

Monetary Policy and Household (De-)leveraging*

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ABSTRACT

This study investigates the interrelation between the household leverage cycle, collateral constraints and monetary policy. Using data on the U.S. economy, we find that contractionary monetary policy shock leads to a large and significant fall in economic activity during periods of household de-leveraging. Contrary, monetary policy shocks have only small and insignificant effects during a household leveraging state. These results are robust to alternative definitions of leveraging and de-leveraging periods, different ways of identifying monetary policy shocks, controlling for the state of the business cycle and controlling for the level of households debt. To provide a structural interpretation for these empirical findings, we estimate a monetary DSGE model with financial frictions and occasionally binding collateral constraints. The model estimates reveal that household de-leveraging periods in the data mainly coincide with periods of binding collateral constraints whereas constraints mainly turn slack during leveraging episodes. Moreover, the model produces an amplification of monetary policy shocks that is quantitatively comparable to our empirical estimates. Thus, the state-dependent tightness of collateral constraints accounts for the asymmetric effects of monetary policy across the household leverage cycle as found in the data.

JEL Codes: E32, E52.

Keywords: Monetary policy, household leverage, occasionally binding constraints.

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1 Introduction

Over the last two decades, private household leverage has fluctuated substantially. The loan-to-value ratio has increased from 35% at the beginning of the 2000s to 56% at the outburst of the latest financial crisis. Due to the massive de-leveraging process that occurred afterwards, the ratio has fallen back to 38% in 2015. A growing number of mostly theoretical studies interprets this significant household leveraging and de-leveraging as the central element to understand the boom and bust period that ended with the Great Recession (Eggertsson and Krugman 2012, Guerrieri and Iacoviello 2017, (GI)). Moreover, recent empirical contributions show that the evolution of household debt is crucial for understanding the propagation and amplification of economic shocks and policy interventions, see e.g., Klein (2016), Mian et al. (2013) and Schularick and Taylor (2012).

Despite the important role of the household credit cycle in shaping macroeconomic outcomes, little is known about whether the effectiveness of monetary policy depends on household debt dynamics. This issue is of particular interest because unconventional monetary policy interventions and massive household de-leveraging have evolved in parallel over the last years. If borrowing constraints play an important role for households' consumption and saving decisions and the tightness of collateral constraints varies considerably with the households' debt position, monetary policy may indeed have asymmetric effects across the leverage cycle.

Against this background, our contribution in this paper is twofold: first, we provide extensive empirical evidence that the leverage cycle crucially affects the monetary transmission mechanism. In particular, we find that a monetary policy shock has strong and significant effects on economic activity during periods of household de-leveraging, whereas during periods of household leveraging there are no discernible effects. Second, to provide a structural interpretation for our empirical findings, we estimate a New Keynesian DSGE model enriched by financial frictions and occasionally binding borrowing constraints. The model implies that time variation in the tightness of collateral constraints explains the asymmetric impact of monetary policy across states of the household leverage cycle.

To investigate the effects of monetary policy shocks conditional on the household leverage cycle, we estimate state-dependent impulse responses of aggregate variables to exogenous monetary policy interventions using local projections as proposed by Jordà (2005). The estimated responses are allowed to depend on whether household leverage expands or contracts. To measure the stance of monetary policy, we use the shadow federal funds rate constructed by Wu and Xia (2016). Thereby, we take the significant de-leveraging process that occurred after the 2008 financial crisis into account. In our baseline estimation, we rely on a timing restriction to identify monetary policy shocks. This assumption is widely used in the traditional VAR literature (see for example Christiano, Eichenbaum, and Evans 2005).

The empirical results reveal that when private households de-lever, an increase in the short-term interest rate leads to large and significant decreases in GDP, inflation, private consumption and investment. In contrast, monetary policy shocks have only small and mostly insignificant effects during a household leveraging state. The maximum GDP response in a de-leveraging state is two times larger than the corresponding GDP response in a leveraging state. Moreover, the cumulated responses in a de-leveraging state are estimated to be statistically significantly larger than the respective responses in a leveraging period.

Our results are robust to alternative definitions of leveraging and de-leveraging periods and different ways of identifying monetary policy shocks. Moreover, we show that positive and negative monetary policy shocks are fairly evenly distributed across leveraging and de-leveraging states, which implies that our findings are not driven by the nature of the shocks.

Notably, our findings prove to be robust when we condition on two other prominent state variables. First, previous studies find that the state of the business cycle affects the impact of a monetary policy shock (Angrist et al. 2017, Tenreyro and Thwaites 2016). However, we show that in periods of household de-leveraging, a contractionary monetary policy shock induces a significant fall in economic activity in expansions but also in recessions. Likewise, irrespective of whether the economy is experiencing a boom or recession,

a monetary policy shock has no significant effect during household leveraging periods. Second, in a related paper Alpanda and Zubairy (2017) find that the level of household debt impacts the effectiveness of monetary policy interventions. We show that the effects of a monetary policy shock are amplified in periods of de-leveraging both in periods of high and low household debt. In addition, during household leveraging periods, monetary policy shocks induce significant changes in economic activity only when household debt is low, although these effects are small and just short-lived. Overall, our findings suggest that the change in household leverage is of first order importance for the effectiveness of monetary policy interventions whereas the state of the business cycle and the level of household debt only plays a secondary role.

Additionally, we conduct an analysis based on more disaggregated data. For this purpose, we construct monetary policy shocks at the level of US geographical states by relying on the identification approach proposed by Nakamura and Steinsson (2014). Our state level estimates support the aggregate finding that the effects of monetary policy shocks are significantly amplified during period of household de-leveraging.

To shed light on the mechanism underlying our empirical results, we set up a DSGE model following Christiano et al. (2005) and Smets and Wouters (2007), and include financial frictions on the household side as proposed by GI. This set-up provides us with a toolkit in which the interrelation between household leverage, collateral constraints and monetary policy can be investigated. The model features two types of households with heterogeneous saving-consumption preferences, which generates borrowing and lending. Borrowing households face a housing collateral constraint which limits borrowing to a maximum fraction of housing wealth. Importantly, this constraint binds only occasionally rather than at all times, implying that the propagation and amplification of economic shocks in general and exogenous monetary policy interventions in particular depend on the endogenous degree of financial frictions.

We match the model to macro data and find significant time-variation in the tightness of collateral constraints. Moreover, the model estimates reveal that prolonged periods of de-leveraging in the data mainly coincide with episodes of binding collateral constraints

in the model. In contrast, constraints mainly turn slack during leveraging episodes. We then compute the model-implied impulse responses to a monetary policy shock when the constraint is binding and in a period in which it turns slack. A contractionary monetary policy shock in the states where the constraint is binding generates amplification effects that are quantitatively comparable to our empirical estimates. These larger responses are driven by financially constrained households, who are forced to cut on their consumption when a bad shock hits the economy.

Our study reveals important implications. From a policy perspective it offers a better understanding on the effectiveness of monetary policy, thereby pointing out the important role of household leveraging and de-leveraging for the conduct of policy interventions. In particular, our results suggest that the significant de-leveraging process that occurred over the last years has amplified the positive effects of unconventional monetary policy interventions.

Our paper contributes to the recent and still growing literature on the role of household debt for understanding the impact of macroeconomic shocks. Mian and Sufi (2011, 2012) show that those US counties which experienced the largest increase in housing leverage before the financial crisis, suffered from more pronounced economic slack in the post-crisis period. Jordà et al. (2016) find that more mortgage-intensive credit expansions tend to be followed by deeper recessions and slower recoveries, while this effect is not present for non-mortgage credit booms. Di Maggio et al. (2017) and Wong (2015) show how households' heterogeneous financial profiles affect the transmission of monetary policy. We contribute to this literature by first, showing that the state of the household leverage cycle matters for the effectiveness of monetary policy and second, by estimating a model in which the degree of financial frictions is endogenously determined to explain these empirical findings.

The rest of the paper is organized as follows. Section 2 describes our empirical method, the definition of household leveraging and de-leveraging periods and the identification of monetary policy shocks. In Section 3, we present our baseline empirical finding and demonstrate that our results are robust to various robustness checks. Section 4 presents

the structure of the DSGE model. In Section 5, we use the model to investigate the interplay between de-leveraging, collateral constraints and monetary policy. Finally, Section 6 concludes.

2 Econometric Method

To investigate the effects of monetary policy shocks depending on the state of the economy, we follow Tenreyro and Thwaites (2016) and Ramey (2016) in estimating state-dependent impulse responses to exogenous monetary policy innovations using local projections as proposed by Jordà (2005). Recently, this method has become a very popular tool to estimate state-dependent models and calculate impulse responses. The main advantages compared to VARs are that local projections are more robust to model misspecifications and do not impose the implicit dynamic restrictions involved in VARs. Moreover, local projections offer a very convenient way to account for state dependence.¹ The Jordà method simply requires estimation of a series of regressions for each horizon, h , and for each variable. The linear model takes the following form:

$$y_{t+h} = \alpha_h + \tau t + \psi_h(L)x_t + \beta_h \epsilon_t + u_{t+h}, \text{ for } h = 0, 1, 2, \dots, \quad (1)$$

where y is a specific variable of interest (e.g. GDP), τ is a linear time trend, x is a vector of control variables, $\psi_h(L)$ is a polynomial in the lag operator, and ϵ measures the identified monetary policy shock. The coefficient β_h measures the response of y at time $t + h$ to the monetary policy shock at time t . Thus, the impulse responses are constructed as a sequence of β_h 's estimated in a series of separate regressions for each horizon. The state-dependent model is easily adapted. More specifically, we estimate a set of regressions for each horizon h as follows:

¹The Jordà method does not uniformly dominate the standard VAR approach for calculating impulse responses. In particular, because it does not impose any restrictions that link the impulse responses across different horizons, the estimates are often erratic because of the loss of efficiency. Moreover, it sometimes display oscillations at longer horizons. For a more detailed discussion, we refer to Ramey and Zubairy (2014).

$$\begin{aligned}
y_{t+h} = & \tau t + I_{t-1} [\alpha_{A,h} + \psi_{A,h}(L)x_t + \beta_{A,h}\epsilon_t] \\
& + (1 - I_{t-1}) [\alpha_{B,h} + \psi_{B,h}(L)x_t + \beta_{B,h}\epsilon_t] + \nu_{t+h},
\end{aligned} \tag{2}$$

where τ is the linear time trend and $I_{t-1} \in \{0, 1\}$ is a dummy variable that captures the state of the economy before the monetary policy shock hits. In particular, I_{t-1} takes the value of one when households de-lever and zero otherwise. Following the literature on state-dependent effects of fiscal policy (see for example Auerbach and Gorodnichenko 2012, Ramey and Zubairy 2014), we include a one-period lag of I_t in the estimation to minimize the contemporaneous correlation between the shock series and changes in the indicator variable. The coefficients of the model (other than the deterministic trend) are allowed to vary according to the household leveraging state of the economy. Thus, the collection of $\beta_{A,h}$ and $\beta_{B,h}$ coefficients directly provide the state-dependent responses of variable y_{t+h} at time $t+h$ to the shock at time t . Given our specification, $\beta_{A,h}$ indicates the response of y_{t+h} to the monetary policy shock in household de-leveraging states whereas $\beta_{B,h}$ shows the effect in household leveraging states.

To define episodes of household leveraging and de-leveraging, we first need an appropriate indicator to measure household leverage. For this purpose, we use the home mortgages-to-real estate ratio. This ratio measures the amount of outstanding housing debt relative to its underlying collateral asset. The same indicator for household leverage was used by Justiniano et al. (2015) and Dynan (2012) who study the impact of household leveraging and de-leveraging on personal consumption and other main aggregates. Moreover, the Bureau of Economic Analysis refers to the mortgages-to-real estate ratio as an important indicator for the state of the aggregate economy. Importantly, this measure is a close analogue to the leverage ratio frequently included in DSGE models with household collateral constraints. Thus, our leverage series mimics the theoretical counterpart used in the later part of this paper.

In our baseline specification, we apply the Harding and Pagan (2002) algorithm to detect periods in which household leverage is expanding and contracting, respectively. The Harding and Pagan (2002) algorithm is widely used in the business cycle literature, to differentiate between economic expansions and contractions. We use a four quarter minimum for expansions and contractions in household leverage to identify leveraging and de-leveraging periods. This procedure implies that out of the 219 periods included in the sample, 107 or 49% are detected as de-leveraging periods, while the remaining 112 episodes or 51% indicate periods of household leveraging.

As shown in Figure 1, we detect five periods of de-leveraging: 1966q3-1973q4, 1975q1-1983q2, 1998q1-2001q2, 2004q2-2006q1, 2010q1-2015q1. These distinct de-leveraging states correspond with distinct episodes in the US economic history. The first period of household de-leveraging which happened from the mid 1960s to the early 1970s indicates the consequences of the so-called Credit Crunch. The second de-leveraging episodes which lasts from the mid 1970s until the beginning of the 1980s coincides with the surge in interest rates towards the end of the great inflation period. Around the 2000s, the Asian and Dot-com Crisis caused two more short-lived de-leveraging periods. Finally, following the Great Recession, private households reduced their leveraging position substantially which corresponds with our fifth de-leveraging episode at the end of the sample.

In a separate exercise it is shown that the results are robust to an alternative definition of household leveraging and de-leveraging states. More precisely, we define a de-leveraging state as a period in which the year-on-year change in the home mortgages-to-real estate ratio is negative for at least two consecutive quarters.

