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Discussion Papers

Deutsches Institut für Wirtschaftsforschung 2019

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IMPRESSUM

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http://www.diw.de

ISSN electronic edition 1619-4535

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Monetary Policy and Household Deleveraging*

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June 12, 2019

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 a contractionary monetary policy shock leads to a large and significant fall in economic activity during periods of household deleveraging. In contrast, monetary policy shocks only have insignificant effects during a household leveraging state. These results are robust to alternative definitions of leveraging and deleveraging periods, different ways of identifying monetary policy shocks, controlling for the state of the business cycle, the level of households debt, and financial stress. 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 deleveraging periods in the data on average coincide with periods of binding collateral constraints whereas constraints tend to turn slack during leveraging episodes. Moreover, the model produces an amplification of monetary policy shocks that is quantitatively comparable to our empirical estimates. These findings indicate that 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.

*Special thanks to Mathias Trabandt for detailed feedback and support. Dario Caldara, Cristiano Cantore, Efrem Castelnuovo, Martin Eichenbaum, Michael Ehrmann, Philipp Engler, Carlo Favero, Marcel Fratzscher, Jordi Galí, Volker Grossmann, Alexander Haas, Matteo Iacoviello, Alejandro Justiniano, Peter Karadi, Michael Krause, Ludger Linnemann, Michael McMahon, John Muellbauer, Gert Peersman, Michele Piffer, Marco Pinchetti, Frank Smets, Thomas Steger, Gregory Thwaites, Peter Tillmann, Lutz Weinke, Roland Winkler, as well as seminar participants at the Berlin International Macroeconomics Workshop, 2018 RES Annual Conference, 2018 IAAE Annual Conference, 2018 CEF International Conference, 2018 EEA-ESEM Annual Congress, University of Melbourne, De Nederlandsche Bank, University of Antwerp, University of Hamburg, HU Berlin, University of Leipzig, University of Gießen, Ghent University, Charles University Prague, TU Dortmund University, Vienna University of Technology, and DIW Berlin also provided useful suggestions.

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1 Introduction

Since the beginning of the 2000s, private household leverage has fluctuated substantially in the U.S. economy. The ratio of aggregate household debt to aggregate housing value increased from 47% in 2005 to almost 70% at the outbreak of the 2008 financial crisis. Due to the massive subsequent deleveraging, the ratio fell back to 54% in 2015. A growing number of mostly theoretical studies interprets this significant household leveraging and deleveraging 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, henceforth)). Moreover, 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 (2017), 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 deleveraging evolved in parallel since the financial crisis. If borrowing constraints play an important role for households' saving-consumption 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 deleveraging, 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 deleveraging process that occurred after the Great Recession into account. In our baseline estimation, we rely on a timing restriction to identify monetary policy shocks.

The empirical results reveal that when private households deleverage, 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 mostly insignificant effects on economic activity during a household leveraging state. The maximum GDP response in a deleveraging state is 50 percent larger than the corresponding GDP response in a leveraging state.

These results are robust to alternative definitions of leveraging and deleveraging periods, different ways of identifying monetary policy shocks, and changes in the sample. Moreover, we show that positive and negative monetary policy shocks are fairly evenly distributed across leveraging and deleveraging 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 three 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 deleveraging, a contractionary monetary policy shock induces a significant fall in aggregate activity both in economic expansions and 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 deleveraging both when household debt is high and low. In contrast, during household leveraging periods, a monetary tightening induces a significant decline in economic activity only when household debt is low, although these effects are small and just short-lived. Third, our results are robust when we condition on financial stress in the economy. When households deleverage, a contractionary monetary policy shock induces a significant decline in economic activity in tranquil times but also in periods of financial stress. Contrary, during a household leveraging episode, monetary policy only has a significant impact on the economy when financial stress is low. 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, the level of household debt, and financial stress only play 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 U.S. geographical states by relying on the identification approach proposed by Nakamura and Steinsson (2014). The state level estimates confirm our findings at the aggregate level: the effects of monetary policy shocks are significantly amplified during periods of household deleveraging.

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 that 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 deleveraging in the data on average coincide with episodes of binding collateral constraints in the model. In contrast, constraints tend to 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 generates amplification effects that are quantitatively comparable to our empirical estimates.

The intuition for these asymmetric effects can be summarized as follows: when the constraint is slack, standard adjustments common to New Keynesian DSGE models occur. Because nominal prices are sticky, the central bank - controlling the short-term interest rate - has leverage over the ex-ante real interest rate. An increase in the nominal rate leads to an increase in the real rate, which in turn reduces aggregate demand and puts pressure on firms to gradually adjust prices to a lower level. Thus, when borrowing constraints are turned off, a monetary tightening has mild contractionary effects. However, there are two additional channels that gain importance when the constraint is binding: debt-deflation and redistribution. The fall in prices induced by the monetary policy shock raises the cost of debt services for constrained households, which induces a redistribution of resources from borrowers to savers. Because borrowers have a higher marginal propensity to consume, aggregate demand falls more strongly compared to the slack constraint case, where they can smoothen the shock out by taking on more debt. In sum, asymmetric responses following a monetary policy shock are driven by financially constrained households, which are forced to cut back consumption when a bad shock hits the economy.

Our paper contributes to the nascent 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 U.S. counties that 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, first, by 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 determined endogenously to explain these empirical findings.

The rest of the paper is organized as follows. Section 2 presents our empirical evidence. Section 3 presents the structure of the DSGE model. In Section 4, we use the model to investigate the interplay between deleveraging, collateral constraints and monetary policy. Finally, Section 5 concludes.

2 Econometric Evidence

2.1 Empirical Model

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). This method has become a popular tool to estimate state-dependent models and calculate impulse responses.[1] 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.[2] 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:

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

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_hs 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:

[1] See, for example, Auerbach and Gorodnichenko (2012a) and Ramey and Zubairy (2018).

[2] The 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 (2018).

$$y_{t+h} = \tau t + I_{t-1} \left[\alpha_{A,h} + \psi_{A,h}(L)x_t + \beta_{A,h}\epsilon_t\right] + (1 - I_{t-1}) \left[\alpha_{B,h} + \psi_{B,h}(L)x_t + \beta_{B,h}\epsilon_t\right] + \nu_{t+h}, \quad (2)$$

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 deleverage and zero otherwise. Following the literature on state-dependent effects of fiscal policy (see, for example, Auerbach and Gorodnichenko 2012b, Ramey and Zubairy 2018), 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 deleveraging states whereas $\beta_{B,h}$ shows the effect in household leveraging states.

To define episodes of household leveraging and deleveraging, we first need an appropriate indicator to measure household leverage. For this purpose, we use the households' total liabilities-to-real estate ratio.[3] This ratio measures the amount of total household credit, which is the sum of mortgages and consumer credit, relative to its underlying collateral asset. A similar indicator for household leverage is used by Justiniano et al. (2015), Guerrieri and Iacoviello (2017) and Dynan (2012) who study the impact of the state of the household leverage cycle and house price movements on personal consumption and other main aggregates. Moreover, the Bureau of Economic Analysis refers to this variable as an important indicator for the state of the aggregate economy (Bridgman and Grimm 2015). In particular, this ratio is interpreted as a key indicator on macro-financial linkages, which provides relevant information for early warning signals and emerging risks in the housing market. Importantly, this measure is a close analogue to the leverage ratio frequently included in DSGE models with household collateral constraints. Thus, our empirical leverage series mimics the theoretical counterpart used in the latter part of the 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 deleveraging periods. This procedure implies that out of the 219 periods included

[3] Details on data construction and sources are given in the Appendix.

in the sample, 109 or 49% are detected as deleveraging periods, while the remaining 110 episodes or 51% indicate periods of household leveraging.

As shown in Figure 1, we detect five distinct episodes of deleveraging: 1966q2-1975q2, 1977q1-1983q1, 1997q4-2001q3, 2003q4-2005q4, and 2009q4-2015q1. These deleveraging states correspond with specific events in the history of the U.S. economy. The first period of household deleveraging, which happened from the mid 1960s to the mid 1970s, indicates the consequences of the so-called Credit Crunch of 1966. The second deleveraging episode, which lasts from the mid 1970s until the beginning of the 1980s, coincides with the surge in interest rates toward the end of the Great Inflation. Around the 2000s, the Asian and Dot-com crises caused two short-lived deleveraging periods. Finally, following the Great Recession, private households reduced their leveraging position substantially, which corresponds with our fifth deleveraging episode at the end of the sample. Importantly, Figure 1 also shows the difference between the traditional business cycle and the household leverage cycle. Official NBER recessions, indicated by the dashed lines, are in general much shorter than household deleveraging periods. Moreover, whereas some recessions coincide with deleveraging phases (e.g., in the 70s and 80s), other economic contractions occured without household deleveraging or vice versa.[4]

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 control variables: the log-level of GDP, the log-level of the GDP deflator, the household leverage ratio and the difference between the 10-year Baa corporate yield and the 10-year Treasury bond yield. The stance of monetary policy is measured by the shadow federal funds rate constructed by Wu and Xia (2016). 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 control variables. 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 the log-level of GDP, the log-level of 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

[4]We study the interrelation between the state of the business cycle and the household leverage cycle in a latter section in more detail. Moreover, it is shown that our empirical results are robust to an alternative definition of household leveraging and deleveraging states.

the short-term interest rate. We include two lags of the endogenous variables in all our estimations.

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 data for the shadow federal funds rate. By measuring the actual stance of monetary policy by the shadow federal funds rate, we are able to include the massive household deleveraging 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) series allows to identify the effects of unconventional monetary policy interventions.

2.2 Baseline Results

In this section, we present our baseline empirical findings. 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 show the responses in a deleveraging 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.

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. This contractionary effects to an increase in the policy rate are in line with previous empirical work (e.g., Christiano et al. 2005, Gertler and Karadi 2015).

As columns 2 and 3 reveal, the effect of monetary policy shocks differ substantially across the household leverage cycle. When households deleverage, GDP falls significantly in response to a contractionary monetary policy innovation. GDP responds in a hump-shaped manner with a peak response around two years after the shock occured. In contrast, GDP does not change significantly in a leveraging state. The response is more erratic and estimation uncertainty is relatively large.

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 deleveraging state, consumption decreases significantly, whereas in a leveraging state the consumption response is mostly insignificant. In addition, investment reacts differently in both leveraging states: in a deleveraging 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 mostly reacts insignificantly in a leveraging state, it falls significantly in a deleveraging state.

The state dependent responses reveal differences in the propagation and amplification of monetary policy shocks under household leveraging and deleveraging 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 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 effects in a deleveraging state are estimated to be statistically significant while the responses are not statistically different from zero in a leveraging state. Moreover, for GDP, inflation, and consumption the aggregate decline is also larger in magnitude. For example, the cumulative loss in GDP following the increase in the interest rate is about 50% larger in a deleveraging state compared to a leveraging state.

Overall, these results suggest that the effectiveness of monetary policy interventions crucially depends on the household leverage cycle. When private households deleverage, 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.

2.3 Robustness

In the following, we consider various robustness checks on our baseline specification. First, we show that our findings are robust to alternative ways of identifying monetary policy shocks, different definitions of leveraging and deleveraging states, and changes in the sample. Moreover, we present evidence that our results are not driven by a different distribution of monetary policy shocks across household leveraging states. We also demonstrate that the household leverage-dependent effects of monetary policy are robust when we additionally control for the state of the business cycle, the level of household debt, and aggregate financial stress. For easier visual comparison, we focus in this section solely on GDP responses.

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 Miranda-Agrippino and Rey (2015), which is available for the period 1969q1-2012q4.[5] The first row of Figure 4 shows that our main results are robust to this alternative identification approach.[6]

[5] This series is available at: `http://silviamirandaagrippino.com/research/`.

[6] We also verify that our results remain when following Tenreyro and Thwaites (2016) and using a nonlinear Romer and Romer (2004) regression, to account for the possibility that the central banks'

In addition, we check whether our results depend on the specific series to measure the stance of monetary policy. In our baseline, we use the shadow federal funds rate as proposed by Wu and Xia (2016). Gertler and Karadi (2015) argue to rely on treasury rates with a longer maturity to capture the effect of unconventional monetary policy. We follow this suggestion and use the 5-year treasury rate. Thus, we identify a monetary policy shocks by using the same set of control variables as in our baseline specification but replace the shadow federal funds rate with the 5-year treasury rate. As shown in the second row of Figure 4, our main results are robust to using this long-term interest rate to measure the stance of monetary policy.

