D_t^p + a_t^H D_{a,t}^H\right) + \tau_i \delta i_t^H D_{i,t}^H.\right]$$

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,

$$\pi_t^b = \left(\phi D_t^p + a_t^H D_{a,t}^H\right) (R_t - R_{at} - \tau_a \delta) + i_t^H D_{i,t}^H (R_t - R_{it} - \tau_i \delta)$$

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:

$$\ln(R_t) = \rho\ln(R_{t-1}) + (1-\rho)\ln(R) + (1-\rho)\left[\theta_\pi ln\left(\frac{\Pi_t}{\bar{\Pi}}\right) + \theta_y ln\left(\frac{GDP_t}{GDP}\right)\right] + \varepsilon_t, \tag{26}$$

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 Calibration and Scenario Construction

In the last part of Section 4 we analyzed the responses of bank deposit rates and net interest margin to a 100 b.p. increase in the annualized monetary policy rates. In this section we redo this exercise in the context of the DSGE model described above. We cannot directly feed into the DSGE model two different interest rate values, high and low, because the policy rate is endogenously determined by the Taylor Rule.

We can however construct an observationally equivalent specification by assuming two different inflation targets. We assume that real rate, determined by β, remains constant and allow for different steady state nominal rates $R = \beta/\bar{\Pi}$. Importantly, the level of the nominal interest rate only matters for the social dynamics and the banking block. We set the low value for the low inflation target to zero and calibrate β and the high value for $\bar{\Pi}$ to match the empirical averages of the Federal Funds Rate in the high and low rate subsamples discussed in Section 3. Accordingly, we construct our "high for long" scenario by setting the gross inflation target $\bar{\Pi}$ to 1.01, or annualized inflation of 4%. We construct our "low for long" scenario by setting the gross inflation target $\bar{\Pi}$ to 1, or annualized inflation of 0%. We calibrate the steady state non-varying value of the real rate $r^* = 1.5\%$ annualized which implies a value of $\beta = 0.9963$. This procedure delivers a steady state nominal rate of 5.5% and 1.5% annualized, respectively, for the "high for long" and "low for long scenario."

Starting from each of the two steady states, we feed in eight MIT-shocks so that the implied interest rate path is the same as the empirical estimates associated with the Bauer-Swanson shock measure. See Figure 1. Thereafter, people assume that policy evolves according to the Taylor rule 26. To respect the timing assumptions adopted in the empirical analysis in Section 3, we assume that people made their period t decisions before seeing the time t monetary policy shock.

Table 2 reports the rest of the parameters of the model. Other than the parameters of the banking model which are discussed in Section 5, the parameters ρ_1^r and ρ_2^r which were discussed in the model setting subsection, and the parameters $\beta, \bar{\Pi}$, all the other parameters are calibrated to fairly standard values in the NK literature. Importantly, we calibrate the share of PIH consumers in the economy ϕ to the value estimated in Bilbiie et al. [2023] for a very similar TANK model.

Table 2: Parameter values

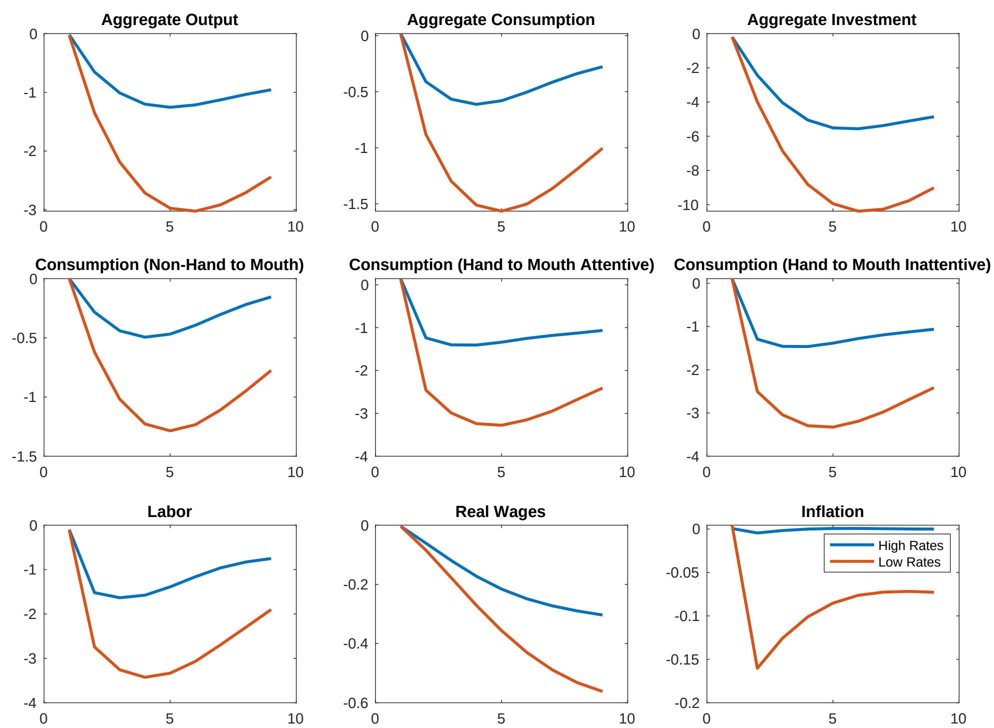
Parameter	Parameter value	Description
κ_i	0.0008	Rate at which inattentive become attentive
κ_a	0.0029	Rate at which attentive become inattentive
χ	1.2173	Social dynamics interaction parameter
τ_a/μ	0.0123	Cost of attracting attentive depositors/matching function parameter
τ_i/μ	0.1333	Cost of attracting inattentive depositors/matching function parameter
δ	0.0237	Fraction of depositors who leave banks for exogenous reasons
ϵ_l	0.005	Cost per dollar of making loans
T_q	1	Frequency of social interactions in a quarter of time
β	0.9963	discount factor
bb	0.8	habit formation
ϕ	0.75	share of Non-Hand-to-Mouth
χ^N	0.5	labour disutility scale
η	1	inverse Frish Elasticity
ψ_K	1.25	investment adjustment cost scale
δ_0	0.025	capital depreciation
δ_1	0.047	capital depreciation due to utilization (linear)
δ_2	0.001	capital depreciation due to utilization (quadratic)
α	1/3	capital share
ε^P	11	demand elast. for retail firms
ϕ^P	0.85	Calvo stickyness for retail firms
γ_1	0.99	wage stikyness
ρ_1^r	0.4	Taylor rule: persistance first coefficient
ρ_2^r	0.4	Taylor rule: persistance second coefficient
θ^{Π}	1.5	Taylor rule: inflation gap reaction
θ^y	0	Taylor rule: output gap reaction
σ^r	0.0025	Taylor rule: shock standard deviation
$\bar{\Pi}$	1.01 or 1	Taylor rule: inflation Target (High and Low)
ρ^A	0.9	Technology process: persistance
σ^A	0.01	Technology process: shock standard deviation
G/Y	0.18	Steady State ratio of Government Spending to Output