In our baseline specification, we calculate monetary policy shocks by relying on a recursive identification scheme commonly used in the traditional VAR literature (see for example Christiano, Eichenbaum, and Evans 2005). As shown by Barnichon and Brownlees (2016), when estimating local projections such a timing restriction correspond to a specific choice of control variables. We include the following variables in the vector of control variables, x_t : the log-levels of GDP, the GDP deflator, the household leverage ratio, the shadow federal funds rate constructed by Wu and Xia (2016) and the corporate

bond spread measured as the difference between the Baa corporate bond yield and the long-term government bond yield. We assume that the monetary authority reacts contemporaneously to changes in GDP, the GDP deflator and the household leverage ratio while it reacts only with a one-period lag to changes in the corporate spread. Thus, we assume that a monetary policy shock has no contemporaneous effects on the first three variables of the data set. Note that, this identification assumption is equivalent to using the contemporaneous shadow federal funds rate as the shock ϵ_t in Equations (1) and (2), and ensuring that the contemporaneous and lagged values of GDP, the GDP deflator, the household leverage ratio, along with the lagged values of the corporate spread and the shadow federal funds rate, are part of x_t in Equations (1) and (2). By including the household leverage ratio into the vector of control variables, we allow the central bank to take the state of the household leverage cycle into account when setting the short-term interest rate. In the baseline specification, x contains two lags each of the dependent variable and the short-term interest rate.

This identification allows us to use a sample period spanning 1960q1-2015q1. The start and end of the sample are characterized by the availability of quarterly data for the shadow federal funds rate.² By measuring the actual stance of monetary policy by the shadow federal funds rate, we are able to include the massive household de-leveraging that occurred after the Great Recession in our estimations. Moreover, in contrast to the effective federal funds that is constrained by the ZLB, the Wu and Xia (2016) allows to identify the effects of unconventional monetary policy interventions.

In a latter exercise we show that our results are robust when identifying monetary policy shocks by the narrative Romer and Romer (2004) series. These shock series are obtained as residuals from a regression of the federal funds rate on the lagged values of output and inflation Greenbook forecasts, which are all in the Federal Reserve's information set. As argued by Romer and Romer (2004), the obtained residuals are exogenous

²We obtain quarterly information on the shadow federal funds rate by simple averaging the monthly series provided by Wu and Xia (2016).

with respect to the business cycle. However, this series is available only for a shorter sample spanning 1969q1-2012q4.³

3 Empirical Results

In this section, we present our main empirical findings. First, we discuss the estimation results based on our baseline specification. We indeed find that the impulse responses reveal significant differences of monetary policy shocks across the household leverage cycle. We then conduct various robustness checks that confirm our baseline findings. Thereby, we show that our findings are robust to alternative ways of identifying monetary policy shocks and different definitions of leveraging and de-leveraging states. Moreover, we present evidence that our results are not driven by a different distribution of monetary policy shocks across household leveraging states. Most importantly, we demonstrate that our finding of household leverage-dependent effects of monetary policy is robust when we additionally control for the state of the business cycle and the level of household debt. In an additional exercise, we conduct an analysis at the level of US geographical states and verify that our main findings are also present when relying on this more disaggregated data.

3.1 Baseline

Figure 2 shows the impulse responses of GDP, inflation, private consumption and investment to a contractionary shock to the shadow federal funds rate for our baseline specification. The first column presents the results of the linear model whereas the second and third columns shows the responses in a de-leveraging and a leveraging state, respectively. The solid lines show the response to a monetary policy shock, where 0 indicates the quarter in which the shock occurs. Shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

³We use the updated Romer-Romer shock series up to 2012q4 from Silvia Miranda Agrippino's website.

We first discuss the results of the linear model. In response to an increase in the federal funds rate, GDP, private consumption and investment decline significantly, where the responses peak between 10 and 12 quarters after impact. The inflation response is more muted and mostly insignificant. Just at the end of the forecast horizon, we observe a significant fall in prices.

As columns 2 and 3 reveal, the effect of monetary policy shocks differ substantially across the household leverage cycle. When households de-lever, GDP falls significantly in response to a contractionary monetary policy innovation. In contrast, GDP does not change significantly in a leveraging state. The response is two times smaller when compared to the de-leveraging state.

When taking a closer look at the subcomponents, it turns out that most of the state-dependent GDP response is driven by private consumption. In a de-leveraging state, consumption decreases significantly, whereas in a leveraging the consumption response is mostly insignificant. Compared to a de-leveraging period, the maximum response is almost two times smaller. Also investment reacts differently in both leveraging states: in a de-leveraging period, investment decreases significantly whereas in leveraging periods, the monetary policy shock induces no significant investment response.

The inflation response also depends on the state of the household leverage cycle. While inflation reacts insignificantly in a leveraging state, it falls significantly in a de-leveraging state. Nevertheless, in a de-leveraging state, the decline in inflation becomes statistically significant only after 10 quarters.

The state dependent responses reveal differences in the propagation and amplification of monetary policy shocks under household leveraging and de-leveraging states at different horizons. In order to further assess the total effectiveness of monetary policy in each state, we also compute the cumulative impulse responses. Figure 3 shows the cumulative effects of each variable in the linear model and in both leveraging states. The cumulative responses are computed using the integral of the corresponding impulse response function. The Figure clearly illustrates that for all variables, the effect in a de-leveraging state is substantially larger than a leveraging state. In a de-leveraging period, the cumulative

GDP response to a contractionary monetary policy shock is three times larger compared to a leveraging state. A similar result emerges when inspecting the respective consumption, investment and inflation responses. Importantly, these difference between the cumulative impulse responses are also statistically significant.

Overall, these results suggest that the effectiveness of monetary policy interventions crucially depends on the household leverage cycle. When private households de-lever, an increase in the short-term interest rate has large and significant effects on aggregate economic activity and inflation. In contrast, monetary policy does not have a significant impact on the economy when households increase their leveraging position.⁴

3.2 Robustness

In this section, we consider various robustness checks on our baseline specification.

Alternative Identification: In our baseline specification, we identify exogenous monetary policy innovations by relying on a timing restriction. Now, we conduct the same analysis as in the previous section, but consider the Romer and Romer (2004) narrative measure. We use the extended series by Silvia Miranda-Agrippino which is available for the period 1969q1-2012q4. Figure 4 and Figure 5 show that our main results are robust to this alternative identification approach.

Alternative State Definition: We now make use of an alternative way to differentiate between leveraging and de-leveraging periods. For this purpose, we define de-leveraging states as those periods in which the year-on-year change in the home mortgages-to-real estate ratio is negative for at least two consecutive quarters. Figure 6 and Figure 7 present the results of this exercise. It turns out that our findings prevail when using this alternative state definition.

⁴Note that, our results cannot be explained by a different reaction of the short-term interest rate. In both leveraging states, the interest rate reacts fairly similar to a contractionary monetary policy shock. These results are available from the authors upon request.

Distribution of Monetary Policy Shocks: One possible explanation for our findings could be that the effects of monetary policy shocks are indeed nonlinear, but are not directly a function of the household leveraging state. Rather, it is possible that policy interventions of different kinds are more common at certain times, and that this generates the apparent dependence of the responses on the household leverage cycle. If, for example, contractionary policy interventions have a larger effect on the economy than expansionary shocks and if contractionary shocks are more common in a de-leveraging state, then the distribution of shocks could be responsible for our results. Indeed, Angrist et al. (2017) and Barnichon and Matthes (2014) provide empirical evidence for this narrative as they show that contractionary monetary policy shocks have significantly larger effect on the economy than expansionary ones. Thus, if we observe proportional more interest rate increases in a de-leveraging state than in a leveraging state, the size of the shocks may well be explaining our results.

Figure 8 shows the distribution of monetary policy shocks from our baseline specification. We see that shocks are fairly evenly distributed across the de-leveraging and leveraging states. For both states, the relative proportion of positive shocks is similar to the relative proportion of negative shocks. Of all monetary policy shocks that happened during a leveraging state, we observe that 54% are positive innovations, whereas the remaining 46% are negative innovations. The respective numbers in de-leveraging periods are 46% (positive shocks) and 54% (negative shocks). This reveals that our main finding of household leverage-dependent effects of monetary policy cannot be attributed to different shock distributions between both leveraging states.⁵

3.3 Controlling for Alternative State Variables

In this section, we show that our results are robust when controlling for two other prominent state variables previously suggested by the literature. First, we control for the state of the business cycle. Second, we condition our estimates on the level of household debt.

⁵Of all positive monetary policy shocks, 45% happened during a de-leveraging state and of all negative innovations, 53% occurred during a de-leveraging state.

3.3.1 Business Cycle

Jorda et al. (2017) and Tenreyro and Thwaites (2016) show that the effects of monetary policy interventions differ substantially according to the state of the business cycle. They find that monetary policy is significantly more effective in an economic expansion. Given this, it is possible that our emphasis on nonlinear effects of monetary policy across household leverage states is simply a relabeling of nonlinear effects across the business cycle. In this subsection we show, however, that our household leverage-dependent effects of monetary policy cannot be attributed to the large effects of monetary policy shocks in periods of economic expansions.

First, we start by investigating whether de-leveraging states mainly coincide with periods of low economic slack, whereas leveraging periods overlap strongly with periods of economic slack. Our sample includes 32 quarters of official NBER recessions. Out of these periods, 14 quarters coincide with episodes of leveraging while the remaining 18 quarters overlap with de-leveraging periods. A similar picture emerges when relying on the output gap, measured as the deviation of GDP from its long-run HP trend ($\lambda = 1600$). 44% of the periods for which we observe a positive output-gap, we also classify as leveraging states, while the remaining 56% of periods with a positive output-gap coincide with periods of de-leveraging. This suggests that our main findings do not simply reflect asymmetric effects of monetary policy across the business cycle.

To further check whether our findings are sensitive to the state of the business cycle, we condition equation (2) on expansionary and recessionary states. Thereby, we follow Jorda et al. (2017) and calculate the cyclical component of GDP measured as deviations from an HP trend with a smoothing parameter $\lambda = 1600$. Positive deviations from the trend are defined as economic expansions and negative deviations as economic contractions.⁶

Figure 9 shows the results of this exercise. We focus on the output response in the following. When private households de-leverage, GDP falls significantly in response to a contractionary monetary policy shock in recessionary but also in expansionary periods. In contrast, in household leveraging states monetary policy interventions are mostly not

⁶Our results are robust to different ways of defining economic expansions and contractions. Details can be found in the appendix.

effective neither in booms nor in recessions. For economic expansions and recessions, we find that the accumulated GDP effect is of larger magnitude in de-leveraging states compared to leveraging periods.

3.3.2 Level of Household Debt

Alpanda and Zubairy (2017) find that the effectiveness of monetary policy depends on the level of household debt in the economy. When household debt is below its long-run trend, monetary policy shocks have larger impact on economic activity compared to a situation in which household debt is above its long-run trend. Thus, while in this study we focus on the change in household leverage, Alpanda and Zubairy (2017) concentrate on the overall level of household indebtedness. Against this background, our results could be explained by the fact that de-leveraging periods mainly coincide with periods of low debt whereas leveraging periods mostly happen when household debt is high. However, in the following we demonstrate that this narrative is not supported by the data. Following Alpanda and Zubairy (2017), we define high (low) household debt states as periods in which the mortgage debt-to-GDP ratio is above (below) its long-run HP-trend. As in their paper, we use a relatively smooth trend ($\lambda = 10,000$) to account for the long duration of credit cycles.

We find that 59% of all de-leveraging periods coincide with periods of high household debt, while 37% of all leveraging periods are also considered as periods of low household debt. Thus, if anything de-leveraging (leveraging) periods more frequently happen when household debt is high (low), which stands in sharp contrast to the hypothesis that the level of household debt is responsible for our findings as described at the beginning of this section.

To further rule out that our results are driven by the level of household debt, we estimate equation (2) but condition on the level of household debt. Figure 10 shows the results of this exercise. As in the previous section, we solely focus on the GDP response. Irrespective of the level of household debt, we find that in a de-leveraging state a contractionary monetary policy shock leads to a significant decline in aggregate

output. In contrast, during a leveraging episode GDP does not respond significantly when household debt is above its long-run trend. We observe a slight and mostly short-lived decline in GDP during leveraging periods that coincide with periods of low household debt. Overall, these findings suggest that the change in household leverage is of greater importance for the effectiveness of monetary policy than the level of household debt.

In sum, the findings of these last two exercises suggest that the change in household leverage is of first order importance for the effectiveness of monetary policy interventions whereas the state of the business cycle and the level of household debt only plays a minor role.

3.4 State-level Evidence

So far, we have relied on aggregate data to study household leverage-dependent effects of monetary policy. In the following, we demonstrate that our main findings can also be obtained when relying on more disaggregated data. In doing so, we use annual data from US geographical states. To identify monetary policy, we make use of the approach suggested Nakamura and Steinsson (2014) to construct exogenous government spending shocks at the US state level. The main regression takes the following form:

$$\Delta z_{i,t} = \beta_L r_{i,t} + (\beta_D - \beta_L) r_{i,t} I_{i,t} + \delta_i + \psi_t + \omega_{i,t}, \quad (3)$$

where $\Delta z_{i,t}$ is the annual growth rate of the variable of interest (GDP or employment) in state i in year t , $r_{i,t}$ is a measure of the interest rate in region i in year t , δ_i , and ψ_t represent state and year fixed effects. The inclusion of state fixed effects implies that we are allowing for state specific time trends in output or employment and the interest rate. The inclusion of time fixed effects allows us to control for aggregate shocks and aggregate policy—such as changes in distortionary taxes and government spending. $I_{i,t}$ is an indicator for a period of de-leveraging, implying that the effects of the interest rate in leveraging and de-leveraging periods are given by β_L and β_D respectively.

We use annual panel data at the US state level for 1990 –2014 and account for the overlapping nature of the observations in our regression by clustering the standard errors by state or region. To measure leverage at the state level, we use data on the loan-to-value ratio from the Monthly Interest Rate Survey conducted by the Federal Housing Finance Agency. We define de-leveraging periods as those episodes in which the annual change in the loan-to-value ratio is negative. US states are part of a monetary union, such that the main monetary policy instrument, the federal funds rate does not differ between states. Therefore, we have to rely on an adequate proxy to measure the stance of monetary policy across individual regions. Because the housing sector is one of the most important driver of the business cycle in the US, and because the household leverage cycle is directly linked to financing conditions in the real estate market, we use the mortgage interest rate as an indicator for the state-specific stance of monetary policy. State-specific mortgage interest rates are also obtained from the Federal Housing Agency. Data on real GDP and employment are taken from the Regional Economic Accounts of the Bureau of Economic Analysis.