Alternative State Definition: We now make use of an alternative way to differentiate between leveraging and deleveraging periods. For this purpose, we define deleveraging states as those periods in which the year-on-year change in the total household liabilities-to-real estate ratio is negative for at least two consecutive quarters. The third row of Figure 4 presents the results of this exercise. It turns out that our findings prevail when using this alternative state definition.

Changes in the Sample: We further check whether our results are driven by specific time periods. In doing so, we first, drop the period of the Great Recession and the subsequent zero lower bound by ending the sample in 2008Q4. Second, we follow Gertler and Karadi (2015) and start the sample in 1979 which coincides with the beginning of Paul Volcker's tenure as Federal Reserve chair. As pointed out by other studies, there might be a regime shift in monetary policy pre- and post-Volcker (e.g., Clarida et al. 2000).[7] As the fourth and fifth row of Figure 4 show our results are robust to both changes in the sample.

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 instance, contractionary policy interventions have a larger effect on the economy than expansionary shocks and if contractionary shocks are more common in a deleveraging 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 effects on the economy than expansionary ones. Thus, if we observe proportionally more interest rate

reaction function changes across different states of the leverage cycle. These results are shown in Figure A1 in the Appendix.

[7]Thanks are due to an anonymous referee for pointing this out.

increases in a deleveraging state than in a leveraging state, the sign of the shocks may well be explaining our results.

It turns out that monetary policy shocks are fairly evenly distributed across the deleveraging and leveraging states: for both states, the relative proportion of positive shocks is similar to the relative proportion of negative shocks. This confirms that our main finding of household leverage-dependent effects of monetary policy cannot be attributed to different shock distributions between both leveraging states.[8]

2.3.1 Controlling for Alternative State Variables

In this section, we show that our results are robust when controlling for three other prominent state variables: the state of the business cycle, the level of household debt, and financial stress.

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 during economic expansions.

First, we start by investigating whether deleveraging 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, 13 quarters coincide with episodes of leveraging, while the remaining 19 quarters overlap with deleveraging periods. A similar picture emerges when relying on the output gap, measured as the deviation of GDP from its long-run HP trend ($\lambda = 1600$). We classify 42% of the periods for which we observe a positive output-gap as leveraging states, while the remaining 58% of periods with a positive output-gap coincide with periods of deleveraging. 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. We use the output gap, measured as the deviation from GDP from its HP trend ($\lambda = 1600$), as indicator for economic slack. The first and second rows of Figure 5 present the GDP responses for the

[8]Of all monetary policy shocks that happened during a leveraging state, 50% are positive innovations and the remaining 50% are negative innovations. The respective numbers in deleveraging states are 47% (positive shocks) and 53% (negative shocks). Of all positive monetary policy shocks, 48% happened during a deleveraging state and of all negative innovations, 51% occurred during a deleveraging state. Figure A2 in the Appendix shows the distribution of shocks across states.

four states of the economy. It turns out that when private households deleverage, 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 insignificant, both in booms and in recessions. Although our estimates suggest that the effects are somewhat amplified during economic expansions, the state of the leverage cycle seems to be of primary importance for the effectiveness of monetary policy interventions.[9]

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 a larger impact on economic activity compared to a situation in which household debt is above its long-run trend. Against this background, our results could be explained by the fact that deleveraging 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 total household liabilities-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 of all low household debt periods, 58% coincide with deleveraging periods while the remaining 42% are considered as leveraging periods. Thus, there is no systematic relation between household deleveraging states and periods of low household debt.

To further rule out that our results are driven by the level of household debt, we estimate equation (2), but further condition on the level of household debt. The third and fourth rows of Figure 5 show the results of this exercise. Irrespective of the level of household debt, we find that in a deleveraging state a contractionary monetary policy shock leads to a significant decline in aggregate output. In contrast, during a leveraging episode GDP does not decline significantly when household debt is above its long-run trend. 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.

Financial Stress: One alternative explanation for our results might be that household deleveraging periods are linked to shifts in credit supply by banks. For example, it is possible that changes in household leverage are caused by stress in the banking sector which reduces credit availability.[10] To study the systematic relation between the household leverage cycle and banking stress, we make use of the Financial Conditions Index

[9] The results also hold when measuring economic slack as the deviation of the unemployment rate from a fixed threshold as proposed by Ramey and Zubairy (2018). These results are available from the authors upon request.

[10] Thanks are due to an anonymous referee for pointing out this possibility.

provided by the Chicago Fed. This index provides an update on U.S. financial conditions in money markets, debt and equity markets, and the traditional and shadow banking systems. Here we focus on the leverage subindex of the aggregate indicator. A positive value of this index indicates that financial conditions are tighter than on average, while negative values indicate the opposite. The data are just available from 1971 onwards, so all remaining results are based on this smaller sample period. There is only a slight overlap between financial stress periods and household deleveraging. 55% of all financial stress states coincide with deleveraging states. However, to further test whether our results depend on the banking cycle, we proceed as before and estimate equation (2), but condition on banking stress. The last two rows of Figure 5 present the results. When households deleverage, GDP falls significantly following an increase in the policy rate, irrespective of the level of financial stress. In contrast, in a leveraging state GDP responds significantly only when the level of financial stress is low, while there is no significant response when financial markets are tight. Moreover, when comparing the responses during normal times, the contractionary effect following the increase in the interest rate is clearly amplified in a deleveraging state.

In sum, the findings of the last 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, the level of household debt, and financial stress only play a secondary role.

2.4 U.S. 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 U.S. geographical states. To identify monetary policy shocks at the U.S. state level, we make use of the approach suggested by Nakamura and Steinsson (2014) in the context of exogenous government spending shocks. The main regression takes the following form:

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

where $\Delta z_{i,t}$ is the annual growth rate of the variable of interest (GDP or employment in our case) 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 deleveraging, implying that the effects of the interest rate in leveraging and deleveraging periods are given by β_L and β_D respectively.

We use annual panel data at the U.S. state level for 1990 –2014 and account for the overlapping nature of the observations in our regression by clustering the standard errors by state. 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 deleveraging periods as those episodes in which the annual change in the loan-to-value ratio is negative. U.S. 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 drivers of the business cycle in the U.S., 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. Therefore, we 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 (1) 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 amplified when the shock hits the economy during a deleveraging episode. This result holds irrespective of the identification of monetary policy shocks for GDP and employment.

In addition to our evidence at the national level, we find that the effects of monetary policy shocks are amplified during periods of household deleveraging at the U.S. state level as well. Based on this robust evidence, in the following we provide a structural interpretation for our empirical findings.

3 A Monetary DSGE Model

To explore the mechanism driving our empirical findings, we set up a Monetary DSGE model following GI and use it as a tool to investigate the interrelationship between household leverage, collateral constraints, and monetary policy. 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 such that newly issued debt is restricted to a maximum of housing wealth. 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 differs 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 key for understanding asymmetric effects of monetary policy across the household leverage cycle as found in the data. In the following, we briefly present the main features of the model.[11]

3.1 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 household utility functions read

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

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

[11] Since the model is very close to GI, we invite the interest reader to find a more detailed discussion and derivations in their paper.

in period t, 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_c and Γ_h 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

$$c_t + q_t h_t + b_t + i_t = \frac{w_t n_t}{x_{w,t}} + q_t h_{t-1} + \frac{R_{t-1} b_{t-1}}{\pi_t} + rk_t k_{t-1} + div_t, \tag{5}$$

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

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

where a_t is an AR(1) investment specific technology 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

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

They also face the following borrowing constraint

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

where $\gamma > 0$ is the degree of debt inertia[12] and M_t is the loan-to-value (LTV) ratio limit. We assume that the LTV ratio follows an exogenous process $\log(M_t) = (1 - \rho_M) \log(M) + \rho_M \log(M_{t-1}) + u_{m,t}$ 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 is important in our analysis later on, when we model periods of leveraging and deleveraging. Innovations in the LTV ratio may capture changes in the

[12]This 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.

lending behavior of private banks or institutional changes in the housing market and the financial system.

3.2 Firms, Nominal Rigidities and Monetary Policy

The firm sector follows the New Keynesian standard, where competitive (wholesale) firms produce intermediate goods that 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

$$\max \frac{y_t}{x_{p,t}} - w_t n_t - w_t^I n_t^I - rk_t k_{t-1} \tag{9}$$

subject to the production technology

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

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 New Keynesian-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:

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

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:

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

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

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 constraint:

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

$\bar{R}$ stands for the nominal gross interest rate and 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 innovations we have mentioned above: housing preference, investment specific, price markup, monetary policy, wage markup, intertemporal preference, and loan-to-value ratio shocks.

4 Quantitative Analysis

In this section we fit the model to U.S. 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 deleveraging 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 nonlinear (deterministic) filter proposed by GI 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 model parameters and empirical data. With this information at hand, we are able to compare periods of deleveraging 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 as estimated by the model.

4.1 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 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 (total household liabilities to real estate at market value).[13] A detailed description of the data and the transformation undertaken to make it consistent with 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

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

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.

The model can be taken to the data with the following observation equation

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

where Y_t is a matrix of observed time series and H_t is a selection matrix that indicates the observed endogenous variables. Following the method proposed by Fair and Taylor (1983), this expression allows filtering 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 how this filter can be used to carry out a full-information Bayesian estimation of the piecewise-linear model, albeit with some important limitations.[14] Crucially, the filter cannot extract shocks that enter occasionally binding constraints in regimes where those shocks become irrelevant for model dynamics. For instance, when the ZLB binds, a monetary policy shock is inconsequential given that the interest rate is stuck at zero. GI circumvent this issue by setting monetary policy shocks to zero and dropping the nominal rate from the set of observables when the ZLB binds. In our setting, we have two such

[13] Leverage in the DSGE model is defined as $b_t/(q_t h_t^I)$, i.e., as the leverage of impatient households, given that patient households do not hold any debt. For robustness, we have estimated the model and performed all exercises discussed in this section using total leverage as the model analog of the empirical leverage series and we obtain similar qualitative results.

[14] The procedure implies that the model is solved at each point in time under the assumption that there are no further shocks in the future. Moreover, the filtering process does not allow for measurement error. For comparison with standard estimation methods and a detailed discussion, see Richter and Throckmorton (2016).

constraints: the ZLB and the collateral constraint. This yields GI's strategy not suitable for estimation.[15]

For this reason, we proceed in two steps. First, we estimate a subset of model parameters ignoring the occasionally binding constraints, that is, assuming that the collateral constraint is always binding and disregarding the ZLB. In the second step, we use GI's deterministic filter to select a subset of parameters in order to match the piecewise linear model to the data, estimate the structural shocks, and compute impulse responses. In the second step we follow GI and drop leverage (the federal funds rate) from the observables and assume that LTV ratio (monetary policy) shocks are zero when the constraint is slack. This procedure implies a time-varying H_t matrix in Equation (16). The technical details of this procedure can be found in the Appendix.

We calibrate some of the parameters as described in Table 2. With the exception of the maximum LTV limit, this calibration follows GI and is fairly standard in the literature.[16] In our baseline estimation we also fix the debt inertia, the share of impatient households, and the discount factor of impatient households to the estimated values by GI, which makes our results more easily comparable to theirs.[17]

The estimated parameters are shown in Table 3. As in GI, the Calvo prices and wages parameters are relatively high, while habit parameters for housing and consumption are below their estimates. When looking at the parameters concerning monetary policy, the response of the policy rate to prices is weak and persistence of the monetary policy shocks is relatively low. Overall, our estimated parameters are fairly similar to the ones obtained by GI and are within the range of values considered standard in the New Keynesian DSGE literature.

These estimated parameters are robust to several alternative specifications. In particular, the estimates are robust to excluding the ZLB period from our sample, to applying an alternative de-trending filter to the data, and to using an alternative definition of leverage in the model. Our estimates are also robust to including a neutral technology shock in the model and to an alternative formulation of the Taylor rule that considers the possibility that the central bank reacts to changes in household leverage. Details on these robustness checks are presented in Table A2 in the Appendix.

In order to fit the piecewise-linear model to the data, we fix the deep estimated parameters and let the parameters of the Taylor rule, as well as the key parameters ruling

[15]It is not only that we have a constraint with a shock on top of the ZLB, but the nature of the collateral constraint is also very different from the ZLB. Whereas the latter only binds in one episode towards the end of the sample, the collateral constraint becomes slack and binding in several episodes and it is crucial to determine leverage dynamics in the model. Therefore, dropping the data on leverage whenever the constraint becomes slack kills the purpose of estimating the model on leverage data in the first place.

[16]We 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. Qualitatively, our results are robust when setting the steady state value to 0.9.