Note: This table displays the parameter values assumed in order to perform the quantitative exercize performed in section 5.4.

6.3 Results Baseline

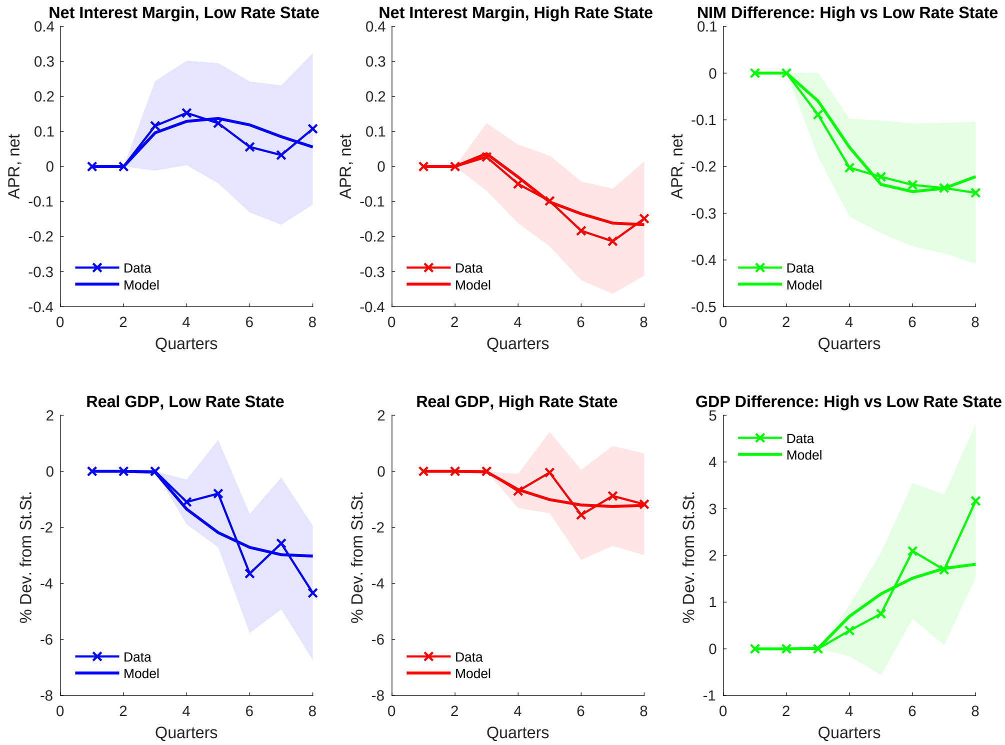
In this section we analyze the impulse response functions to a 25 b.p. monetary policy shock under the “high for long” and “low for long” scenarios constructed as described in section 5.3. Figure 15 displays these impulse response functions for the main aggregates of interest. Following the shock both output and consumption tend to decrease considerably and for an extended period of time, exhibiting an hump shaped pattern characteristic of standard NK models. The first main result is that the magnitude of the response is state dependent. At the peak of the response, aggregate output decreases by roughly double the amount of the decrease in the high rate scenario. A similar conclusion can be drawn for consumption and investments. The response of real wages is muted by wage stickyness. The labor market adjusts through significant movements in hours worked. The second main result is that the NIM increases after a monetary shock in the "low rates" scenario while it increases in the "high rate" scenario. This pattern emergies because there is perfect passthrough from the Federal Funds Rate to the interest rate on loans but imperfect passthorugh to the average deposit interest rates. This imperfect pass-through varies with the interest rate setting. In the "low rates" scenario, many more households are inattentive, so banks are paying the lower "inattentive deposit rate" on a relatively higher share of their deposits (extensive margin), in addition they pass-through less of the change in the policy rate to their inattentive customers than to their attentive customers (intensive margin). In the high interest rate scenario the opposite occurs.