An important challenge to identifying the effect of monetary policy is that interest rates are potentially endogenous. We, therefore, follow Nakamura and Steinsson (2014) and estimate equation (3) using an instrumental variables approach. In the first stage, we instrument for the state mortgage interest rate using an aggregate monetary policy shock interacted with a state dummy. Thus, we allow for different interest rate sensitivities to an exogenous national monetary policy intervention across different states. This procedure yields scaled versions of mortgage interest rates as fitted values for each state, which are then used in the second stage, to estimate equation (3). To check for the robustness of our results, we use two different measures of national monetary policy shocks. We use the monetary policy shocks employed in our local projection estimation and the extended Romer and Romer (2004) narrative series described above.

Table (2) shows the results of this exercise. The estimates indicate that the economy does not respond significantly to a contractionary monetary policy shocks in a leveraging state. In contrast, the effects are significantly reduced when the shock hits the economy

during a de-leveraging episode. This result holds irrespective of the identification of monetary policy shocks for GDP and employment.

In addition to our evidence on the national level, we find that the effects of monetary policy shocks are amplified during periods of household de-leveraging also at the US state level. Based on this robust evidence, in the following we set-up a monetary DSGE model to account for asymmetric effects of monetary policy interventions across the household leverage cycle.

4 A Monetary DSGE model

To explore the mechanism driving our empirical findings, we set up a Monetary DSGE model following GI. The fundamental structure follows closely the seminal papers by Christiano et al. (2005) and Smets and Wouters (2007), but the key feature of the model is that household debt plays an important role for the dynamics, due to the introduction of financial frictions on the household side and a housing sector. There are two types of households which only differ in that one has a lower discount factor than the other: impatient (borrowers) and patient (lenders). The supply of housing is fixed, but house prices evolve endogenously as a function of demand for housing. Housing enters the utility function as a durable good separately from non-durable consumption and labor, and it is also used as collateral by the impatient households. Most importantly, this collateral constraint is only occasionally binding such that the degree of financial frictions is endogenously determined in the model. This implies that the impact of economic shocks on the economy changes between periods of binding collateral constraints and episodes in which the constraints turn slack. This state-dependence in the propagation and amplification of exogenous innovations will be of central importance for understanding asymmetric effects of monetary policy across the household leverage cycle as found in the data.

House prices are one major factor that determines the tightness of collateral constraints. When they are high, the value of collateral of borrowing households is high and they face little or no credit constraints. The opposite is true for low house prices:

the collateral value is low and credit constraints become binding. An important consequence of this setting is that during housing booms, housing wealth has a limited effect on consumption. On the contrary, during busts in the housing market falling housing wealth makes credit constraints tight and has thereby a strong impact on consumption. An additional source of asymmetries arises when the constraint binds: borrowers have a limited capacity to take on debt, which limits their capacity to smoothen consumption and leads to an amplification of macroeconomic shocks. Even if the model relies heavily on the paper by GI, in the following we present its basic features for this study to be self-contained.

4.1 Households

Both types of households work, consume and accumulate housing. Patient households own the productive capital of the economy, they supply funds to firms and to the impatient households. Impatient households accumulate just enough net worth to meet the down payment on their home and are subject to a binding collateral constraint in equilibrium. Each group has measure 1 and its relative size is given by their wage share, which is assumed constant through a constant elasticity of substitution production function. The utility functions reads

$$E_0 \sum_{t=0}^{\infty} \mathbf{z}_t (\beta^i)^t \left(\Gamma_c^i \log(c_t^i - \varepsilon_c c_{t-1}^i) + \Gamma_h^i \mathbf{j}_t \log(h_t^i - \varepsilon_h h_{t-1}^i) - \frac{1}{1+\eta} (n_t^i)^{1+\eta} \right) \quad (4)$$

with $i = \{P, I\}$, where P refers to patient households and I to impatient ones and the discount factors satisfy $\beta^I < \beta^P$. In what follows, to simplify notation we denote the impatient household with the I superscript, while the variables with no superscript refer to the patient household. c_t , h_t and n_t stand for consumption, housing and hours worked, respectively. \mathbf{z}_t is an AR(1) intertemporal preference shock and \mathbf{j}_t is an AR(1) housing preference shock that shifts preferences from consumption and leisure to housing. ε_c and ε_h measure the degree of habit formation in both consumption goods, while the Γ

terms are scaling factors to ensure that marginal utility of consumption and housing are independent of habits in the non-stochastic steady state.

The budget constraint of the patient household is given by

$$c_t + q_t h_t + b_t + i_t = \frac{w_t n_t}{x_{w,t}} + q_t h_{t-1} + \frac{R_{t-1} b_{t-1}}{\pi_t} + r k_t k_{t-1} + div_t, \quad (5)$$

which implies that the value of durable and non-durable consumption, investment and loans to the impatient household (right hand side) must equal income from labor, the returns on the loans to the impatient households and capital, dividends from final good producing firms div_t and housing wealth (left hand side). Here, q_t is the price of housing, R_t is the nominal risk-free interest rate, w_t is the real wage, $r k_t$ is the return on capital, $x_{w,t}$ is a markup due to monopolistic competition in the labor market, and $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate. The law of motion for capital reads

$$k_t = a_t \left(i_t - \phi \frac{(i_t - i_{t-1})^2}{\bar{i}_t} \right) + (1 - \delta) k_{t-1}, \quad (6)$$

where a_t is an AR(1) investment specific shock and ϕ captures the degree of investment adjustment costs. The patient household chooses consumption c_t , housing h_t , hours n_t , loans b_t , investment i_t and capital k_t to maximize utility subject to (5) and (6).

Impatient households do not accumulate capital and do not own final good firms. Their budget constraint is given by

$$c_t^I + q_t h_t^I + \frac{R_{t-1} b_{t-1}}{\pi_t} = \frac{w_t^I n_t^I}{x_{w,t}^I} + q_t h_{t-1}^I + b_t. \quad (7)$$

They also face the following borrowing constraint

$$b_t \leq \gamma \frac{b_{t-1}}{\pi_t} + (1 - \gamma) M_t q_t h_t^I, \quad (8)$$

where $\gamma > 0$ is the degree of debt inertia⁷ and M_t is the loan-to-value (LTV) ratio limit, which we assume follows the exogenous process $\log(M_t) = (1 - \rho_M) \log(M) +$

⁷This is the formulation of GI, who argue that this setting tries to capture the idea that borrowing constraints are only fully reset when households refinance their mortgages and the empirical observation that aggregate debt lags house price movements.

$\rho_M \log(M_{t-1}) + u_{m,t}$ where $u_{m,t}$ is a normally distributed i.i.d. loan-to-value shock similar to the one introduced in Justiniano et al. (2015) and M is the steady state loan-to-value ratio limit. This shock will be important in our analysis later on, when we model periods of leveraging and de-leveraging.

4.2 Firms, Nominal Rigidities and Monetary Policy

The firm sector follows the New Keynesian standard, where competitive (wholesale) firms produce intermediate goods which are later differentiated at no cost and sold at a markup $x_{p,t}$ over marginal cost by monopolistically competitive final good firms. Wholesale firms hire capital from the patient households and labor from both types of households to produce intermediate goods y_t . They solve

$$\max \frac{y_t}{x_{p,t}} - w_t n_t - w_t^I n_t^I - r k_t k_{t-1} \quad (9)$$

subject to the production technology

$$y_t = n_t^{(1-\sigma)(1-\alpha)} n_t^{I\sigma(1-\alpha)} k_{t-1}^\alpha, \quad (10)$$

where σ measures the labor income share of impatient households. Note that if this parameter is set to zero, the model collapses to the standard NK-model without borrowing constraints.

Final good firms face Calvo-style price rigidities: each period, a fraction $(1 - \theta_\pi)$ of firms set their price optimally and a fraction θ_π have to index their price to the steady state inflation $\bar{\pi}$. The linearized forward-looking Phillips curve takes the standard form:

$$\log(\pi_t/\bar{\pi}) = \beta E_t \log(\pi_{t+1}/\bar{\pi}) - \varepsilon_\pi \log(x_{p,t}/\bar{x}_p) + u_{p,t}, \quad (11)$$

where $\varepsilon_\pi = (1 - \theta_\pi)(1 - \beta\theta_\pi)/\theta_\pi$, and $u_{p,t}$ is a normally distributed i.i.d. price markup shock.

The labor market is also subject to Calvo-style rigidities, with a fraction $(1 - \theta_w)$ of wages being set optimally each period, and θ_w being indexed with $\bar{\pi}$. As in Smets and

Wouters (2007) labor unions differentiate labor services that are then combined into the homogeneous labor composites n_t and n_t^I by labor packers. This framework implies the following linearized wage Phillips curves:

$$\log(\omega_t/\bar{\pi}) = \beta E_t \log(\omega_{t+1}/\bar{\pi}) - \varepsilon_w \log(x_{w,t}/\bar{x}_w) + u_{w,t}, \quad (12)$$

$$\log(\omega_t^I/\bar{\pi}) = \beta^I E_t \log(\omega_{t+1}^I/\bar{\pi}) - \varepsilon_w^I \log(x_{w,t}^I/\bar{x}_w^I) + u_{w,t}, \quad (13)$$

where $\varepsilon_w = (1 - \theta_w)(1 - \beta\theta_w)/\theta_w$, $\varepsilon_w^I = (1 - \theta_w)(1 - \beta^I\theta_w)/\theta_w$, $\omega_t = \frac{w_t\pi_t}{w_{t-1}}$, $\omega_t^I = \frac{w_t^I\pi_t}{w_{t-1}^I}$, and $u_{w,t}$ is a normally distributed i.i.d. wage markup shock.

Monetary policy follows a Taylor rule that responds to deviations of inflation and GDP from their steady state values, allows for interest rate smoothing with smoothing parameter r_R and is subject to the ZLB:

$$R_t = \max \left[1, R_{t-1}^{r_R} \left(\frac{\pi_t}{\bar{\pi}} \right)^{(1-r_R)r_\pi} \left(\frac{y_t}{\bar{y}} \right)^{(1-r_R)r_Y} \bar{R}^{(1-r_R)} \mathbf{e}_t \right]. \quad (14)$$

\bar{R} stands for the nominal gross interest rate and \mathbf{e}_t is a monetary policy shock that follows an AR(1) process.

The model is stable at the non-stochastic steady state, where all the optimality conditions are satisfied, the collateral constraint binds and the economy is not constrained by the ZLB. This steady state is also the point around which we approximate the model, while its dynamics come from the seven shocks we have mentioned above: housing preference, investment specific, price markup, monetary policy, wage markup, intertemporal preference and loan-to-value shocks.

5 Quantitative Analysis

In this section we fit the model to US data in order to provide a structural explanation for the amplification of monetary policy shocks across states of the leverage cycle found in the data. In particular, we explore the interplay between de-leveraging periods in the data,

the tightness of collateral constraints in the model and the state-dependent impact of monetary policy. We combine standard estimation techniques for linearized DSGE models with the non-linear (deterministic) filter proposed by GI in order to extract the structural shocks that drive the model when fitted to a set of key macroeconomic variables. This provides us with a full characterization of the periods when the collateral constraint is filtered to be binding or slack, given the parameters and the data. With this information at hand, we are able to compare periods of de-leveraging in the data with periods of binding collateral constraints in the model. Thus, this procedure allows us to investigate whether the state-dependent effects of monetary policy shocks across the leverage cycle presented in the empirical part of this paper, can be attributed to the time-varying tightness of households' collateral constraints.

5.1 Data, solution, filtering and estimation

We fit the model to seven macro time series: real household consumption, price inflation (GDP deflator), wage inflation, real investment, real house prices, the Federal Funds Rate, and household leverage. As in our empirical application in the first part of the paper, the sample covers the period 1960q1-2015q1. The first six variables are the same as in GI and can be considered standard in a macro model with a housing sector. On top of that we include household leverage, since our main goal is to understand its role in the transmission of monetary policy shocks. Leverage is defined as in our empirical application (home mortgages to real estate at market value). A detailed description of the data and the transformation undertaken to make it consistent to model variables is provided in the appendix.

The fact that collateral constraints bind only occasionally rather than at all times is the key feature of the model to explain the asymmetries in the transmission of monetary policy shocks. For this reason, it is important to use a solution method that allows for occasionally binding constraints. Hence, we use the OccBin toolbox proposed by Guerrieri and Iacoviello (2015) to solve the model. The solution has the form

$$X_t = P(X_{t-1}, \epsilon_t)X_{t-1} + D(X_{t-1}, \epsilon_t) + Q(X_{t-1}, \epsilon_t)\epsilon_t, \quad (15)$$

where X_t contains all the variables of the model and ϵ_t is the vector of innovations to the shock processes. The reduced-form coefficient matrices P and Q , and the reduced-form coefficient vector D are all state-dependent: in any given period, they depend on the value of the state in the previous period but also on the contemporaneous realization of ϵ_t .

Furthermore, the model can be taken to the data with the following observation equation

$$Y_t = H_t P(X_{t-1}, \epsilon_t)X_{t-1} + H_t D(X_{t-1}, \epsilon_t) + H_t Q(X_{t-1}, \epsilon_t)\epsilon_t, \quad (16)$$

where Y_t is a matrix of observed time series and H_t is a selection matrix that selects the observed endogenous variables. Following the method proposed by Fair and Taylor (1983), this expression allows to filter the structural shocks of the piecewise-linear model ϵ_t given the state of the model X_{t-1} , the current realization of the data Y_t and initial conditions X_0 . GI show that with these shocks at hand, the likelihood of the model takes the form

$$\log(f(Y)) = -\frac{T}{2} \log(\det(\Sigma)) - \frac{1}{2} \sum_{t=1}^T \epsilon_t' (\Sigma^{-1}) \epsilon_t - \sum_{t=1}^T \log(|\det H_t Q(X_{t-1}, \epsilon_t)|). \quad (17)$$

In principle, this expression allows to use standard maximum likelihood or Bayesian methods to estimate the piecewise-linear model; however, this approach entails important limitations.⁸ First, the model is solved at each point in time under the assumption that there are no further shocks in the future. Second, the filter does not allow for measurement error. Third, and most important for our study, all shocks must actually generate dynamics in the model at all times. The reason is that if at least one of the shocks does not generate any dynamics in the model, there are infinitely many ϵ_t that satisfy equation (15). This problem arises when one of the shocks enters an occasionally binding constraint, as in the Taylor rule and the collateral constraint in our model. For example, when the collateral

⁸For comparison with standard estimation methods and discussion, see Richter and Throckmorton (2016)

constraint is slack, a LTV shock becomes irrelevant in the model since the constraint may become “more” binding or slack, but as long as it is not moved to a point where it binds again those movements generate no dynamics in the model. Consequently, we cannot extract shocks and evaluate the likelihood in those situations. Since the collateral constraint is key to our analysis, this limitation is particularly important for our application⁹.