[17]We try different values for these parameters and the key results are robust to different specifications.

the behavior of impatient households, vary. More precisely, we look for the values of r_π, r_R, y_Y, β^I and γ that give the best fit, conditional on all other parameters in Table 3. We then choose M so as to minimize the discrepancy between the model implied leverage and observed leverage. The resulting parameter values are reported in Table 4. The parameters that we had kept fixed so far, β^I and γ, are very close to GI's estimates, even if we use a much longer sample. This procedure allows us to extract the structural shocks that generate the data, conditional on the set of deep parameters.[18]

We are aware of the limitations of our approach. In particular, by ignoring the occasionally binding constraints in the first step the estimated parameters could be biased. Nevertheless, there are good reasons to think that the procedure fulfills its purpose. First, GI show that the difference between the estimated parameter values with an occasionally binding collateral constraint and those obtained under the assumption that the constraint is always binding is only small-sized. Second, the focus of the paper is not on drawing conclusions about specific parameter values. Third, while the computational burden of our approach is nontrivial, exploiting the piecewise-linear nature of the occasionally binding collateral constraint is much more efficient than other popular techniques, such as using projection methods to solve the model and a particle filter to evaluate it. For instance, the work by Gust et al. (2017), which considers a significantly smaller model without financial frictions, illustrates how costly this approach can be.

4.2 Model Estimation Results

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

4.2.1 Inspecting the Mechanism

Figure 6 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 (deleveraging) periods as a series of 6 positive (negative) 5% LTV ratio shocks to make the constraint slack (more binding).[19] The figure depicts the simulated

[18]Since 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 some errors. Figure A3 shows the smoothed and observed variables. Note that for all variables, the correlations between smoothed and observed series is very close to 1.

[19]Recall that in our baseline calibration the constraint binds in the steady state. We use 6 shocks of size 5% because this generates the desired expansion (to about 100%) and contraction (to about 74%) of the LTV limit to illustrate the model dynamics. Similar dynamics could be obtained with other arbitrary series of shocks.

paths for some key variables: the LTV limit increases (decreases) by about 13 percentage points in each case, and the constraint becomes slack after the first positive LTV shock. Recall that 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: house prices decline, which forces households to deleverage. In addition, the figure showcases the key macroeconomic asymmetry in the model: when the borrowing constraint is slack, consumption decisions are not restricted by collateral constraints implying a slight increase in consumption expenditures following the rise in house prices. On the other hand, when the constraint binds, households reduce consumption over and above the unconstrained optimum, which explains why the reaction of variables is stronger under a tightening of lending conditions.

How important are borrowing constraints for the transmission of monetary policy shocks? Figure 7 shows the responses of output and consumption to an annualized 100 basis points monetary policy shock in the leveraging and deleveraging regime. The upper and lower panels show the responses under a steady state LTV limit of 80% and 90% (GI's baseline), respectively. Leveraging and deleveraging episodes are simulated by feeding the same series of positive and negative LTV ratio shocks as in Figure 6. After six consecutive LTV shocks materialize, a monetary policy shock hits in period seven. When the shock hits, the constraint is expected to remain slack for four and five quarters in the upper and lower panels, respectively. The figure shows that monetary policy shocks are amplified when households are financially constrained; moreover, a longer expected duration of slack credit constraints implies greater amplification effects. In the upper panel the maximum responses of output and consumption (3 quarters after the shock) are amplified by 14% and 18%, respectively, while the amplification is 27% and 34% in the lower panel.

What explains this state-dependent impact of monetary policy shocks? When the constraint is slack, the model produces dynamics that are common across a wide range of New Keynesian DSGE models. Because prices are sticky, an increase in the nominal interest rate also leads to an increase in the real interest rate, which depresses private consumption and investment, and thus aggregate demand and output. This induces pressure on firms to lower prices. Thus, in a slack constraint regime the model implies modest declines in output, consumption, and inflation following an unexpected monetary tightening. When the constraint binds, two additional channels are responsible for the stronger contractionary effects. First, the lower price level induced by a higher interest rate implies a rise in real debt service costs. Constrained households have to use a higher share of their income stream to meet their debt payments. Second, this debt-deflation implies a redistribution of resources from borrowers to savers. Because savers have a lower marginal propensity to consume, they do not compensate for the lower consumption expenditures by borrowing households. Overall, financially constrained households, which are forced to cut back consumption strongly when a bad shock hits the economy, are responsible for the asymmetric responses to a monetary policy shock.

To illustrate the importance of these different channels, Figure 7 also presents results of a model version with nominal debt contracts such that debt-deflation effects are shut down. The responses of this model are given by the black crossed lines. In line with Iacoviello (2005), without debt-deflation the contractionary effects of a monetary policy shock are clearly reduced. Moreover, the figure illustrates that the key state-dependent amplification mechanism of monetary policy shocks in our model is the degree to what credit constraints bind. The higher the steady state loan-to-value ratio limit, the higher the steady state level of household debt and the larger the decline in economic activity in response to a contractionary monetary policy shock. Thus, the tighter financial frictions get, the more important the interplay between falling prices, higher debt service cots, and redistribution from borrowers to lenders becomes for the monetary policy transmission mechanism.

This simulation exercise offers a first model-based characterization of the channels that explain the asymmetric effects of monetary policy shocks between leveraging and deleveraging periods. Relying on these insights, we formulate the following hypothesis: when deleveraging 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.

4.2.2 Collateral Constraints, Deleveraging, and Monetary Policy

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 deleveraging in the data. In order to explore this issue we use the deterministic filter described above to take the nonlinear model to the data.

Figure 8 shows the smoothed series of leverage in the model and the Lagrange multiplier on the borrowing constraint, along with the deleveraging periods that we have used for our state-dependent local projections (shaded areas) and the empirical leverage series. Starting from the (binding) steady state, the constraint becomes slack at the beginning of the sample, and quickly becomes binding following the deleveraging that occurred during the credit crunch of 1966. It then returns to slack and becomes binding at the peak of the deleveraging 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 in 1986 for a short period of two quarters. Then it becomes binding again until the beginning of 1993 due to a sharp decrease in house prices.[20] Thereafter, the constraint becomes slack during a period of sharp leveraging in the mid 1990s and during the U.S. housing boom of the mid 2000s. We clearly miss the short deleveraging periods around the Asian and Dot-com crises. This may be due to two factors. First, given the high degree of persistence in the model, an abrupt switching from one regime to the other is a difficult task. Second, both the Asian and Dot-com crises only had a relatively small effect on the U.S. housing market when compared to the more prolonged downturns at the beginning and end of the sample. Importantly, the constraint becomes binding again in 2009, which corresponds to the large deleveraging that happened during the Great Recession. Specifically, it binds for 16 quarters in this period, from 2009q4 until 2013q3, and it becomes slack again when U.S. house prices start picking up in 2013.

By and large, the model captures the longest deleveraging episodes as periods of binding collateral constraints. Three out of the five deleveraging periods identified in the data coincide with binding constraints in the estimated model. In addition, we observe an overlap between leveraging periods defined through the data and model implied episodes of slack collateral constraints. Most importantly, the persistent and long leveraging period due to fundamental changes in the financial and housing market that started in the mid 1980s and culminated with the Great Recession, is mostly detected as a period of loose financial constraints by the model.[21] Qualitatively, this finding is robust to several modifications of the model and estimation strategy, like including a neutral technology shock, dropping the period of the ZLB or applying a different de-trending of the data.[22]

At this point it is interesting to see whether the two regimes identified by our model estimation produce similar amplification effects to a monetary policy shock compared to our empirically identified leveraging and deleveraging states. To investigate this issue, we re-estimate our baseline local projections but define a leveraging state as periods in which the estimated Lagrange multiplier equals zero whereas deleveraging periods are defined as episodes in which the Lagrange multiplier is larger than zero. Figure 9 presents the results of this exercise. Solid lines show the cumulative responses form our baseline empirical model and dashed lines present the cumulative effects when using the estimated model to define both states. Shaded areas indicate 90% confidence bands based on our baseline empirical specification. The responses are remarkably similar: when using the model implied states, we see an amplification effect in deleveraging states that closely

[20]The reason for the positive co-movement between leverage and the Lagrange multiplier in this particular episode is that the increase in the leverage ratio is mostly driven by a decrease in house prices (in the denominator) and not by an increase in credit (in the numerator). Since house prices determine impatient households' collateral in the model, a sharp decrease in house prices makes the constraint binding. Note that GI find the same result for this period (see Figure 5 of their paper).

[21]At this stage it is important to note that getting a perfect fit between deleveraging (leveraging) episodes and binding (slack) constraints might be an unrealistic target. As discussed above, different deleveraging episodes may in principle differ in their causes and consequences. For this reason, a simple common narrative for all these periods might be inappropriate.

[22]Results of these exercises are available from the authors upon request.

replicates our empirical findings. We interpret this result as additional evidence for the close connection between leveraging and deleveraging states in the data and slack and binding collateral constraints in the model.[23]

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 is 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 10 shows the responses to an annualized 100 basis points 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. When the monetary policy shock hits in 2006q1 and no further shocks materialize, the expected duration of the slack constraint is 20 quarters. The peak responses of output and consumption are amplified by 38% and 57%, respectively, 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 10 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 monetary policy shock hits the economy, they can borrow more and smoothen consumption optimally. This is what the blue dashed line shows in the right panel. On the contrary, when financial constraints bind, a higher interest rate shifts resources from impatient to patient households with the former reducing consumption expenditures sharply.[24] Note also that this mechanism is completely absent in the case of patient households: the response of investment shows that they can always cut on their investment spending in order to smoothen consumption optimally. Given that investment decisions depend exclusively on patient households, the investment response is essentially the same whether the constraint is binding or slack. Thus, although our empirical analysis reveals some state-dependence in the investment response, the model is not able to account for this asymmetry. Combining occasionally binding collateral constraints with alternative fric-

[23]Figure A4 in the appendix shows the non-cumulative impulse responses of this exercise.

[24]The close connection between states of the leverage cycle and household net worth in the model is also supported by the data. In particular, we observe a strong positive correlation between household leverage and the household net worth-to-GDP ratio (the correlation coefficient is 0.66 and highly significant). This implies that on average deleveraging periods correspond to a low level of household net worth, whereas household net worth is high during leveraging episodes.

tions in the business sector, see e.g., Iacoviello and Neri (2010) and Liu et al. (2013), to produce stronger regime-dependent investment dynamics provides a promising and interesting area for future research.

As we have highlighted before, the amplification of monetary policy shocks in the model crucially depends on the expected duration of the slack state when the shock hits. In particular, if the borrowing constraint is expected to be slack for long, impatient households will increase their borrowing aggressively in order to absorb the bad shock. Contrary, amplification is mild when agents expect financial constraints to become binding soon after the shock. What determines the expected duration of the slack constraint in a given period is the state of the economy, which in turn is determined by the specific series of shocks that led to it. The two main shocks affecting the behavior of leverage and the constraint in the model are the house price and LTV shocks. For instance, the constraint can become slack when leverage is relatively low with a series of positive house price shocks; alternatively it can become slack when leverage is relatively high with a series of positive LTV shocks.[25] Going back to our previous exercise, in 2006q1 the constraint becomes slack mostly due to house price shocks. In contrast, in 1993 for instance, it is LTV shocks that drive the slackness. If a monetary policy shock had hit in 1994q1, the expected duration of the slack constraint is only three quarters, as compared to twenty quarters in 2006q1.

In order to shed light on this asymmetry, we repeat our previous exercise for all periods in our sample where the constraint is slack (every dot where the Lagrange multiplier is at zero in Figure 8). Figure 11 shows the amplification effects for GDP and consumption as a function of the expected duration of the slack constraint after a monetary policy shock. Amplification is computed in terms of the maximum response, which happens 3 quarters after the shock hits. The figure illustrates that if credit constraints are expected to be slack for only 4 quarters, amplification in output and consumption is only between 10% and 15%, but it increases to over 50% for consumption and 35% for output if credit constraints are expected to remain slack for 15 quarters or more. The longer agents expect to stay within a regime of unconstrained borrowing, the larger the response differences get compared to a situation of constrained borrowing.

4.2.3 Historical decomposition

The model also provides us with key information about the drivers of collateral constraints in the data. Figure 12 decomposes the smoothed series of the multiplier on the borrowing

[25]In order to shed light on the cyclical properties of leverage, we show the responses of leverage to all shocks in the model in Figure A5 in the Appendix.

constraint in terms of the marginal contributions of the different shocks.[26] It turns out that LTV shocks are one important driver of the time-varying degree of collateral constraints.