Figure 15: Impulse Responses to a monetary policy shock of 25 basis points (100 b.p. annualized). Macroeconomic Aggregates.



Note: All figures display percentage deviations from steady state. All responses are expressed on an quarterly basis.

Figure 16: Impulse Responses to a monetary policy shock of 25 basis points (100 b.p. annualized). Net Interest Margin.



Note: All figures display level deviations from steady state. All responses are expressed on an quarterly basis.

7 Conclusion

We show that the impact of monetary shocks on the economy varies depending on whether they occur after a period of low or high interest rates. This state dependence is evident in both banking sector profitability measures and key macroeconomic variables, including GDP, consumption, and investment.

These empirical findings can be explained in a general equilibrium model featuring competitive banks with two key characteristics. First, some depositors are inattentive to the interest rates offered by banks. Second, this inattentive fraction increases when interest rates are low. The state dependence in deposit interest rates affects the broader economy because there are households with a high propensity to save out of liquid wealth.

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8 Appendix

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

$$S_{i,t} = min_{K_{i,t},N_{it}} R^l_t [r^k_t K_{i,t} + w_t N_{it}]$$

subject to

$$Y_{i,t} = (K_{i,t})^{\alpha} N_{i,t}^{1-\alpha}.$$

The first-order conditions for this problem are,

$$R^l_t r^K_t = s_{i,t} \alpha (K_{i,t})^{\alpha-1} N_{i,t}^{1-\alpha},$$

$$R^l_t w_t = s_{i,t}(1-\alpha)(K_{i,t})^{\alpha} N_{i,t}^{-\alpha}.$$

Combining,

$$\frac{r^K_t}{w_t} = \frac{\alpha N_{i,t}}{(1-\alpha)K_{i,t}}$$

We can now compute the i^{th} firm's real marginal cost, $s_{i,t}$,

$$s_{i,t} = \frac{R^l_t \left(r^K_t\right)^{\alpha} w_t^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}$$

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

$$\pi_{i,t} = P_{i,t} Y_{i,t} - P_t s_{i,t} Y_{i,t}.$$

The first-order conditions for optimal price setting are:

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

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

$$P_t C^H_{j,t} = R_{j,t} W_t N^H_{j,t}.$$

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,

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

$$P_t C^H_{j,t} = R_{j,t} W_t N^H_{j,t}.$$

The first-order conditions are,

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

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

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

Permanent income households

$$U_t = E_t \sum_{l=0}^{\infty} \beta^l \left\{ \ln(C^P_{t+l} - bC^P_{t+l-1}) - \psi \frac{(N^P_{t+l})^{1+\eta}}{1+\eta} \right\}, \tag{27}$$

subject to

$$P_t \left(C^P_t + I_t \right) + B_{t+1} - R_{t-1} B_t + \Psi_t = \left(W_t N^P_t + R^K_t u_t \bar{K}_t - D^P_t \right) + D^P_t R_{a,t} + \Phi_t, \tag{28}$$

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

$$[1 - \Delta(u_t)] \bar{K}_t + \left[1 - \frac{s_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t - \bar{K}_{t+1} = 0. \tag{29}$$

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

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

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,

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

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

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

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

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

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

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

$$C_t = \phi C_t^P + a_t^H C_{a,t}^H + i_t^H C_{i,t}^H$$

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

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

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

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

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

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

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

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

$$C_{a,t}^H = R_{a,t} w_t N_{a,t}^H$$

$$C_{i,t}^H = R_{i,t} w_t N_{i,t}^H$$

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

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

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

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

$$GDP_t = C_t + I_t + G_t$$

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

$$\widetilde{\upsilon}_{at} = \delta\phi d_t^p + \delta a_t^H d_{a,t}^H$$

$$\widetilde{\upsilon}_{it} = \delta i_t^H d_{i,t}^H$$

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

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

$$d_{a,t}^H = w_t N_{a,t}^H$$

$$d_{i,t}^H = w_t N_{i,t}^H$$

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

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

$$\upsilon_t = \frac{a_t^H d_{a,t}^H}{\phi d_t^p + a_t^H d_{a,t}^H}$$

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

$$G_t = G$$

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

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

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

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

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

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

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

$$w_t = \vartheta w_{t-1} + (1-\vartheta) w + (1-\vartheta) \frac{N_t}{N}$$

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 38 equations in 38 variables:

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

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

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

$$nim_t, \upsilon_t, a_t, i_t^H, a_t^H, d_t^p, d_{a,t}^H, d_{i,t}^H$$