For these reasons, we estimate the model with Bayesian methods using the Kalman filter under the assumption that the collateral constraint is always binding and disregarding the ZLB. Note that, conditional on a set of parameters and data, we can still use the nonlinear filter to extract the implied structural shocks from the piecewise linear model with the occasionally binding collateral constraint, for example, by following GI and dropping leverage from the observables and assuming that the LTV shocks are zero when the constraint is slack. This is in fact what we do in the next section and in practice implies that matrix H_t in equation (17) is time-varying.

We calibrate some of the parameters as described in Table 3. With the exception of the maximum LTV limit this calibration follows GI and is fairly standard in the literature.¹⁰ In our baseline estimation we also fix the values of the share of impatient households, the discount factor of impatient households and debt inertia to the estimated values by GI, which makes our results more easily comparable to theirs.¹¹

The estimated parameters are shown in Table 4. As in GI, the habit parameters for housing and consumption are relatively high, as are the calvo prices and wages parameters. The housing preference shock plays an important role in the model and it is highly persistent. The LTV shock has a large standard deviation, which at least to some extent reflects the fact that we are pinning down the model with the leverage series without an explicit modeling of the financial sector. When looking at the parameters concerning

⁹GI have to deal with this problem as well in their treatment of the ZLB. They opt for dropping the interest rate from the set of observables and set the monetary policy shock to zero when the model hits the ZLB.

¹⁰We decide to fix the steady state value of the maximum LTV limit to 0.8 (instead of GI’s 0.9) given that we introduce LTV shocks that make the LTV limit time-varying.

¹¹We have tried different values for these parameters and the key results are robust to different specifications.

monetary policy, the response of the policy rate to prices is weak and persistence of the monetary policy shocks is relatively low.

5.2 De-leveraging, collateral constraints and monetary policy

In this section we use the piecewise linear solution method described in the previous section, conditional on the parameter estimates, to conduct quantitative exercises in order to shed light on the mechanism underlying the asymmetries in the transmission of monetary policy shocks.

Figure 11 illustrates the mechanics in the relation between shifts in the collateral constraint and the leveraging behavior of households. Starting from the model's steady state, we simulate leveraging (de-leveraging periods) as a series of 6 positive (negative) LTV shocks to make the constraint slack (more binding).¹² The figure depicts the simulated paths for some key variables: the LTV increases (decreases) by about 20% in each case, and the constraint becomes slack after two consecutive positive LTV shocks (a value of zero for the borrowing constraint's lagrange multiplier indicates that the constraint is slack). A loosening of lending conditions leads impatient households to consume more and to buy more housing, which increases house prices and leverage. The opposite is true for a tightening of lending conditions. In addition, the figure showcases the key macroeconomic asymmetry in the model: when the borrowing constraint is slack, households consume optimally. On the other hand, when the constraint binds, they are forced to de-lever and reduce consumption over and above the unconstrained optimum, which explains why the reaction of variables is stronger in absolute value under a tightening of lending conditions.

How important are borrowing constraints for the transmission of monetary policy? Figure 12 shows the responses of output and consumption to an annualized 100 basis points monetary policy shock. The upper and lower panels show the responses under a steady state LTV limit of 80% and 90% (GI's baseline), respectively. Leveraging and de-leveraging episodes are simulated as described in the previous paragraph. The figure shows that monetary policy shocks are amplified when households are financially

¹²Recall that in our baseline calibration the constraint binds in the steady state.

constrained; moreover, looser lending conditions in the steady state imply greater amplification effects. This simulation exercise offers a first model-based insight into asymmetric effects of monetary policy shocks between leveraging and de-leveraging periods. When de-leveraging periods coincide with bindings collateral constraints, the impact of monetary policy interventions are amplified. In contrast, when collateral constraints turn slack during leveraging periods, the effectiveness of monetary policy is significantly reduced.

The fact that the model predicts an amplification of monetary policy shocks when households are constrained is interesting in its own right. However, the crucial question for our study is whether the periods of binding collateral constraints in the model coincide with periods of household de-leveraging in the data. In order to explore this issue we use the deterministic filter described above to take the nonlinear model to the data. As we have pointed out before, one key challenge is how to deal with periods where the collateral constraint becomes slack. We follow GI in their treatment of the ZLB and proceed as follows: whenever the borrowing constraint becomes slack, we drop leverage from the set of observables and set the LTV shock to zero; analogously, whenever the model hits the ZLB we drop the federal funds rate from the set of observables and set the monetary policy shock to zero.

In order to fit the model to the data, we fix the deep estimated parameters and we let the parameters of the Taylor rule, as well as the key parameters ruling the behavior of impatient households vary. More precisely, we look for the values of r_π , r_R , y_Y , β^I , σ and γ that minimize equation (17), conditional on all other parameters in Table 4. The resulting parameter values are reported in Table 5. Note that all parameter values that we had kept fixed so far are similar to the estimated ones by GI as shown in Table 3, supporting the adequacy of this exercise. Because we use a longer sample period compared to GI slight changes in the size of the deep parameters seem reasonable. This allows us to extract the structural shocks that generate the data, conditional on the set of deep parameters.¹³

¹³Since there is no measurement error, if we were able to extract the shocks for all variables at all points in time, the smoothed variables would match the observed variables exactly. However, given the challenges described in the previous paragraph, we are able to match the observed variables only with

Figure 13 shows the smoothed series of the lagrange multiplier on the borrowing constraint, along with the de-leveraging periods that we have used for our state-dependent local projections and the observed leverage series. The constraint becomes slack at the beginning of the sample, and quickly becomes binding following the de-leveraging that occurred during the credit crunch of 1966. It then returns to slack and becomes binding at the peak of the de-leveraging that coincides with the jump on interest rates at the end of the great inflation in the beginning of the 1980s and the onset of the savings and loans crisis in the years that followed. Thereafter, the lagrange multiplier systematically drops until the constraint becomes slack during the big leveraging phase that started in the 1990s. We clearly miss the short de-leveraging periods around the Asian and Dot-com crises, which should not come as a big surprise, given the simplicity of our treatment of financial frictions in the model. Importantly, the constraint becomes binding again around 2010, when the big de-leveraging of the Great Recession started. The constraint remains binding for about 10 quarters in the great recession and it becomes slack again when US house prices start recovering, towards 2012. By and large, the model captures the most important de-leveraging episodes as periods of binding collateral constraints. In addition, we observe a strong overlap between leveraging periods defined through the data and model implied episodes of slack collateral constraints.

This exercise provides us with the key information to assess the effects of monetary policy shocks through the lens of the DSGE model throughout our sample. This is important since it tells us when the model predicts that monetary policy will be more effective, and what are the mechanisms at play in the amplification of the transmission. In particular, we can ask: what is the response to a monetary policy shock when borrowing constraints bind and when they are slack? To answer this question we can simply feed a monetary policy shock when the constraint in the model is filtered to be binding and when it is slack. Figure 15 shows the responses to an annualized 100 bp monetary policy shock in 2006q1 and in 2010q1. While the estimated model implies a slack collateral constraint in 2006q1, it shows a bindings constraint in 2010q1. The peak response of output

some errors. Figure 14 shows the smoothed and observed variables. Note that the correlations between smoothed and observed variables is very close to 1 for all variables (it ranges from 0.92 to 0.99).

is amplified by close to 50% and the peak response of total consumption is about twice as large when the constraint binds. It is noteworthy that the DSGE model generates amplification effects that are quantitatively comparable to our empirical estimates from the local projections.

We can further use the model to explore the mechanism driving the amplification of monetary policy shocks. The second row of Figure 15 shows the responses of consumption from the patient (left) and impatient (right) household. It is interesting to note that the amplification of aggregate consumption is entirely driven by financially constrained (impatient) households. When impatient households are not financially constrained and a bad shock hits the economy, they can borrow more and smoothen consumption optimally. This is what the blue dashed line shows in the lower right panel. On the contrary, when financial constraints bind they are forced to de-lever and cut on consumption sharply in order to meet their budget constraint. Note also that this mechanism is completely absent in the case of patient households: since they are never financially constrained, they can always take optimal consumption-investment decisions.

All in all, we show that that a standard New Keynesian model augmented with an occasionally binding collateral constraint captures big de-leveraging episodes in the US economy as periods of tight financial conditions. The model generates an amplification of monetary policy shocks that is quantitatively comparable to our empirical estimates, and the underlying mechanism is the asymmetric response of consumption of financially constrained households.

6 Conclusion

This paper shows that the household leverage cycle significantly determines the effects of monetary policy shocks. Based on quarterly US data, we find that monetary policy interventions in a de-leveraging state have a significant impact on the economy. Contrary, in a leveraging state monetary policy has no discernible effects on the economy. We use a standard New Keynesian model with financial frictions and an occasionally binding borrowing constraints to provide a structural interpretation for our empirical findings.

When estimating the model, we find that de-leveraging periods in the data mainly coincide with periods of binding collateral constraints whereas constraints mainly turn slack during leveraging periods. Because the impact of monetary policy shocks are amplified when collateral constraints become binding, the model highlights the importance of state-dependent financial frictions for understanding asymmetric monetary policy effects across the leverage cycle. Thus, the model provides a coherent intuition for our empirical results: demand shocks in general and monetary policy shocks in particular have amplified effects on output and consumption when credit constraints limit households' capacity to absorb shocks. Our study implies that the monetary authority should take the current state of the leverage cycle into account when evaluating different policy actions.

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Appendix

Data: local projections

Table 1: Data Definitions and Sources

Variable	Definition	Source
GDP	Nominal GDP	BEA
PGDP	GDP deflator	BEA
PCOM	Commodity price index	FRED
Wu and Xia shadow rate	Shadow federal funds rate	Atlanta Fed website
Consumption	Nominal personal consumption expenditures	BEA
Investment	Nominal fixed private investment	BEA
Romer and Romer shocks	Extended narrative series	Silvia Agrippino website
Household leverage	Home mortgages/real estate at market value	FRED

Data: DSGE model

- Consumption: Real personal consumption expenditures, log transformed and detrended with one-sided HP filter (smoothing parameter set to 1,600). Source: St. Louis FRED (code PCECC96).
- Price inflation: quarterly change in GDP Implicit Price Deflator minus steady state inflation. Source: BEA.
- Wage inflation: Non-farm business sector real compensation, log transformed, detrended with one-sided HP filter (smoothing parameter set to 1,600), first differenced and expressed in nominal terms by adding back price inflation. Source: St. Louis FRED (code COMPRNFB).
- Investment: Real private non-residential fixed investment, log transformed and detrended with one-sided HP filter (smoothing parameter set to 1,600). Source: St. Louis FRED (code PNFI).
- House prices: Robert Shiller's Real Home Price Index, log transformed and detrended with one-sided HP filter (smoothing parameter set to 100,000). Source:

Robert J. Shiller, *Irrational Exuberance*, 3rd. Edition, Princeton University Press, 2015.

- Nominal interest rate: Effective Federal Funds Rate, annualized percent divided by 400. Source: St. Louis FRED (code FEDFUNDS).
- Leverage: Home Mortgages (Households and Nonprofit Organizations) divided by real estate at market value, expressed in percentage deviations from the mean of the series. Source: St. Louis FRED.

Table 2: US State Level Evidence

	LP-Shocks		Romer/Romer Shocks	
	Output	Employment	Output	Employment
β_L	-.021 (.022)	-.010 (.008)	.001 (.021)	-.014 (.008)
$\beta_D - \beta_L$	-.004** (.001)	-.002* (.001)	-.004*** (.001)	-.002** (.001)
Obs.	1224	1224	1122	1122

Notes: Standard errors clustered at the state level are in parentheses. The unit of observation is US states for all regressions in the table. β_L measures the effect in leveraging states and $\beta_D - \beta_L$ measures the difference between the effect in de-leveraging and leveraging periods. The regressions include state and time fixed effects interacted with the de-leveraging dummy. The regression are estimated by two-stage least squares.