The figure highlights that there has been substantial variation in the drivers of collateral constraints over the past decades. Note that house prices have become increasingly relevant since the 1990s, which is consistent with the evidence presented in GI (their data set starts in 1985). Price markup shocks play an important role during the years of the Great Inflation, throughout the 1970s and in the early 1980s, but much less so thereafter. The prolonged period of slack credit constraints between the late 1990s and the onset of the Great Recession is chiefly explained by house price and LTV shocks. Note that absent the LTV shocks, borrowing constraints would have become binding already in 2006, as in GI, given that house prices start falling around that time. The bulk of the action in the multiplier during the Great Recession is clearly explained through house price shocks. The model implies that monetary policy and LTV shocks contributed to loosen collateral constraints during the Great Recession.

All in all, we show that that a standard New Keynesian model augmented with an occasionally binding collateral constraint captures big deleveraging episodes in the U.S. 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.

5 Conclusion

This paper shows that the household leverage cycle significantly determines the effects of monetary policy shocks. Using data on the U.S. economy, we provide extensive empirical evidence that monetary policy interventions in a deleveraging state have a significant impact on the economy. Contrary, in a leveraging state monetary policy has no discernible effects. We use a standard New Keynesian DSGE model with financial frictions and an occasionally binding borrowing constraint to provide a structural interpretation for our empirical findings. When estimating the model, we find that deleveraging periods in the data on average coincide with periods of binding collateral constraints whereas constraints tend to turn slack during leveraging periods. Because the impact of monetary

[26]Since the model is nonlinear, the order in which the shocks are marginalized (fed into the model) matters when computing their marginal contribution. Here we follow GI and use the following ordering: housing preference, investment specific, price markup, monetary policy, wage markup, intertemporal preference, and, lastly, loan-to-value. Even though results vary, the main results are robust to using different orderings. An additional caveat is in place for this exercise: given that we match the data on leverage only occasionally, the model needs big LTV shocks to account for periods when the constraint goes from slack to binding. This explains the big LTV shocks at the beginning of the sample, in the early 1980s and in 2010. Given that the way we compute the shock decomposition is non-standard, Figure A6 shows the decomposition using Kalman smoother on the linearized model under the assumption that the collateral constraint is always binding.

policy shocks is amplified when collateral constraints become binding, the model highlights the importance of state-dependent financial frictions for understanding the asymmetric effects of monetary policy across the leverage cycle born out in the empirical analysis. 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 state of the leverage cycle plays an important role in understanding the impact and transmission of monetary policy actions.

References

Alpanda Sami and Zubairy Sarah. (2017) "Household debt overhang and transmission of monetary Policy". *Texas A&M University, mimeo.*

Angrist Joshua D., Jordà Òscar, and Kuersteiner Guido M. (2017) "Semiparametric Estimates of Monetary Policy Effects: String Theory Revisited". *Journal of Business & Economic Statistics forthcoming.*

Auerbach Alan J and Gorodnichenko Yuriy. (2012a) "Fiscal multipliers in recession and expansion". In: *Fiscal Policy after the Financial crisis.* University of Chicago press, 63–98.

Auerbach Alan J. and Gorodnichenko Yuriy. (2012b) "Measuring the Output Responses to Fiscal Policy". *American Economic Journal: Economic Policy 4* (2), 1–27.

Barnichon Regis and Matthes Christian. (2014) "Gaussian Mixture Approximations of Impulse Responses and the Nonlinear Effects of Monetary Shocks". Working Paper 16-8. Federal Reserve Bank of Richmond.

Barnichon Régis and Brownlees Christian. (2016) "Impulse Response Estimation By Smooth Local Projections". CEPR Discussion Papers 11726.

Bridgman Benjamin and Grimm Bruce. (2015) "BEA Statistics and New Indicators of Economic Conditon". Survey of Current Business. Bureau of Economic Analysis.

Christiano Lawrence J., Eichenbaum Martin, and Evans Charles L. (2005) "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy". *Journal of Political Economy 113* (1), 1–45.

Clarida Richard, Galí Jordi, and Gertler Mark. (2000) "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory*". *The Quarterly Journal of Economics 115* (1), 147–180.

Di Maggio Marco, Kermani Amir, Keys Benjamin J., Piskorski Tomasz, Ramcharan Rodney, Seru Amit, and Yao Vincent. (2017) "Interest Rate Pass-Through: Mortgage Rates, Household Consumption, and Voluntary Deleveraging". *American Economic Review 107* (11), 3550–88.

Dynan Karen. (2012) “Is a Household Debt Overhang Holding Back Consumption”. *Brookings Papers on Economic Activity 43*, 299–362.

Eggertsson Gauti B. and Krugman Paul. (2012) “Debt, Deleveraging, and the Liquidity Trap: A Fisher-Minsky-Koo Approach”. *The Quarterly Journal of Economics 127* (3), 1469–1513.

Fair Ray and Taylor John. (1983) “Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models”. *Econometrica 51* (4), 1169–85.

Fernald J. G. (2012) “A quarterly, utilization-adjusted series on total factor productivity”. Technical report, Federal Reserve Bank of San Francisco.

Gertler Mark and Karadi Peter. (2015) “Monetary Policy Surprises, Credit Costs, and Economic Activity”. *American Economic Journal: Macroeconomics 7* (1), 44–76.

Guerrieri Luca and Iacoviello Matteo. (2015) “OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily”. *Journal of Monetary Economics 70* (C), 22–38.

——— (2017) “Collateral constraints and macroeconomic asymmetries”. *Journal of Monetary Economics 90*, 28 –49.

Gust Christopher, Herbst Edward, López-Salido David, and Smith Matthew E. (2017) “The Empirical Implications of the Interest-Rate Lower Bound”. *American Economic Review 107* (7), 1971–2006. DOI: `10.1257/aer.20121437`.

Harding Don and Pagan Adrian. (2002) “Dissecting the cycle: a methodological investigation”. *Journal of Monetary Economics 49* (2), 365–381.

Iacoviello Matteo. (2005) “House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle”. *American Economic Review 95* (3), 739–764.

Iacoviello Matteo and Neri Stefano. (2010) “Housing Market Spillovers: Evidence from an Estimated DSGE Model”. *American Economic Journal: Macroeconomics 2* (2), 125–64.

Jordà Òscar. (2005) “Estimation and Inference of Impulse Responses by Local Projections”. *American Economic Review 95* (1), 161–182.

Jordà Òscar, Schularick Moritz, and Taylor Alan M. (2016) “The Great Mortgaging: Housing Finance, Crises, and Business Cycles”. *Economic Policy 131*, 107–152.

Jorda Oscar, Schularick Moritz, and Taylor Alan M. (2017) “Large and State-Dependent Effects of Quasi-Random Monetary Experiments”. Working Paper Series 2017-2. Federal Reserve Bank of San Francisco.

Justiniano Alejandro, Primiceri Giorgio, and Tambalotti Andrea. (2015) “Household leveraging and deleveraging”. *Review of Economic Dynamics 18* (1), 3–20.

Klein Mathias. (2017) “Austerity and Private Debt”. *Journal of Money, Credit, and Banking, 49*, 1555–1585.

Liu Zheng, Wang Pengfei, and Zha Tao. (2013) “Land-Price Dynamics and Macroeconomic Fluctuations”. *Econometrica 81* (3), 1147–1184.

Mian Atif R. and Sufi Amir. (2011) "House Prices, Home Equity-Based Borrowing, and the US Household Leverage Crisis". *American Economic Review 101* (5), 2132–56.

——— (2012) "What explains high unemployment? The aggregate demand channel". NBER Working Papers 17830. National Bureau of Economic Research, Inc.

Mian Atif R., Rao Kamalesh, and Sufi Amir. (2013) "Household Balance Sheets, Consumption, and the Economic Slump". *The Quarterly Journal of Economics 128* (4), 1687–1726.

Miranda-Agrippino Silvia and Rey Hélene. (2015) "US monetary policy and the global financial cycle". *NBER working paper 21722*.

Nakamura Emi and Steinsson Jón. (2014) "Fiscal Stimulus in a Monetary Union: Evidence from US Regions". *American Economic Review 104* (3), 753–92.

Newey Whitney K and West Kenneth D. (1987) "A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix". *Econometrica 55* (3), 703–708.

Ramey V.A. (2016) "Macroeconomic Shocks and Their Propagation". In: vol. 2. Handbook of Macroeconomics. Elsevier, 71–162.

Ramey Valerie A and Zubairy Sarah. (2018) "Government spending multipliers in good times and in bad: evidence from US historical data". *Journal of Political Economy 126* (2), 850–901.

Richter Alexander and Throckmorton Nathaniel. (2016) "Are nonlinear methods necessary at the zero lower bound?" Working Papers 1606. Federal Reserve Bank of Dallas.

Romer Christina D. and Romer David H. (2004) "A New Measure of Monetary Shocks: Derivation and Implications". *American Economic Review 94* (4), 1055–1084.

Schularick Moritz and Taylor Alan M. (2012) "Credit Booms Gone Bust: Monetary Policy, Leverage Cycles, and Financial Crises, 1870-2008". *American Economic Review 102* (2), 1029–61.

Smets Frank and Wouters Rafael. (2007) "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach". *American Economic Review 97* (3), 586–606.

Tenreyro Silvana and Thwaites Gregory. (2016) "Pushing on a String: US Monetary Policy Is Less Powerful in Recessions". *American Economic Journal: Macroeconomics 8* (4), 43–74.

Wong Arlene. (2015) "Population Aging and the Transmission of Monetary Policy to Consumption". *working paper*.

Wu Jing Cynthia and Xia Fan Dora. (2016) "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound". *Journal of Money, Credit and Banking 48* (2-3), 253–291.

Tables

Table 1: U.S. State Level Evidence

	LP-Shocks		Romer/Romer Shocks	
	Output	Employment	Output	Employment
β_L	$-.021$	$-.010$	.001	.013
	(.022)	(.008)	(.021)	(.008)
$\beta_D - \beta_L$	$-.004^{***}$	$-.002^{*}$	$-.003^{***}$	$-.002^{***}$
	(.001)	(.001)	(.001)	(.001)
Obs.	1224	1224	1122	1122

Notes: Standard errors clustered at the state level are in parentheses. The unit of observation is U.S. geographical states for all regressions in the table. β_L measures the effect in leveraging periods and $\beta_D - \beta_L$ measures the difference between the effect in deleveraging and leveraging periods. LP-Shock refers to the shocks obtained by the local projections at the federal level. The regressions include state and time fixed effects interacted with the deleveraging dummy. The regressions are estimated by two-stage least squares.
* Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

Table 2: 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 3: Estimated Parameters

	parameter	prior	posterior			
			mode	5%	median	95%
ε_c	habit in consumption	beta 0.7(0.1)	0.6697	0.6170	0.6783	0.7411
ε_h	habit in housing	beta 0.7(0.1)	0.6922	0.5198	0.6449	0.7573
ϕ	invest. adjustment cost	gamma 5(2)	8.4712	6.4277	9.0386	11.9457
r_π	Taylor Rule, inflation	norm 1.5(0.25)	1.0393	1.0132	1.0581	1.1042
r_R	Taylor Rule, inertia	beta 0.75(0.1)	0.6398	0.5916	0.6423	0.6912
y_Y	Taylor Rule, output	beta 0.125(0.025)	0.0433	0.0351	0.0533	0.0730
θ_p	Calvo, prices	beta 0.5(0.075)	0.9003	0.8926	0.9048	0.9166
θ_w	Calvo, wages	beta 0.5(0.075)	0.9046	0.8879	0.9024	0.9167
ρ_J	AR(1) housing shock	beta 0.75(0.1)	0.9905	0.9800	0.9865	0.9900
ρ_K	AR(1) investment shock	beta 0.75(0.1)	0.5513	0.4543	0.5358	0.6130
ρ_R	AR(1) monetary shock	beta 0.5(0.1)	0.2781	0.1878	0.2738	0.3590
ρ_Z	AR(1) preference shock	beta 0.75(0.1)	0.7776	0.6674	0.7613	0.8427
ρ_M	AR(1) LTV shock	beta 0.85(0.1)	0.7237	0.6573	0.7149	0.7715
σ_J	stdv. housing shock	invgamma 0.01(1)	0.0429	0.0417	0.0538	0.0729
σ_K	stdv. investment shock	invgamma 0.01(1)	0.0734	0.0581	0.0832	0.1122
σ_P	stdv. price markup shock	invgamma 0.01(1)	0.0056	0.0052	0.0057	0.0062
σ_R	stdv. monetary shock	invgamma 0.01(1)	0.0025	0.0023	0.0025	0.0027
σ_W	stdv. wage markup shock	invgamma 0.01(1)	0.0089	0.0084	0.0091	0.0099
σ_Z	stdv. preference shock	invgamma 0.01(1)	0.0191	0.0168	0.0200	0.0235
σ_M	stdv. loan-to-value shock	invgamma 0.01(1)	0.1459	0.1355	0.1471	0.1590

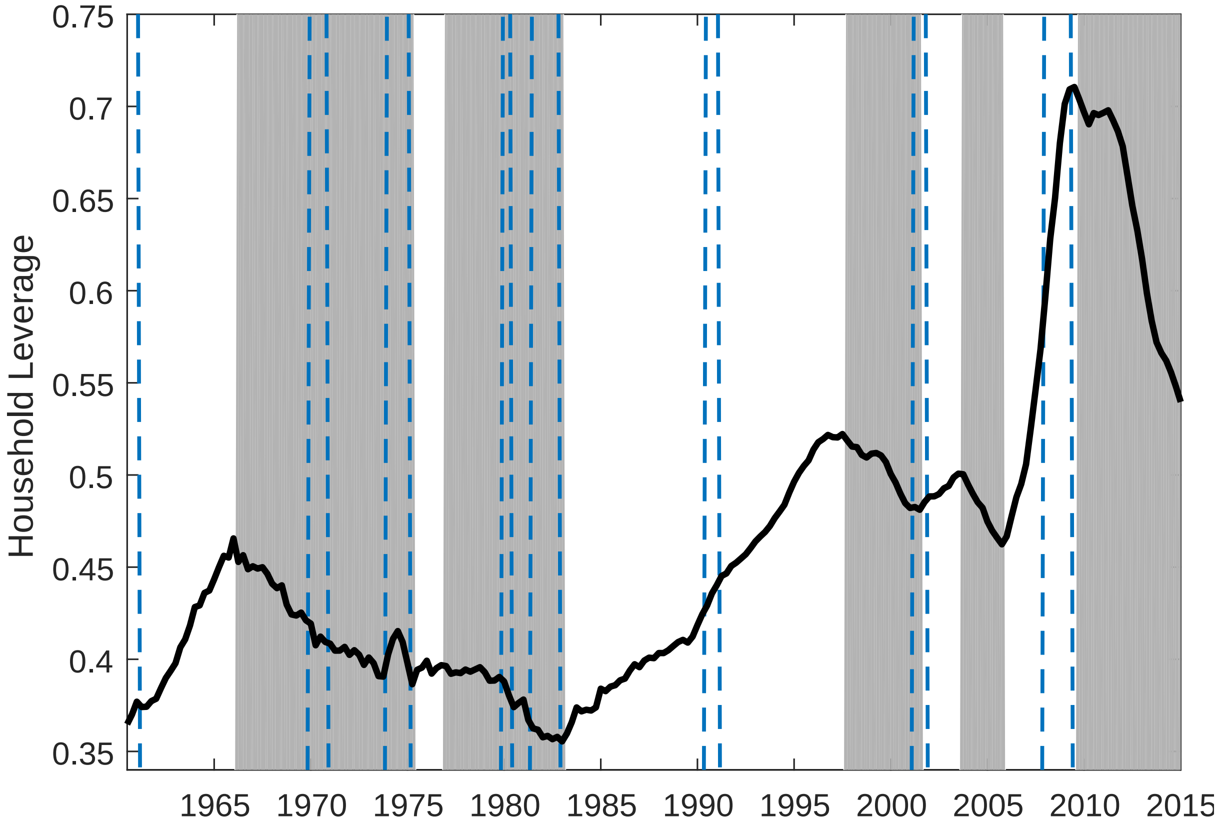
Notes: Posterior statistics based on 3 chains of 250,000 MCMC replications, where the first 50.000 are discarded as burnin. The prior column indicates the prior shape, mean and standard deviation in parenthesis.

Table 4: Parameters for Deterministic Filter

	parameter	
r_π	Taylor Rule, inflation	1.6004
r_R	Taylor Rule, inertia	0.6049
r_Y	Taylor Rule, output	0.0349
β^I	impatient discount factor	0.9935
γ	inertia, borrowing const.	0.6839
M	steady state LTV limit	0.87

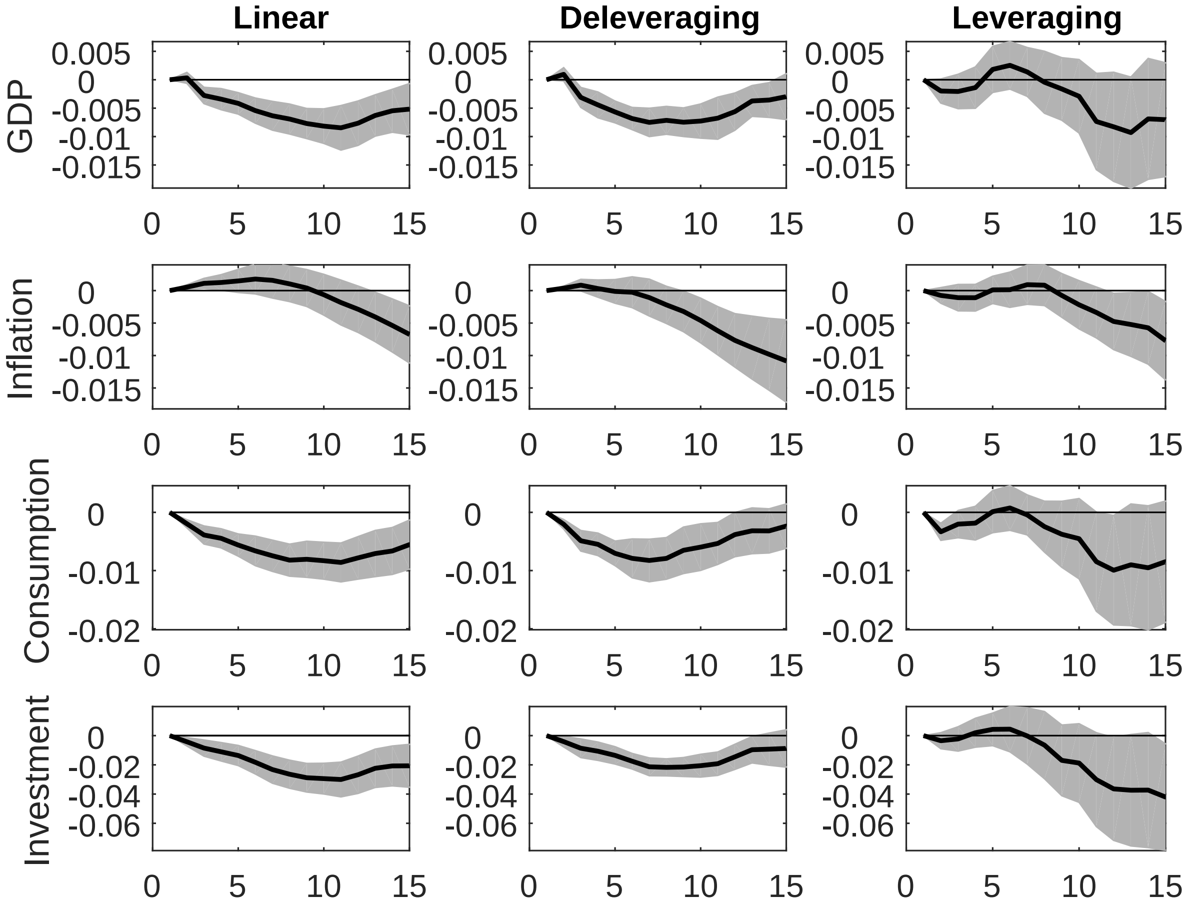
Figures

Figure 1: Household Leverage



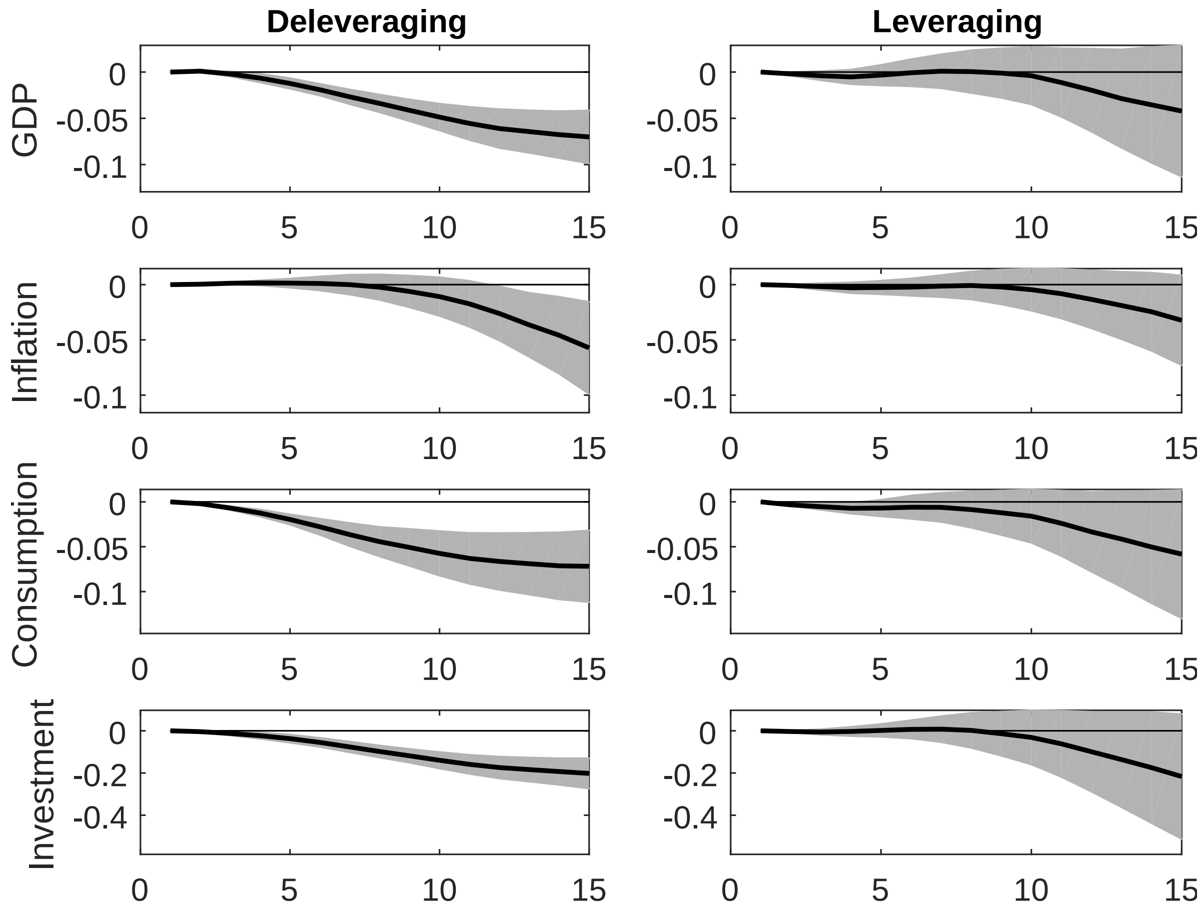
Notes: Household leverage is defined as mortgages over real estate value. The shaded areas indicate our baseline deleveraging identified periods. Dashed lines show official NBER recessions.