Table 3: Calibrated parameters

parameter		
β	patient discount factor	0.995
α	capital share in production	0.3
δ	capital depreciation rate	0.025
\bar{j}	housing weight in utility	0.04
η	labor disutility	1
\bar{x}_p	price markup	1.2
\bar{x}_w	wage markup	1.2
$\bar{\pi}$	steady state inflation	1.005
M	steady state LTV limit	0.8
β^I	impatient discount factor	0.9922
σ	impatient wage share	0.5013
γ	inertia, borrowing const.	0.6945

Table 4: Estimated parameters

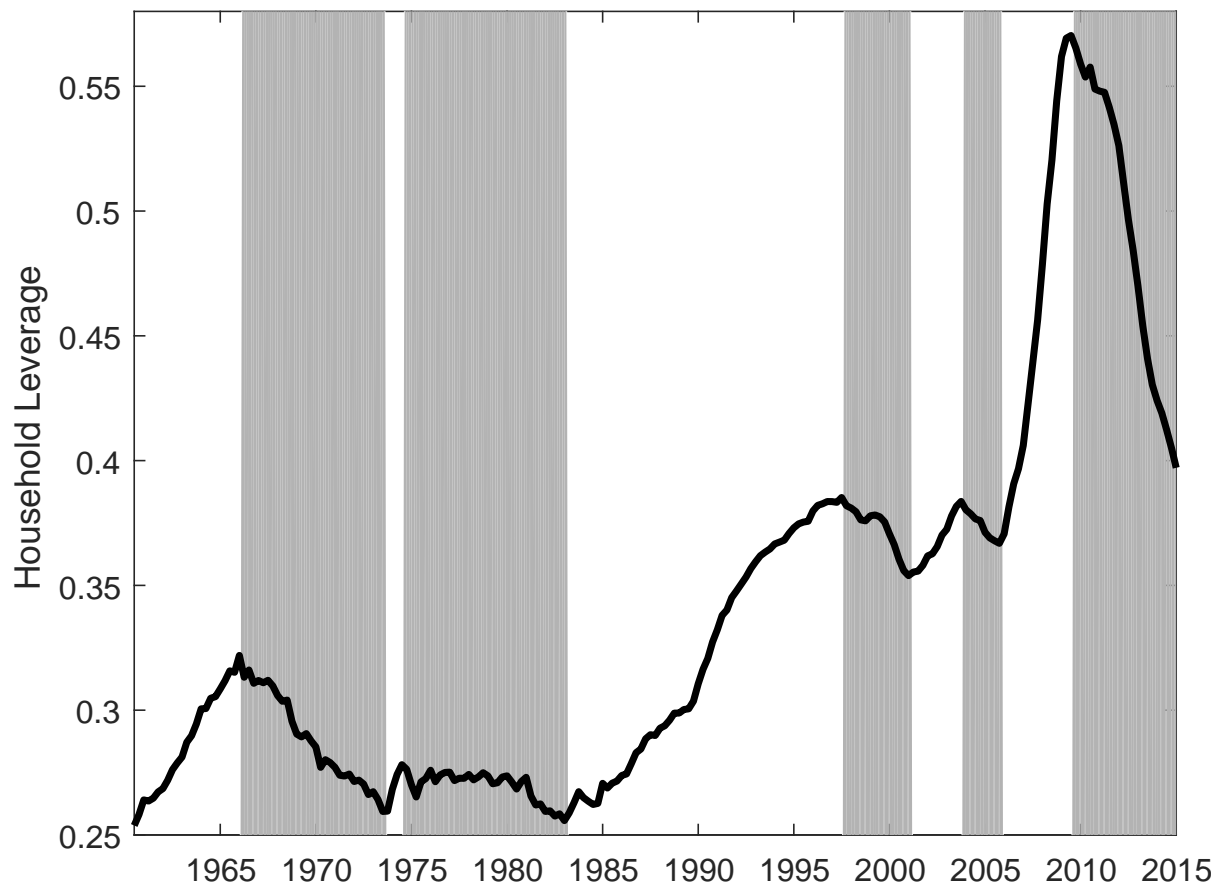
parameter	prior	posterior				
		mode	5%	median	95%	
ε_c	habit in consumption	beta 0.7(0.1)	0.7987	0.7382	0.7856	0.8302
ε_h	habit in housing	beta 0.7(0.1)	0.7619	0.5816	0.7020	0.8001
ϕ	invest. adjustment cost	gamma 5(2)	9.2113	6.7240	9.2809	0.9922
r_π	Taylor Rule, inflation	norm 1.5(0.25)	1.0615	1.0310	1.0780	1.1277
r_R	Taylor Rule, inertia	beta 0.75(0.1)	0.5939	0.5229	0.5785	0.6338
r_Y	Taylor Rule, output	beta 0.125(0.025)	0.0642	0.0372	0.0582	0.0802
θ_p	Calvo, prices	beta 0.5(0.075)	0.8944	0.8837	0.8966	0.9090
θ_w	Calvo, wages	beta 0.5(0.075)	0.9113	0.8962	0.9097	0.9229
ρ_J	AR(1) housing shock	beta 0.75(0.1)	0.9878	0.9707	0.9812	0.9900
ρ_K	AR(1) investment shock	beta 0.75(0.1)	0.5951	0.5013	0.5766	0.6527
ρ_R	AR(1) monetary shock	beta 0.5(0.1)	0.3098	0.2607	0.3414	0.4196
ρ_Z	AR(1) preference shock	beta 0.75(0.1)	0.5311	0.4557	0.5613	0.6622
ρ_M	AR(1) LTV shock	beta 0.75(0.1)	0.7210	0.6672	0.7265	0.7829
σ_J	stdv. housing shock	invgamma 0.01(1)	0.0512	0.0440	0.0691	0.0992
σ_K	stdv. investment shock	invgamma 0.01(1)	0.0811	0.0596	0.0825	0.1064
σ_P	stdv. price markup shock	invgamma 0.01(1)	0.0054	0.0049	0.0054	0.0059
σ_R	stdv. monetary shock	invgamma 0.01(1)	0.0026	0.0024	0.0026	0.0029
σ_W	stdv. wage markup shock	invgamma 0.01(1)	0.0091	0.0081	0.0088	0.0096
σ_Z	stdv. preference shock	invgamma 0.01(1)	0.0288	0.0225	0.0276	0.0331
σ_M	stdv. loan-to-value shock	invgamma 0.01(1)	0.1550	0.1440	0.1566	0.1695

Notes: Posterior statistics based on 3 chains of 250.000 MCMC replications, where the first 50.000 are discarded as burnin. The prior column indicates the prior shape, mean and standard deviation in parenthesis.

Table 5: Parameters for deterministic filter

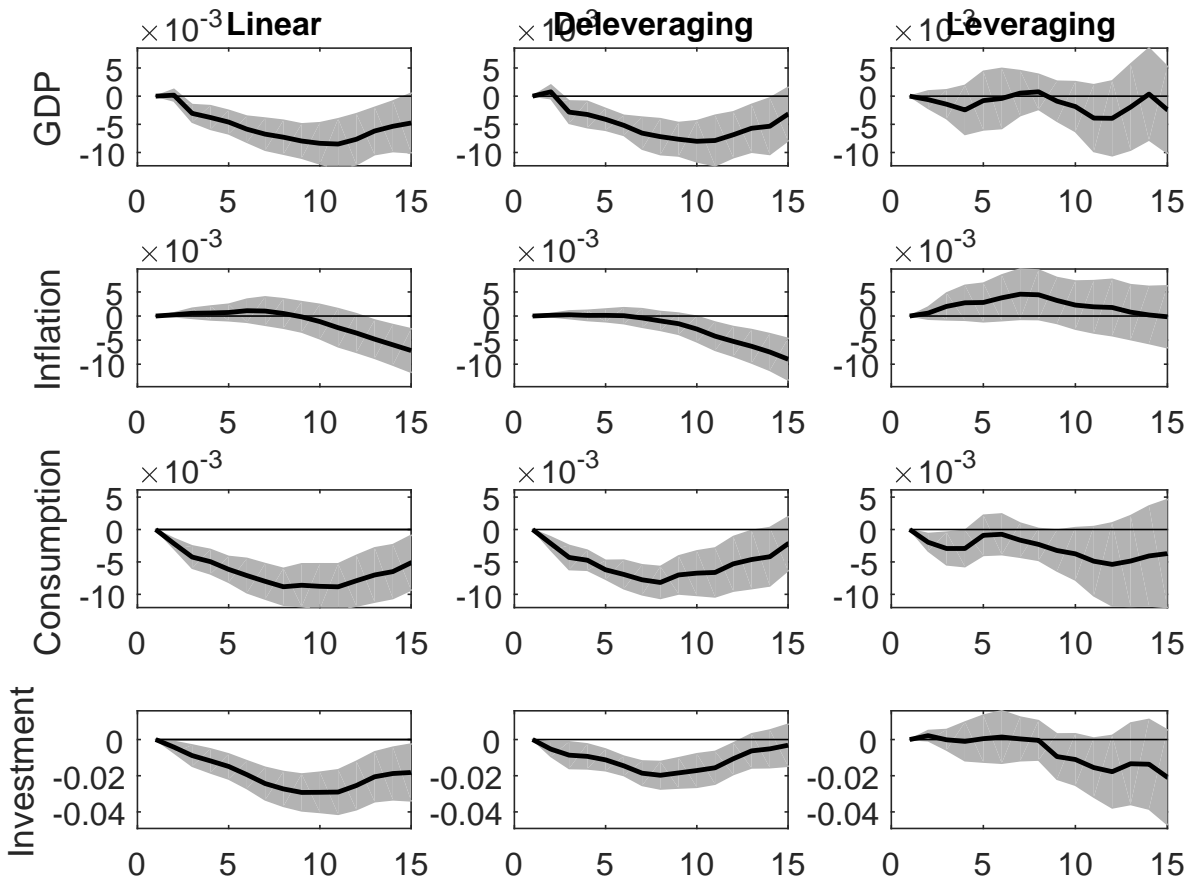
parameter		
r_π	Taylor Rule, inflation	1.0664
r_R	Taylor Rule, inertia	0.4710
r_Y	Taylor Rule, output	0.0587
β^I	impatient discount factor	0.9937
σ	impatient wage share	0.3300
γ	inertia, borrowing const.	0.7216

Figure 1: Household leverage



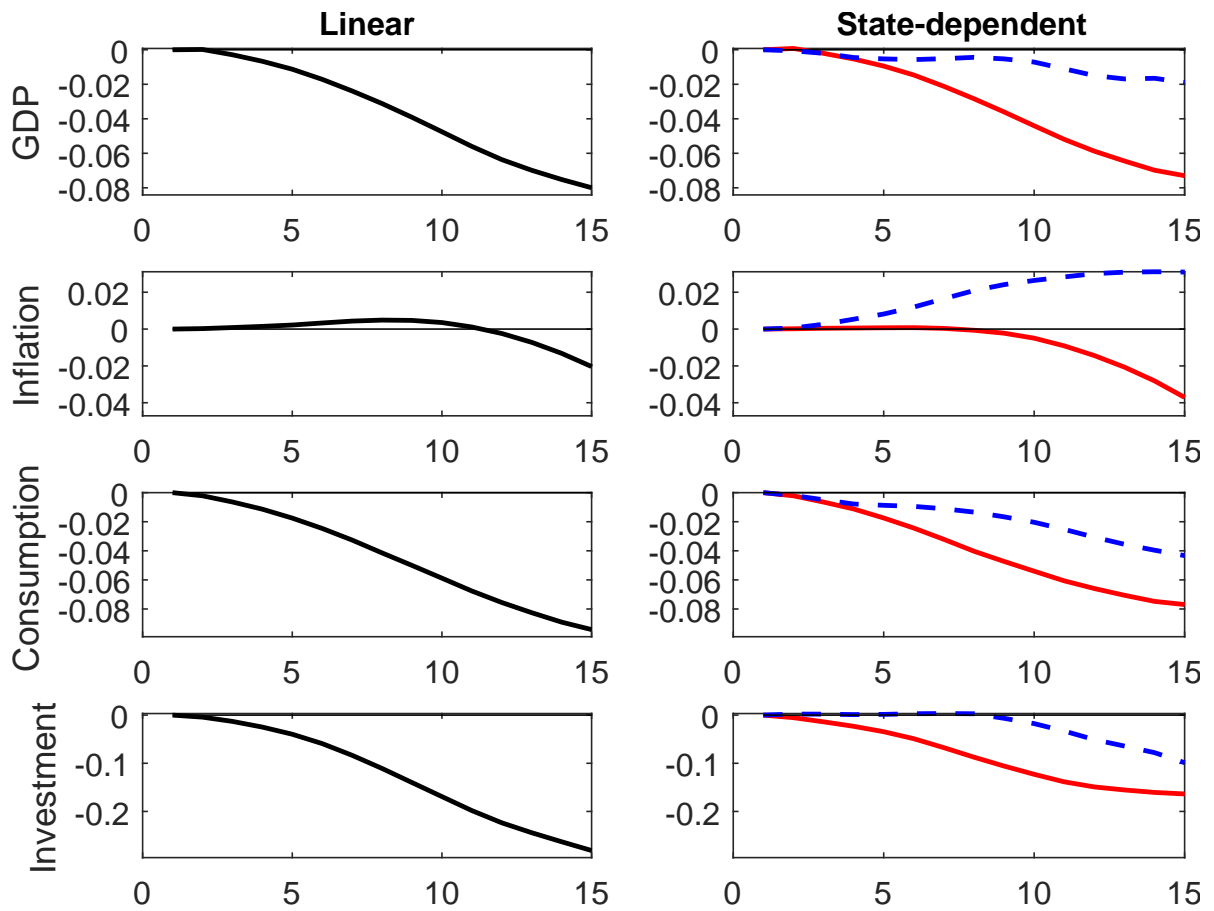
Notes: Household leverage is defined as mortgages over real estate value. The shaded areas indicate our baseline de-leveraging identified periods.

Figure 2: Baseline: Impulse Responses



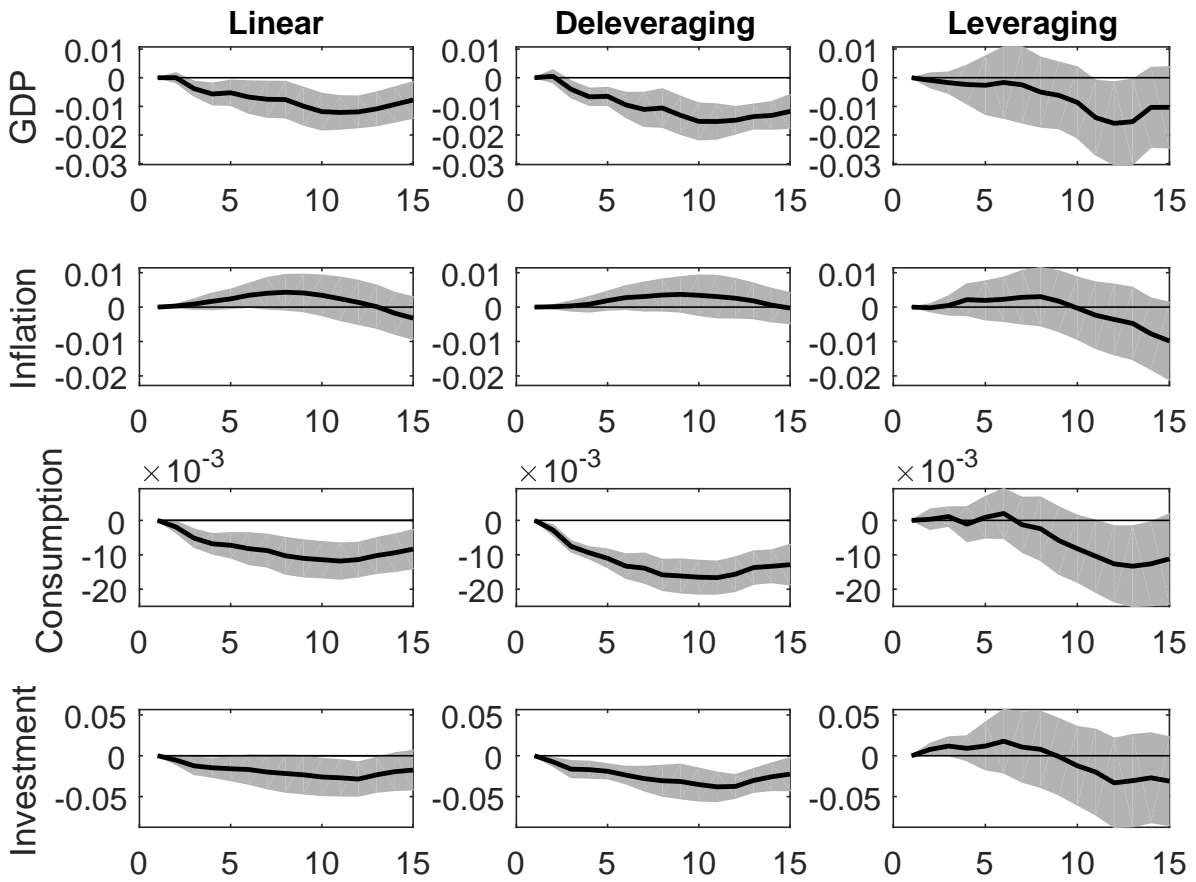
Notes: The first column shows the impulse responses of a monetary policy shock on a variable in the linear model. The second and third column show impulse responses of a monetary policy shocks on a variable in a household de-leveraging (second column) and leveraging (third column) state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

Figure 3: Baseline: Cumulative Effects



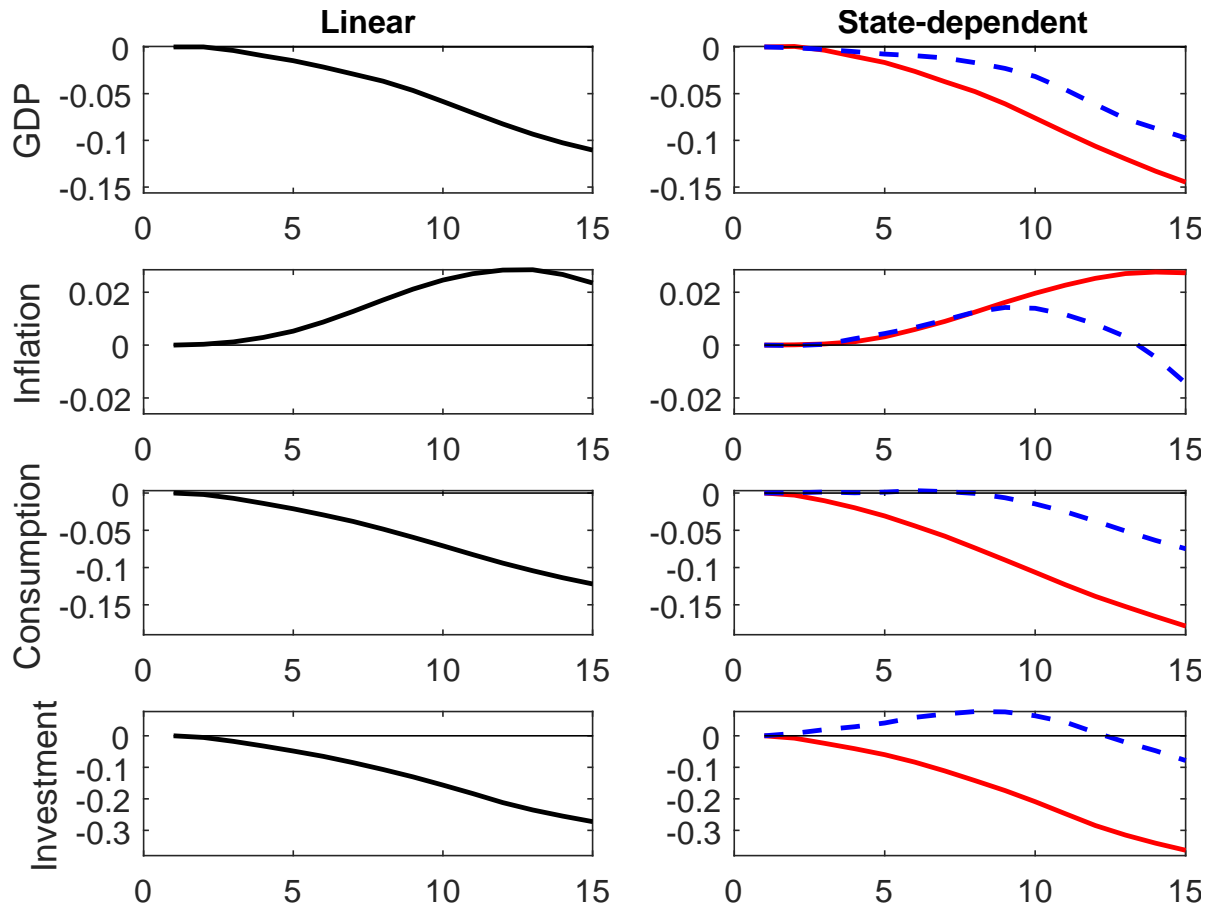
Notes: The first column shows the cumulative effects of a monetary policy shock on a variable in the linear model. The second column shows cumulative effects of a monetary policy shocks on a variable in household de-leveraging (red solid line) and household leveraging (blue dashed line) states.

Figure 4: Alternative Identification: Impulse Responses



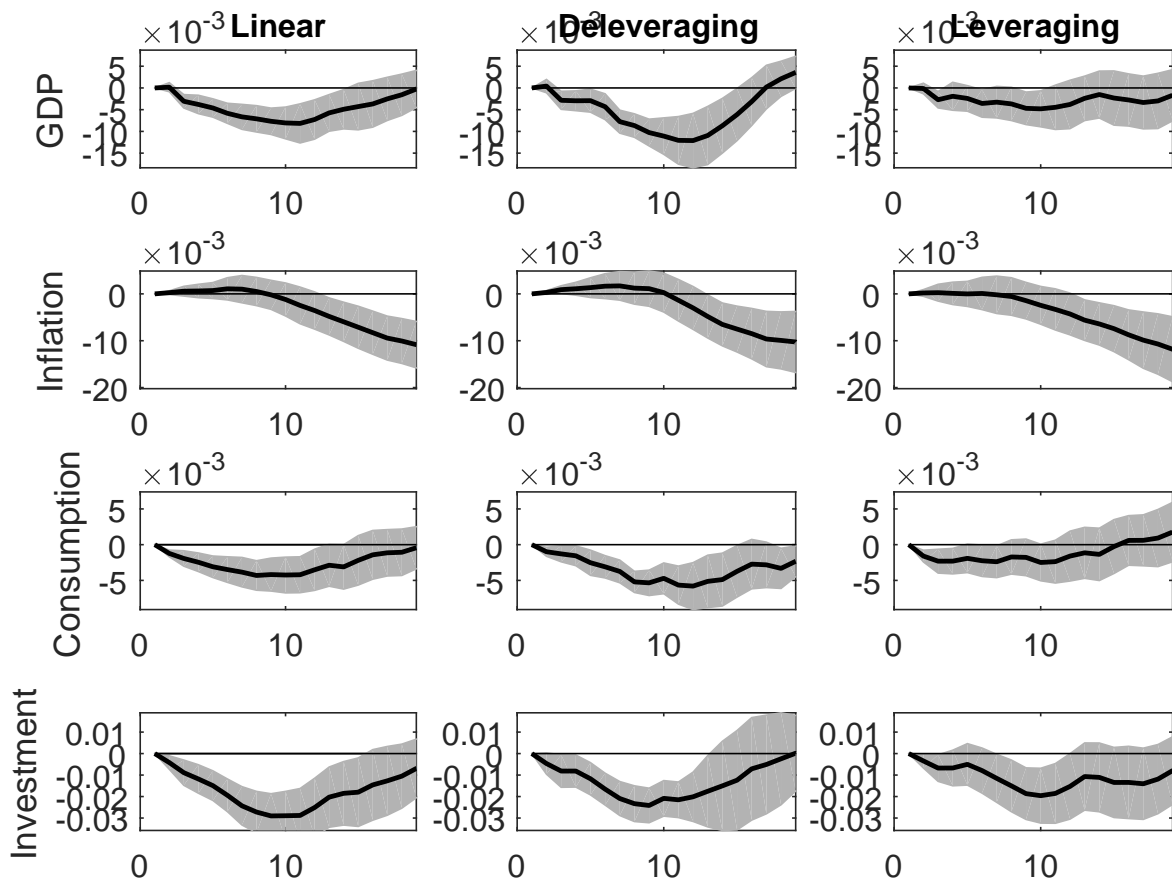
Notes: The first column shows the impulse responses of a monetary policy shock on a variable in the linear model. The second and third column show impulse responses of a monetary policy shocks on a variable in a household de-leveraging (second column) and leveraging (third column) state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

Figure 5: Alternative Identification: Cumulative Effects



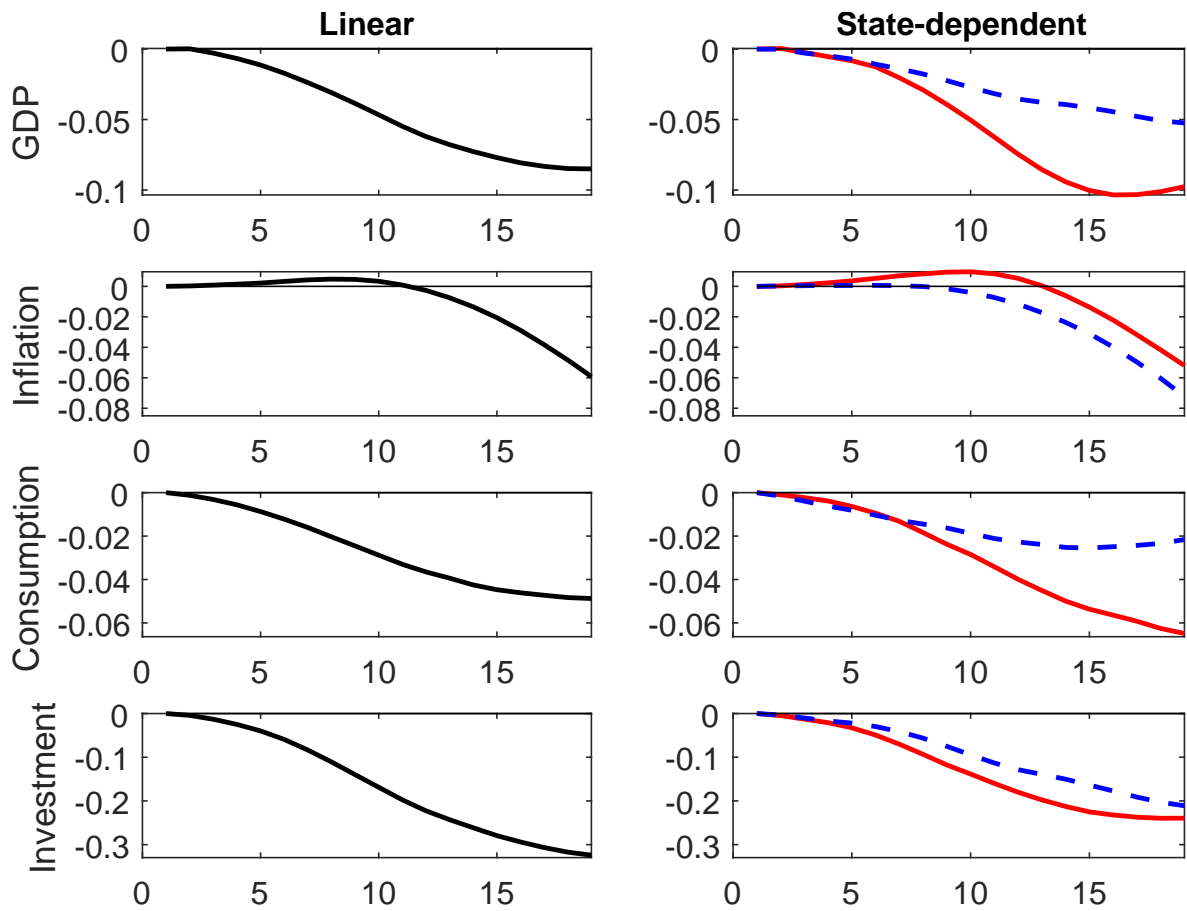
Notes: The first column shows the cumulative effects of a monetary policy shock on a variable in the linear model. The second column shows cumulative effects of a monetary policy shocks on a variable in household de-leveraging (red solid line) and household leveraging (blue dashed line) states.

Figure 6: Alternative State Definition: Impulse Responses



Notes: The first column shows the impulse responses of a monetary policy shock on a variable in the linear model. The second and third column show impulse responses of a monetary policy shocks on a variable in a household de-leveraging (second column) and leveraging (third column) state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

Figure 7: Alternative State Definition: Cumulative Effects



Notes: The first column shows the cumulative effects of a monetary policy shock on a variable in the linear model. The second column shows cumulative effects of a monetary policy shocks on a variable in household de-leveraging (red solid line) and household leveraging (blue dashed line) states.