Figure 2: Baseline: Impulse Responses



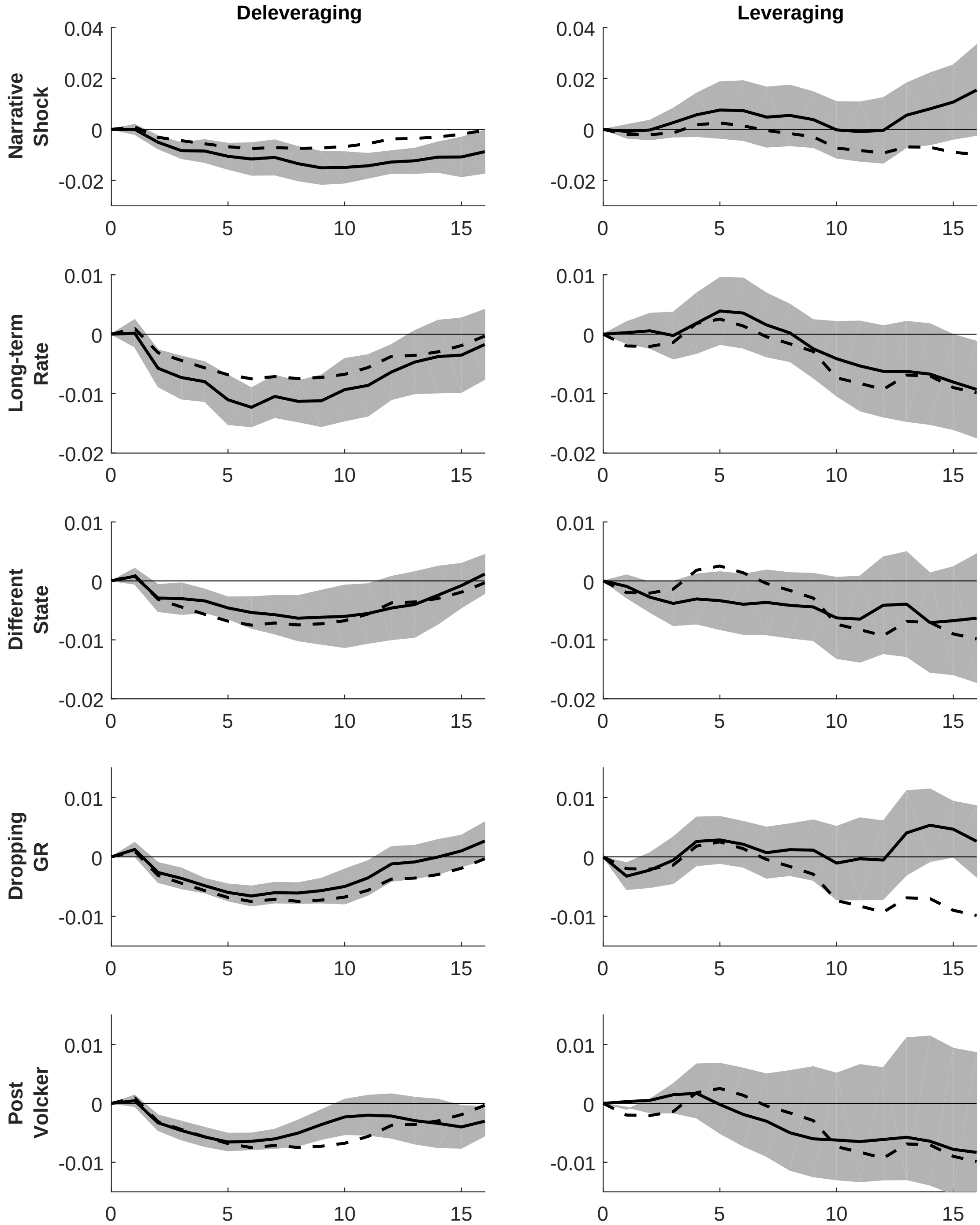
Notes: The first column shows the impulse responses of a monetary policy shock on a variable in the linear model. The second and third column show impulse responses of a monetary policy shocks on a variable in a household deleveraging (second column) and leveraging (third column) state. The shaded areas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

Figure 3: Baseline: Cumulative Effects



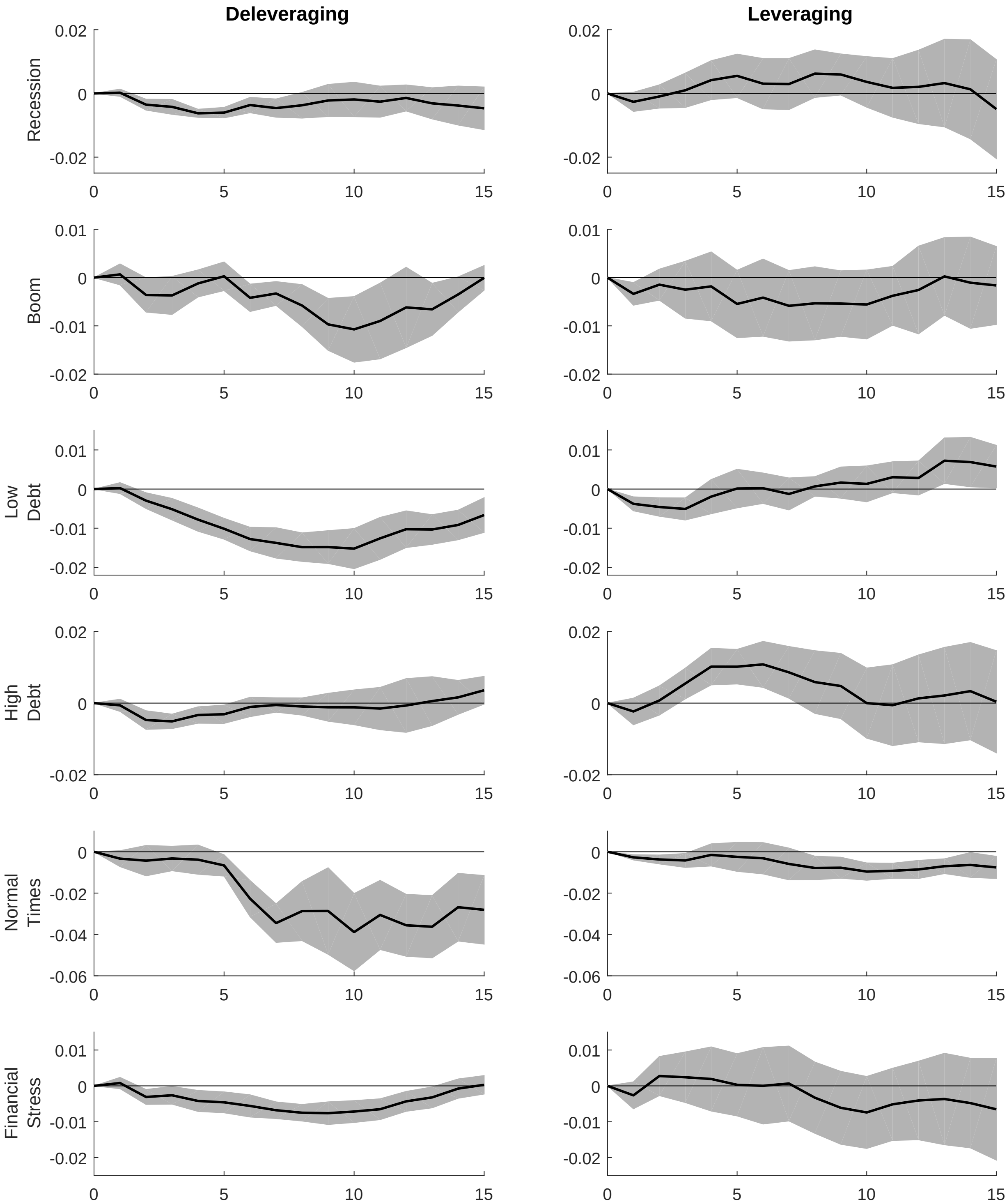
Notes: The first column shows the cumulative effects of a monetary policy shock on a variable in a household deleveraging state. The second column shows the cumulative effects of a monetary policy shocks on a variable in a leveraging state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors.

Figure 4: Robustness (GDP responses)



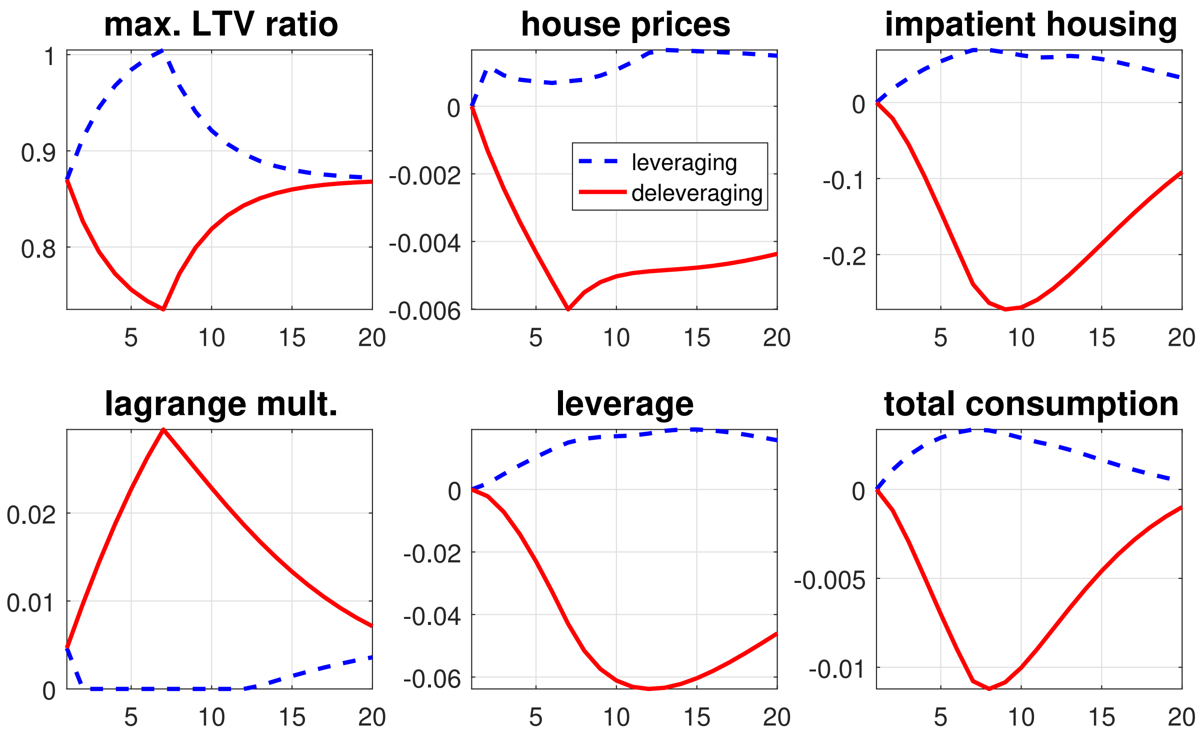
Notes: The first column shows the impulse responses of a monetary policy shock on GDP in a household deleveraging state. The second column shows the impulse responses of a monetary policy shocks on GDP in a leveraging state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors. The dashed line shows the impulse responses from the baseline estimation.

Figure 5: Controlling for Additional States (GDP responses)



Notes: The first column shows the impulse responses of a of a monetary policy shock on GDP in a household deleveraging state. The second column shows the impulse responses of a monetary policy shocks on GDP in a leveraging state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors. The dashed line shows the impulse responses from the baseline estimation.

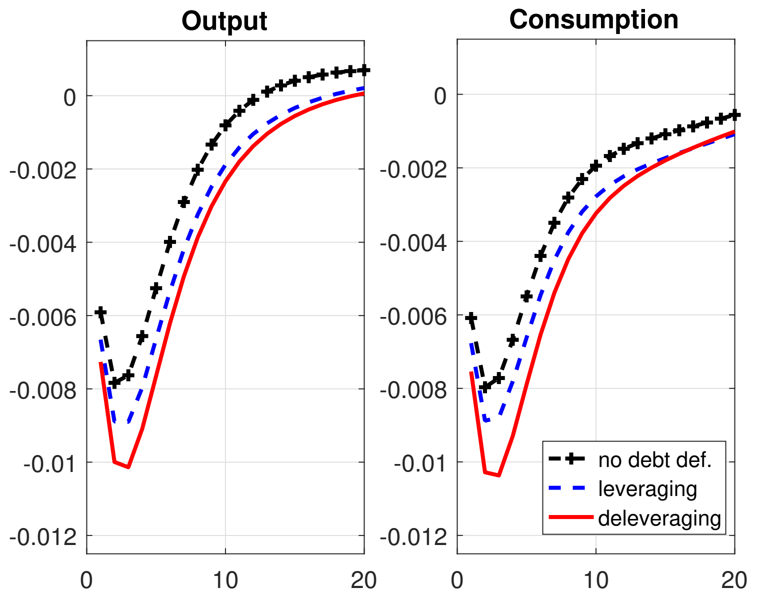
Figure 6: Sequence of Positive and Negative LTV Shocks



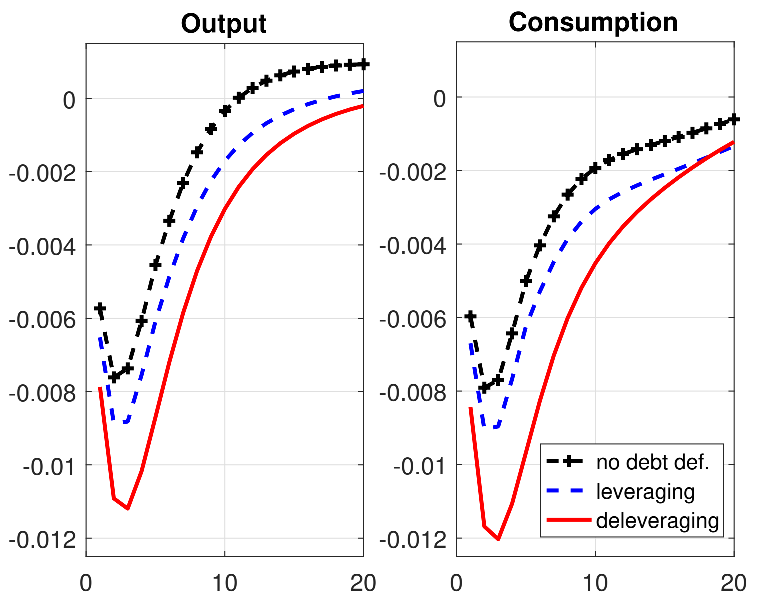
Notes: Starting from the steady state, the blue (dashed) and red (solid) lines show a series of 6 unexpected positive and negative LTV shocks, respectively. No other shocks occur during or after the series of LTV shocks and the model converges to the steady state after the sixth shock. The y-axis shows the responses in levels for the maximum LTV ratio and the lagrange multiplier. For all other variables it shows the responses in percentage deviations from the steady state. The x-axis shows quarters.