Figure 8: Distribution of Monetary Policy Shocks

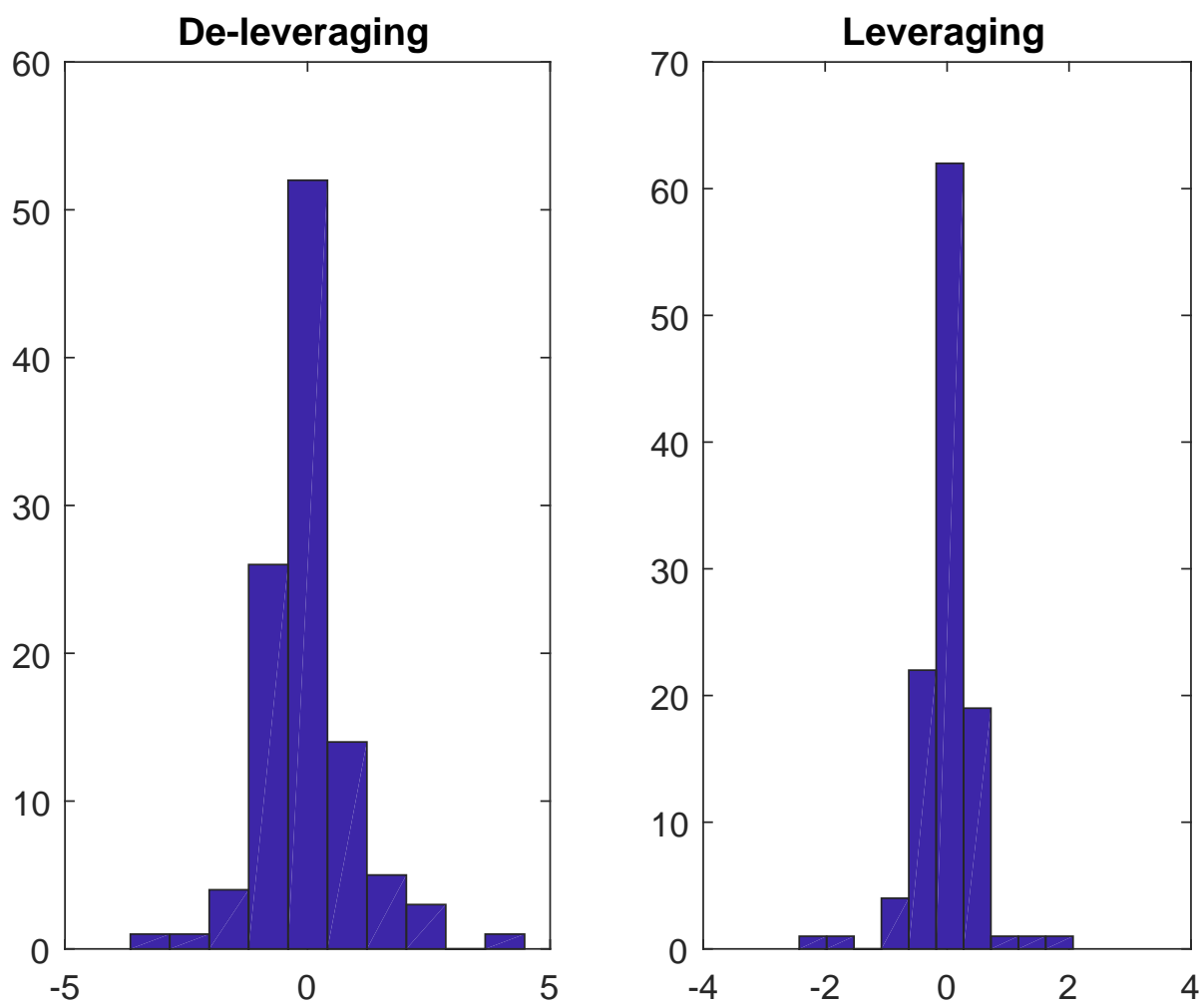
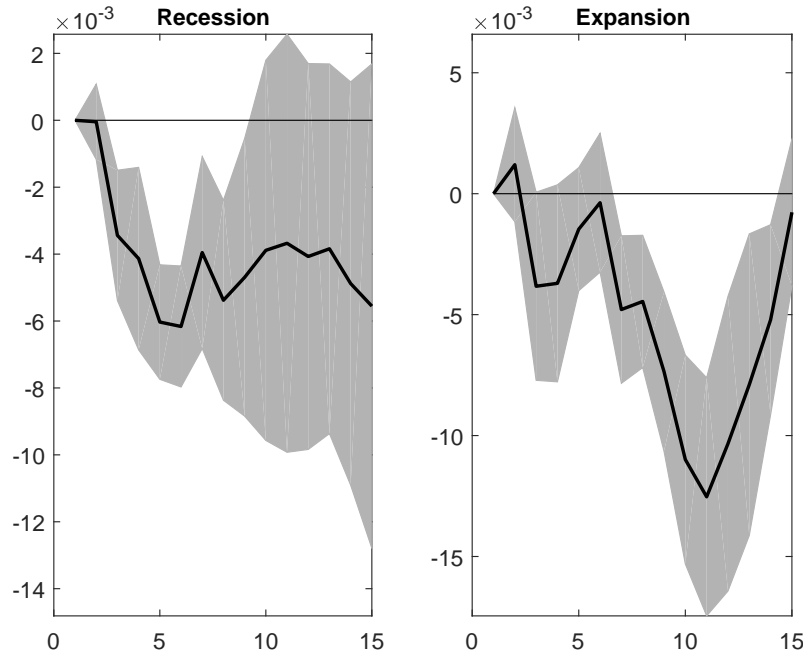
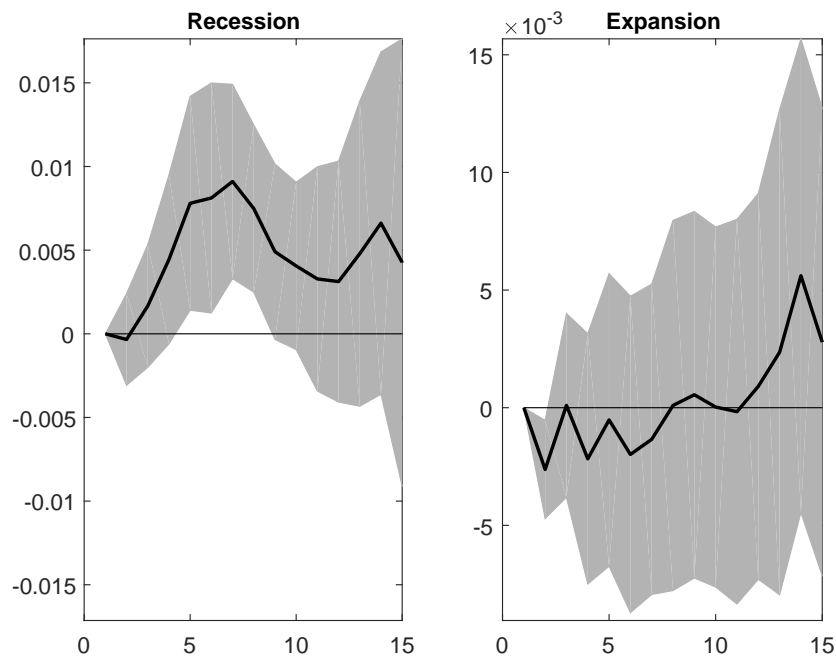


Figure 9: Controlling for the Business Cycle.

(a) Deleveraging



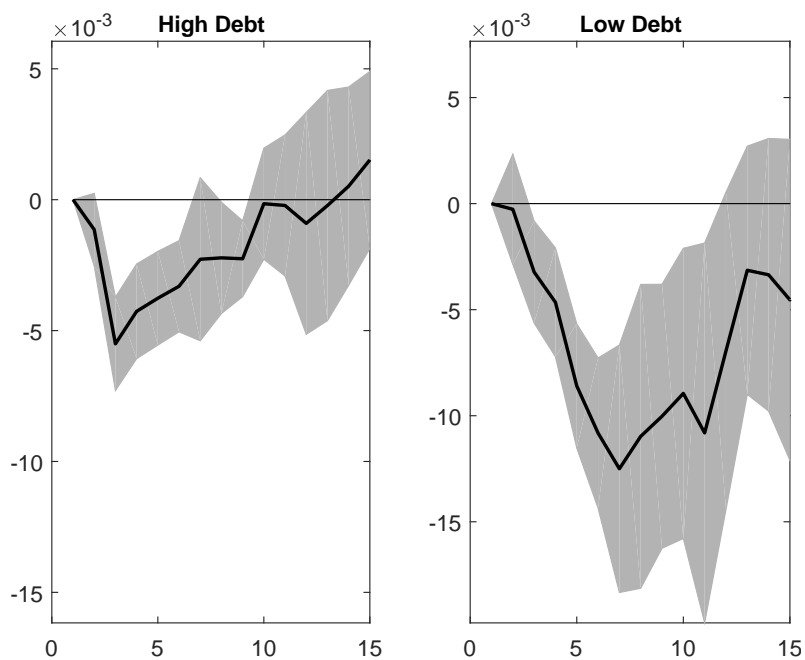
(b) Leveraging



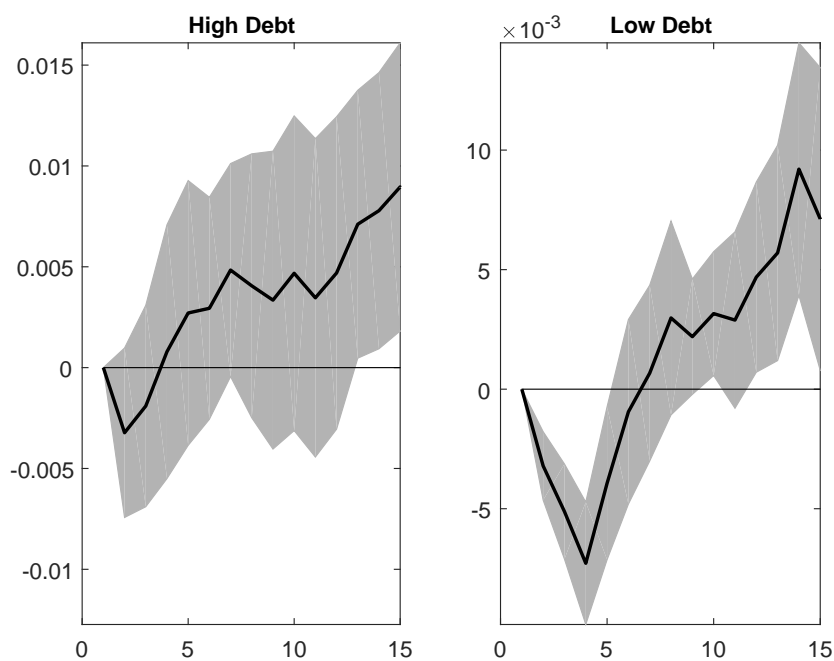
Notes: GDP responses to a monetary policy shock in household de-leveraging and household leveraging states when controlling for the state of the business cycle. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

Figure 10: Controlling for the Level of Household Debt.

(a) Deleveraging

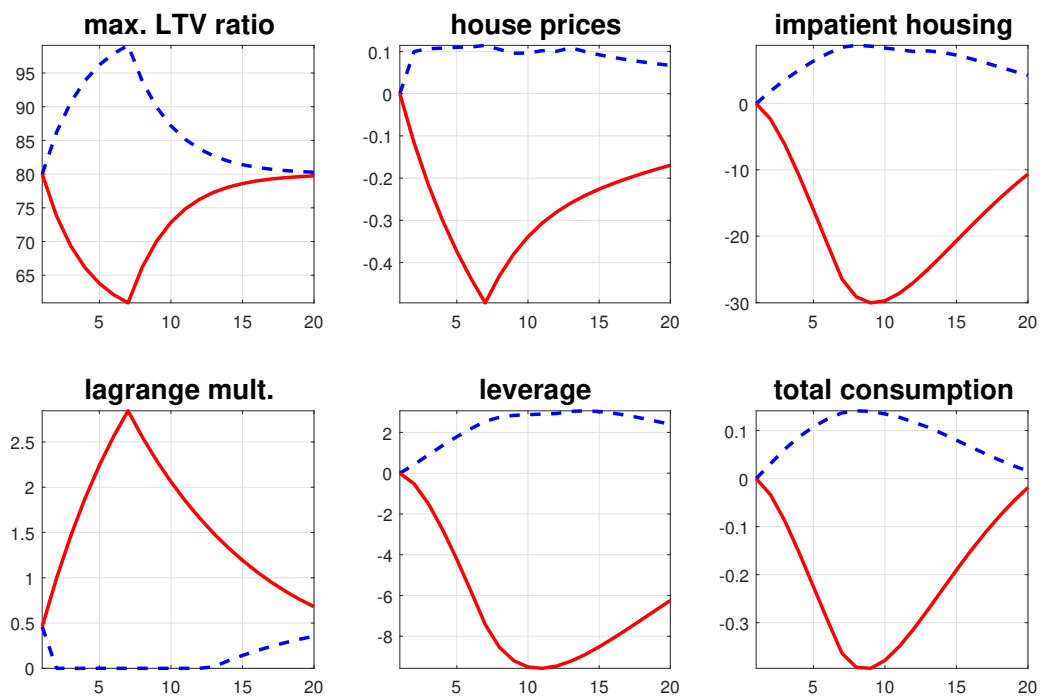


(b) Leveraging



Notes: GDP responses to a monetary policy shock in household de-leveraging and household leveraging states when controlling for the level of household debt. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

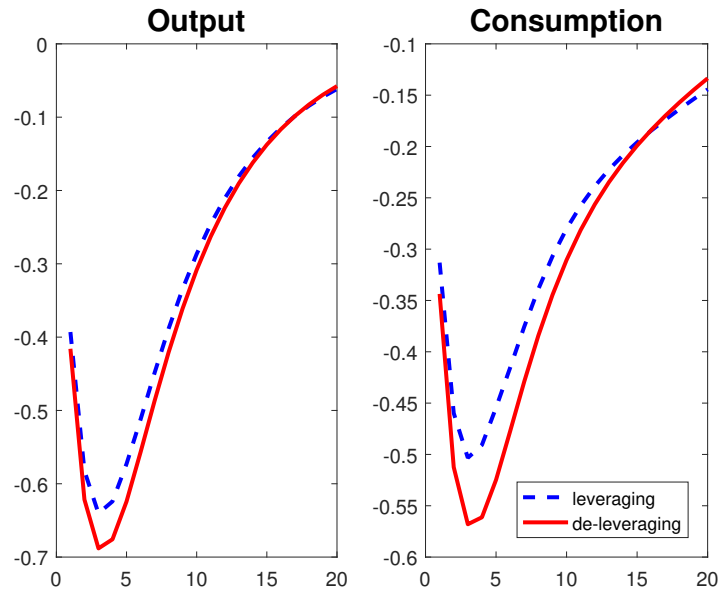
Figure 11: A sequence positive and negative LTV shocks



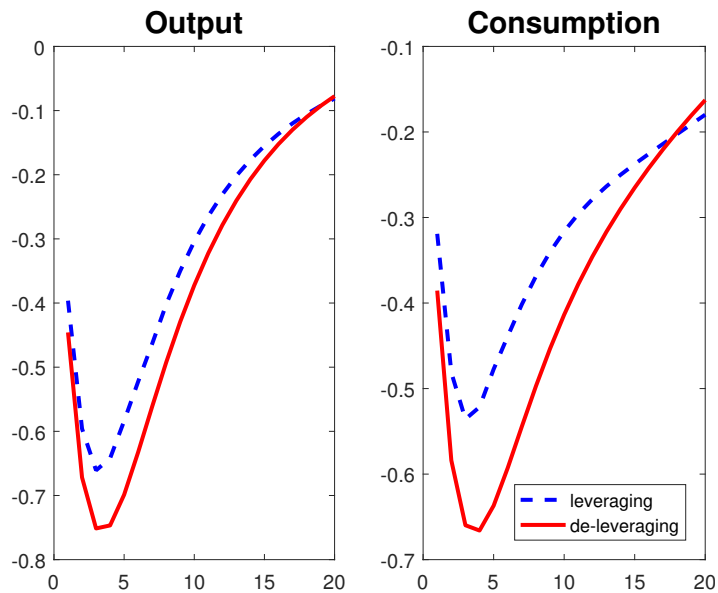
Notes: The blue (dashed) and red (solid) lines show a series of 6 unexpected positive and negative LTV shocks, respectively. The maximum LTV ratio and the lagrange multiplier are in levels. All other variables in percentage deviations from the steady state.

Figure 12: Simulated IRFs under leveraging and de-leveraging

(a) $M = 0.8$

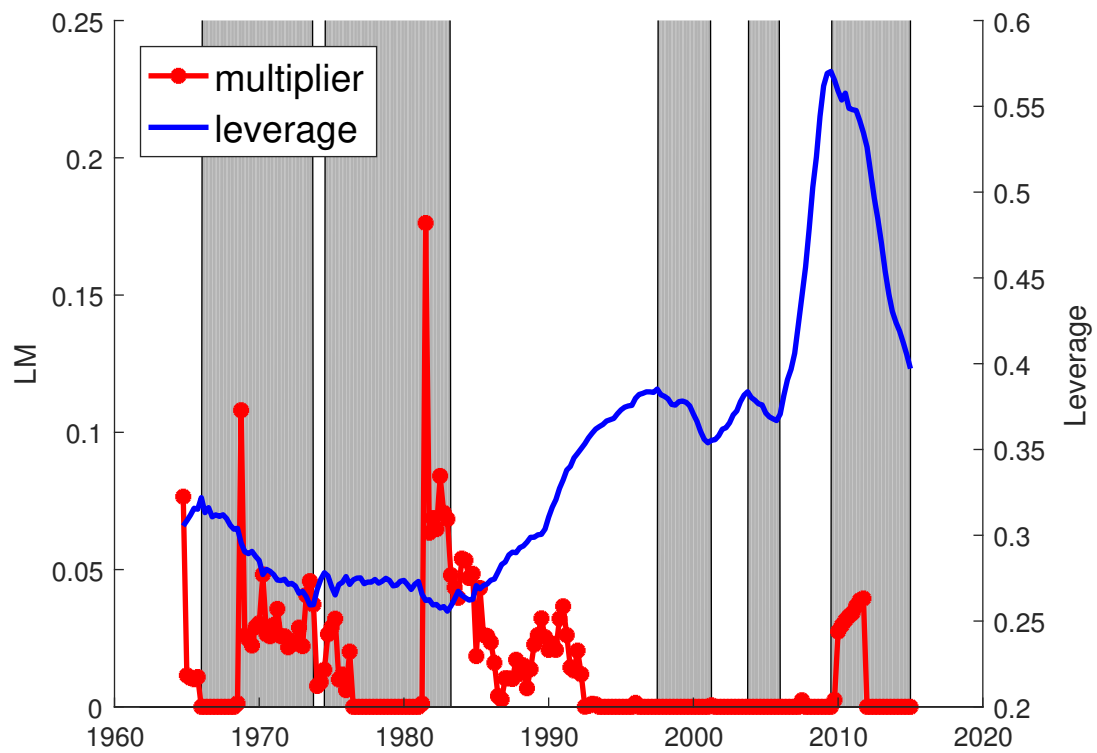


(b) $M = 0.9$



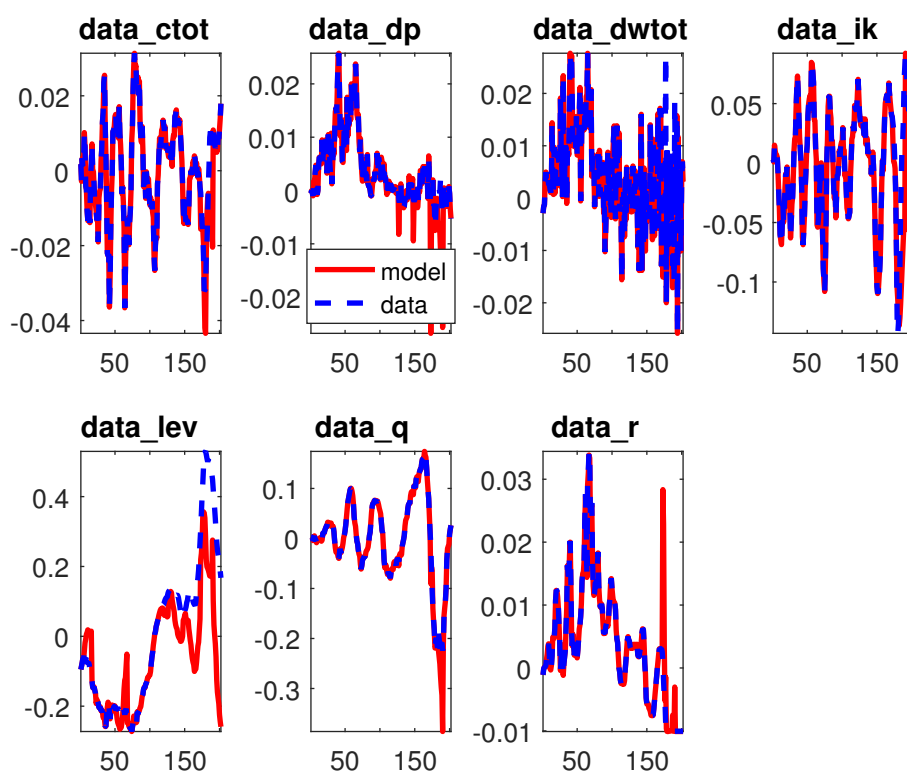
Notes: IRFs to an (annualized) 100 basis points monetary policy shock under leveraging and de-leveraging. The leveraging and de-leveraging states are simulated as a series of 6 consecutive positive and negative LTV shocks, respectively. Variables in percentage deviations from the steady state. Upper and lower panel refer to a steady state LTV limit of 0.8 and 0.9, respectively.

Figure 13: De-leveraging and borrowing constraints



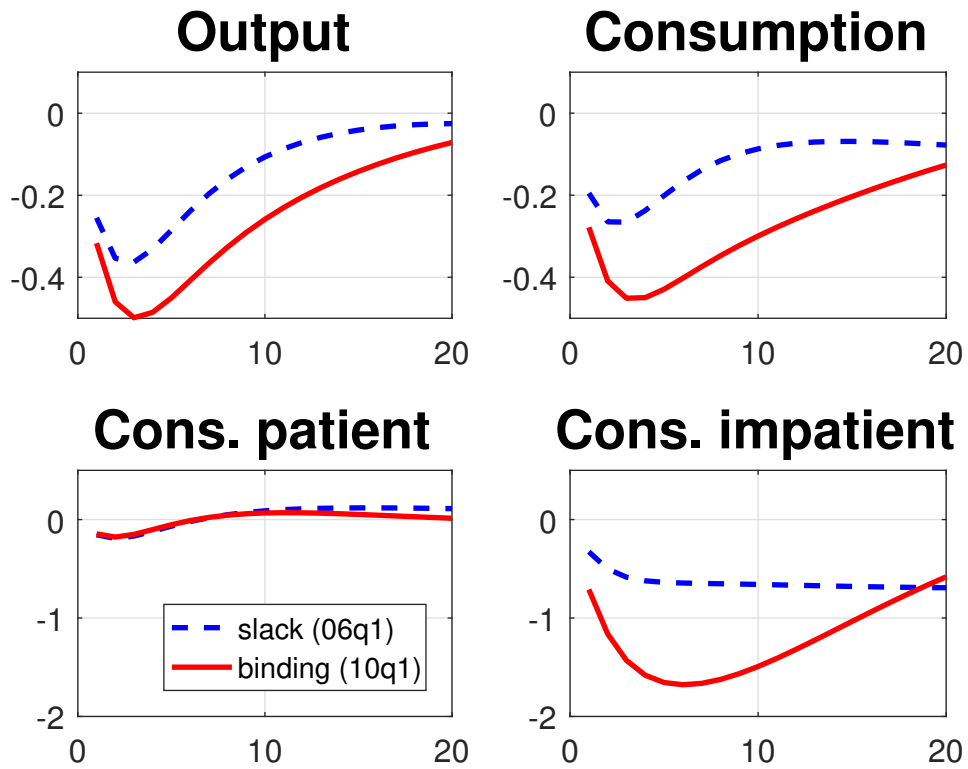
Notes: Shaded areas indicate periods of De-leveraging in the data. The red (circled) line corresponds to the lagrange multiplier in the borrowing constraint in the DSGE model. The blue (solid) line corresponds to the leverage data.

Figure 14: Smoothed variables and data



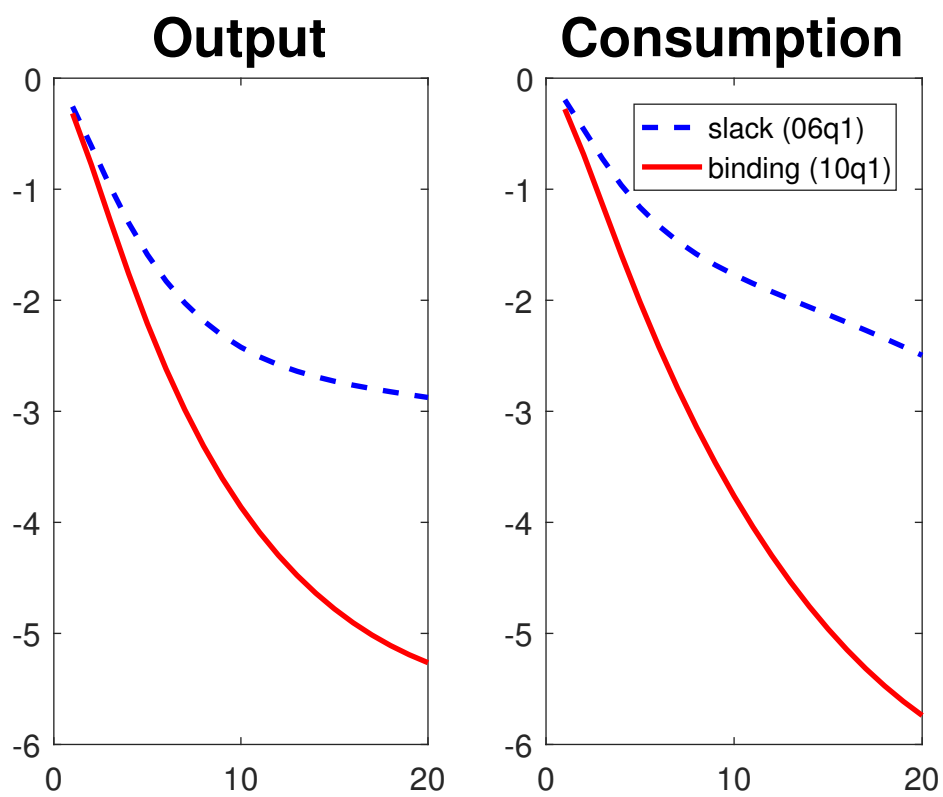
Notes: Smoothed variables from the DSGE model using the deterministic filter and data. The correlations between the two are: 0.98 for consumption, 0.94 for price inflation, 0.95 for wage inflation, 0.95 for investment, 0.92 for leverage, 0.99 for house prices and 0.95 for the federal funds rate.

Figure 15: IRFs to a contractionary monetary policy shock



Notes: IRFs to an (annualized) 100 basis points monetary policy shock. The blue dashed line shows a shock in 2006q1 and the red solid line a shock in 2010q1. Results are shown in percentages.

Figure 16: Cumulative IRFs to a contractionary monetary policy shock



Notes: IRFs to an (annualized) 100 basis points monetary policy shock. The blue dashed line shows a shock in 2006q1 and the red solid line a shock in 2010q1. Results are shown in percentages.