Figure 7: Simulated IRFs under Leveraging and Deleveraging

(a) $M = 0.8$

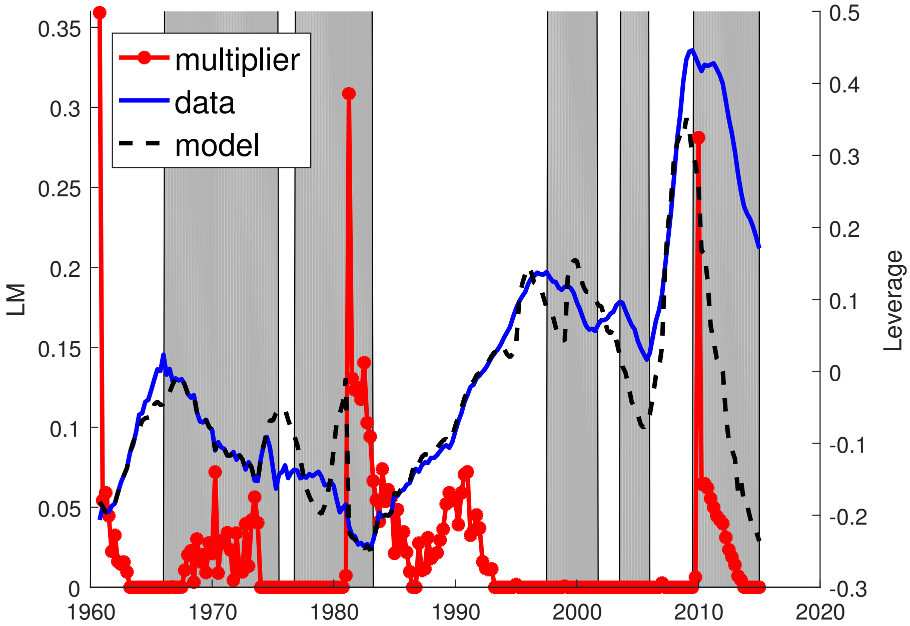


(b) $M = 0.9$



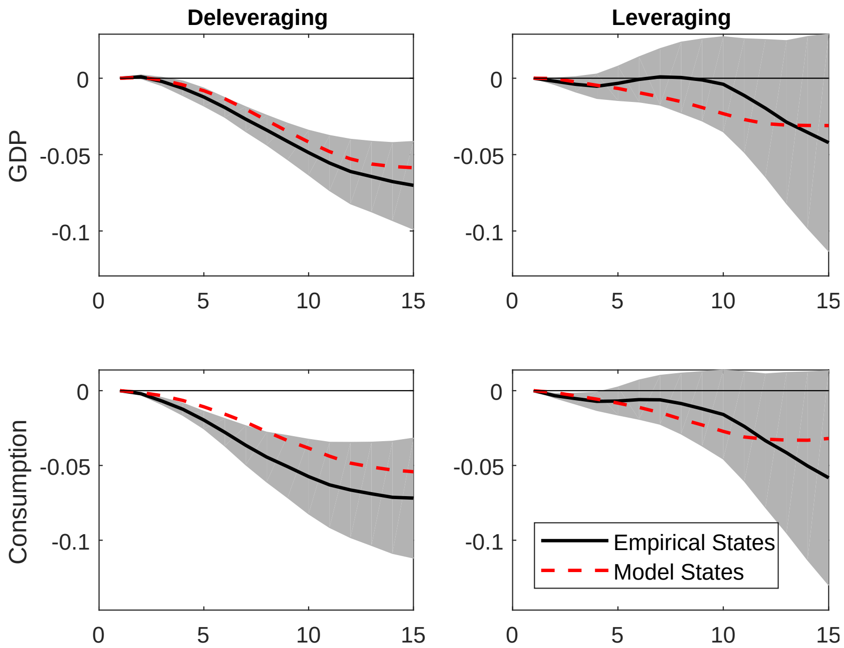
Notes: IRFs to an (annualized) 100 basis points monetary policy shock under leveraging and deleveraging. Starting from the steady state, leveraging and deleveraging states are simulated as a series of 6 consecutive positive and negative LTV shocks, respectively. After the sixth LTV shock, in period 7 a monetary policy shock hits; thereafter, no further shocks occur. In the upper panel (steady state LTV limit of 0.8), the constraint is expected to remain slack for four periods when the monetary policy shock hits. In the lower panel (steady state LTV limit of 0.9), the constraint is expected to remain slack for five periods when the monetary policy shock hits. The black crossed lines show the same exercise for leveraging states under nominal debt contracts, i.e., when there is no debt-deflation effect. The y-axis shows the responses in percentage deviations from the steady state. The x-axis shows quarters after the monetary policy shock hits.

Figure 8: Deleveraging and Borrowing Constraints



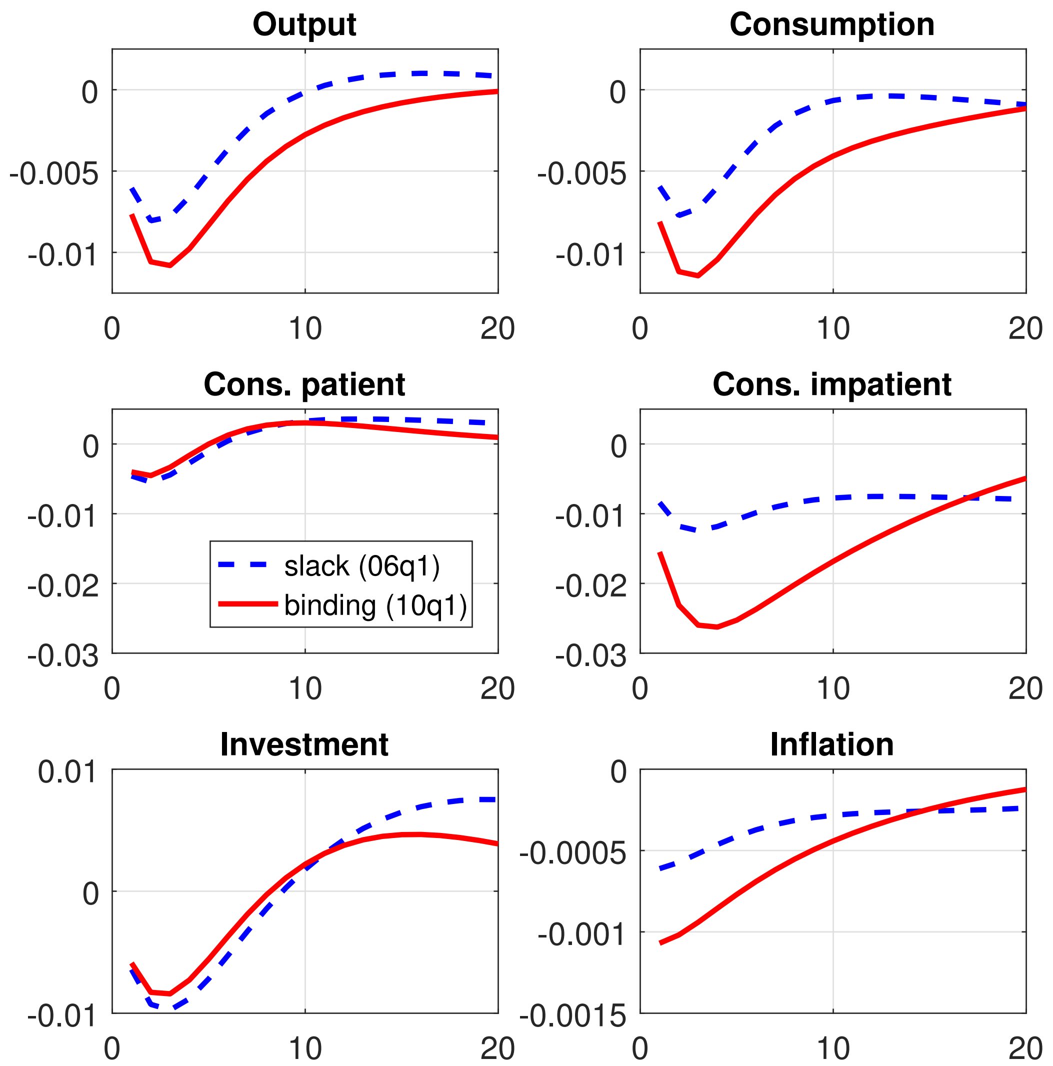
Notes: Shaded areas indicate periods of deleveraging in the data. The red (circled) line corresponds to the lagrange multiplier on the borrowing constraint in the DSGE model. The blue (solid) line corresponds to the leverage data used in the estimation of the DSGE model. The black (dashed) line corresponds to smoothed leverage in the model.

Figure 9: Cumulative Effects: Empirical States and Model States



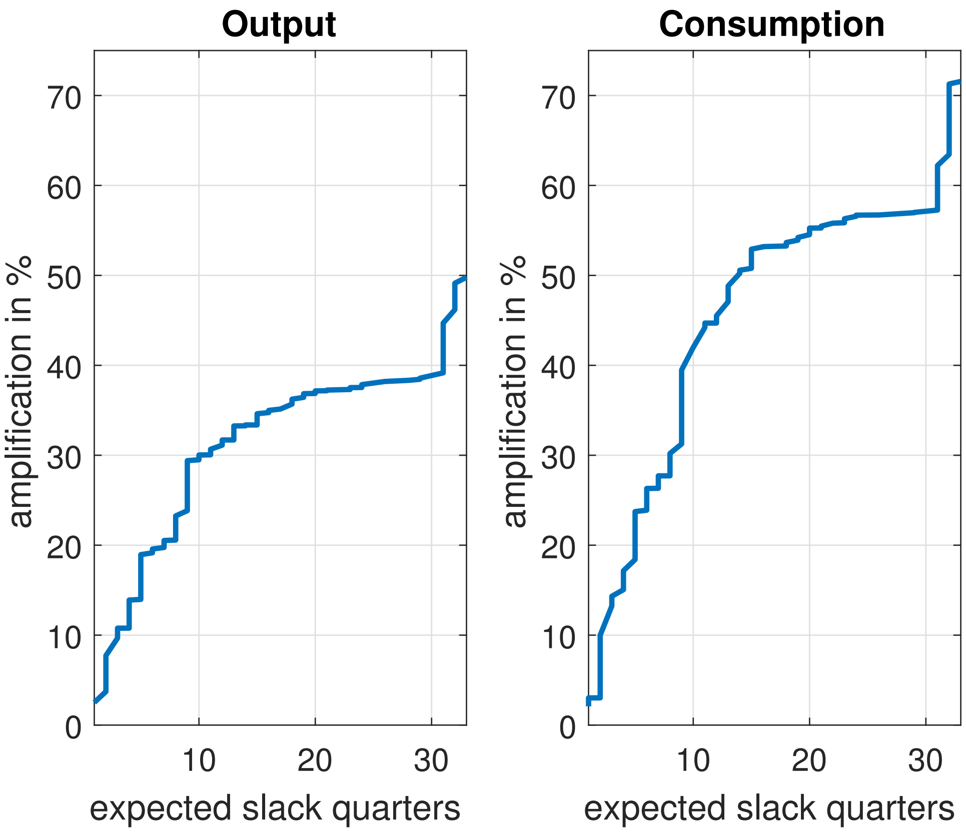
Notes: Solid lines show responses based on the baseline empirical specification. Dashed lines show responses based on the model implied states. Shaded areas indicate 90% confidence bands based on the baseline empirical specification.

Figure 10: IRFs to a Contractionary Monetary Policy Shock



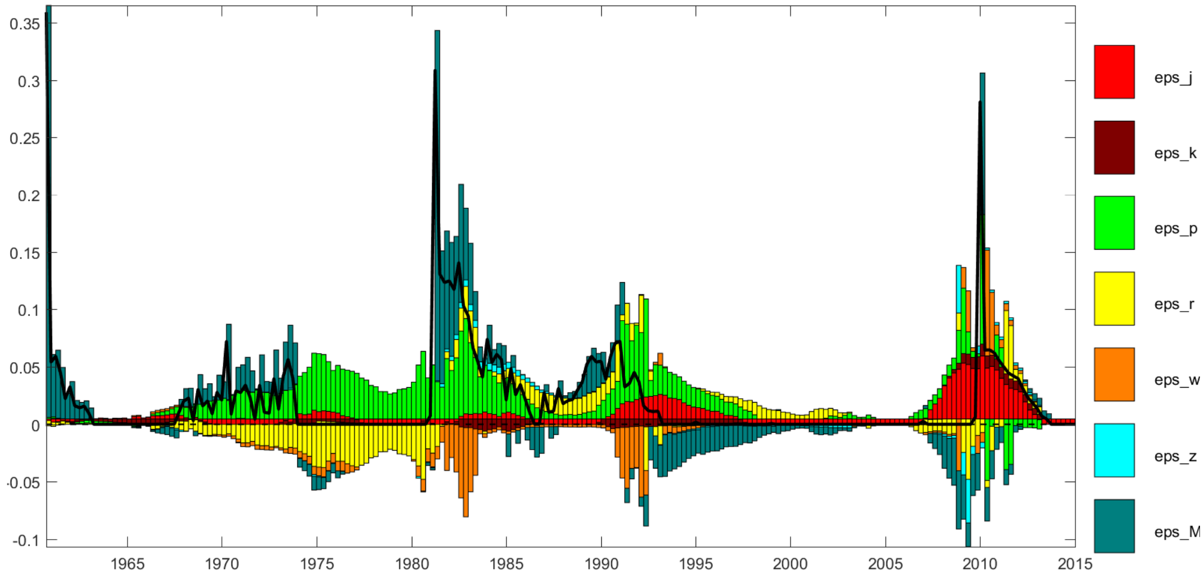
Notes: IRFs to an (annualized) 100 basis points monetary policy shock. The blue dashed line shows the responses to a shock in 2006q1, when the constraint is slack. After the monetary policy shock hits, no further shocks materialize and the expected duration of the slack constraint is 20 quarters. The red solid line shows the responses to a shock in 2010q1, when the constraint is binding (it remains binding throughout the duration of the IRFs'). The y-axis shows the responses for all variables but inflation in percentage deviations from steady state. Inflation in percentage points. The x-axis shows quarters after the monetary policy shock hits. Note that the quantitative effect in this figure differs from Figure 7 not only because of the expected duration of the slack constraint, but also because of different values of the steady state LTV limit (0.87 in this figure as compared to 0.8 and 0.9 in the previous one).

Figure 11: Amplification Effects After a Monetary Policy Shock



Notes: The y-axis shows the percentage difference the responses of output and consumption to a monetary policy shock in states where the constraint is binding, with respect to states where when it is slack. Amplification is computed as the difference between the maximum response (which happens 3 quarters after the shock) for each variable. The x-axis shows the number of quarters that the constraint is expected to remain slack when the monetary policy shock hits. When the constraint is slack and a contractionary monetary policy shock hits, the expected duration of the slack period depends on the state of the economy. When the constraint is binding and a contractionary monetary policy shock hits, the constraint remains binding throughout the IRFs' (20 quarters).

Figure 12: Shock Decomposition: Nonlinear Model



Notes: Smoothed multiplier on the borrowing constraint using the deterministic filter and the piecewise linear solution of the model. The black solid line depicts the multiplier in levels; a value of zero indicates that the borrowing constraint is slack. Shocks are marginalized (fed into the model) in the following order: housing preference (eps_j), investment specific (eps_k), price markup (eps_p), monetary policy (eps_r), wage markup (eps_w), intertemporal preference (eps_z) and loan-to-value (eps_M). The steady state maximum LTV limit is fixed at M=0.87.

Appendix to Monetary Policy and Household Deleveraging by Martin Harding and Mathias Klein

This appendix includes additional information, tables and figures mentioned in the main text.

A1 Data

Local Projections

Table A1: Data Definitions and Sources

Variable	Definition	Source
GDP	Nominal GDP	BEA
PGDP	GDP deflator	BEA
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	Total Household Liabilities/real estate at market value	FRED
Corporate bond yield	BAA corporate bond yield	FRED
Long-term bond yield	10-year government bond yield	Robert Shiller website
5-year rate	5-Year Treasury Constant Maturity Rate	FRED
Financial stress	Financial Conditions: Bank Leverage	Chicago FED website

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) plus consumer credit divided by real estate at market value, expressed in percentage deviations from the mean of the series. Source: St. Louis FRED.

A2 DSGE model estimation details

In order to estimate the model parameters, shocks and regimes we proceed in two steps. We first estimate the linearized model with Bayesian methods using the Kalman filter under the assumption that the collateral constraint is always binding and disregard the ZLB. In the second step, we take the estimated parameters as given and use the nonlinear filter to extract the implied structural shocks from the piecewise linear model with the occasionally binding collateral constraint and ZLB constraint. We use the same data (described in section A1) for the period 1960q1 to 2015q4 in each step.

The estimation of the linear model yields the parameters shown in table 3. In order to match the piecewise-linear model to the data, we proceed as follows. GI show that the likelihood of the model takes the form

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

Given the parameters of table 3, in an intermediate step we drop leverage from our sample and look for the values of r_π, r_R, y_Y, β^I and γ that give the best fit, that is, that maximize equation A.1. The parameters that result from this exercise are those shown in table 4. We are unable to maximize equation A.1 when using leverage as observable due to the complications described in section 4.1. If we could, then we would just perform a standard Bayesian full-information estimation of the piecewise-linear model.

In the second step, we take the parameters of tables 3 and 4 (note that the parameters of the Taylor rule are those of table 4) as given, and use the deterministic filter to estimate the smoothed shocks and regimes for our full sample, including leverage. We select $M = 0.87$ in order to minimize the discrepancies between observed leverage and smoothed leverage from the model. Recall that the filter is able to match leverage only occasionally, when the constraint binds.

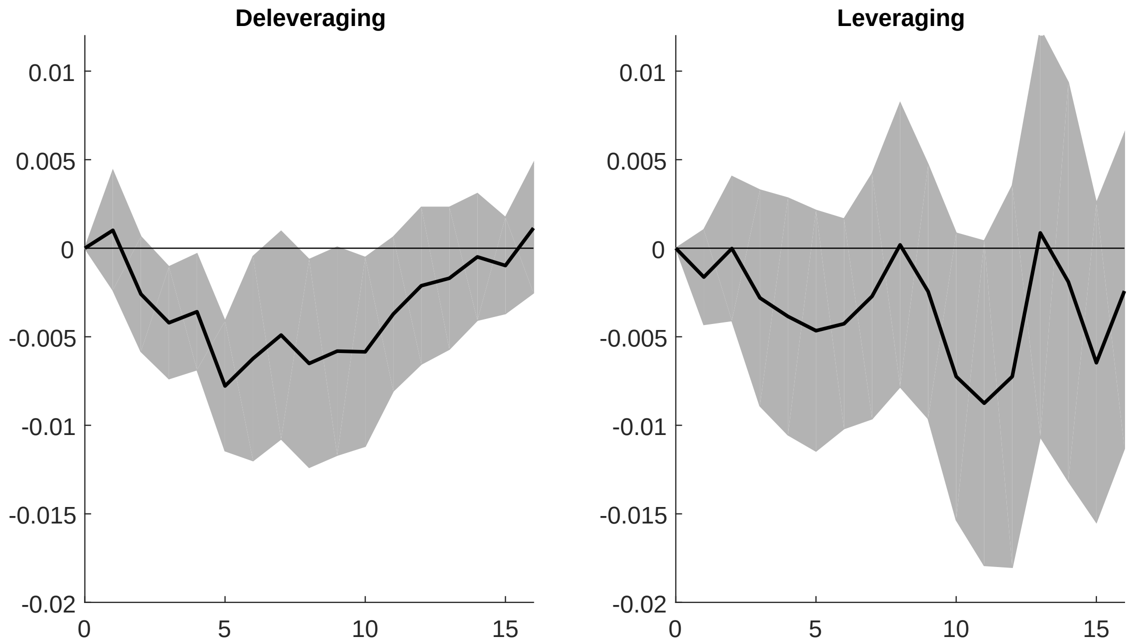
Table A2: Robustness Analysis: Alternative Model Specifications

	(1) Baseline	(2) noZLB	(3) lin. trend	(4) lev in T.R.	(5) neutral tech. shock	(6) alt. lev
ε_c	0.6697	0.5334	0.9771	0.6688	0.6327	0.6539
ε_h	0.6922	0.7522	0.6145	0.7284	0.5975	0.7124
ϕ	7.3368	10.3422	13.7186	9.6469	2.0338	8.5021
r_π	1.0311	1.0626	1.0005	1.1160	1.0002	1.0174
r_R	0.6253	0.6620	0.6654	0.6635	0.6085	0.6379
y_Y	0.0576	0.0515	0.0162	0.0362	0.0348	0.0611
θ_p	0.9003	0.8891	0.9219	0.8999	0.9162	0.8782
θ_w	0.9046	0.8861	0.9919	0.9032	0.8972	0.8908
ρ_J	0.9905	0.9900	0.9899	0.9900	0.9893	0.9961
ρ_K	0.5513	0.3953	0.6663	0.5068	0.7593	0.4676
ρ_R	0.2781	0.1673	0.3167	0.2524	0.2284	0.2744
ρ_Z	0.7776	0.8685	0.5856	0.7710	0.7935	0.7159
ρ_M	0.7237	0.5292	0.9891	0.7291	0.6994	0.9541
σ_J	0.0429	0.0397	0.0621	0.0424	0.0420	0.0272
σ_K	0.0734	0.1142	0.1115	0.0890	0.0147	0.0869
σ_P	0.0056	0.0056	0.0041	0.0056	0.0051	0.0054
σ_R	0.0025	0.0025	0.0024	0.0025	0.0027	0.0025
σ_W	0.0089	0.0084	0.0103	0.0089	0.0096	0.0090
σ_Z	0.0191	0.0156	0.3016	0.0186	0.0163	0.0179
σ_M	0.1459	0.1183	0.0939	0.1468	0.1488	0.0318
τ_c			0.0005			
τ_i			0.0087			
τ_q			0.0015			
r_{lev}				0.0041		
ρ_A					0.9368	
σ_A					0.0098	

Notes: Columns report the parameters estimates at the mode for different specifications. Column (1) is our baseline. Column (2) is the baseline model estimated excluding the ZLB period, that is, using the sample 1960q1-2008q4. Column (3) reports the estimates of the model using deviations around a linear trend instead of the one-sided H.P. filter to de-trend the data. In particular, we specify 3 different deterministic trends: one for consumption, one for investment and one for house prices; we assume that real wages grow at the same rate as real consumption. The parameters τ_c, τ_i and τ_q show the growth rate estimates for consumption, investment and house prices, respectively. Column (4) shows the results of using a modified Taylor Rule where the central bank also responds to deviations of leverage from its steady state. The parameter r_{lev} measures the responsiveness of the central bank to leverage. Column (5) shows the estimates resulting from adding an neutral technology shock and estimating the model adding the (demeaned) business sector TFP series from Fernald (2012). We estimate the model adding the observation equation $TFP_t = \hat{a}_t^N + \mu\hat{a}_t$, where a_t^N is neutral productivity, μ measures the share of investment on total output and the hat notation indicates percentage deviations from steady state. The neutral technology shock is assumed to follow an AR(1) process with persistence parameter ρ_A and standard deviation σ_A. Column (6) shows the results of estimating the model using total leverage instead of leverage of the impatient household as the model analog of the leverage ratio in the data. Since the total amount of housing in the model is fixed, we can normalize it to one and define leverage in this model specification as b_t/q_t, while in the baseline estimation it is defined as $b_t/(q_t h_t^I)$.

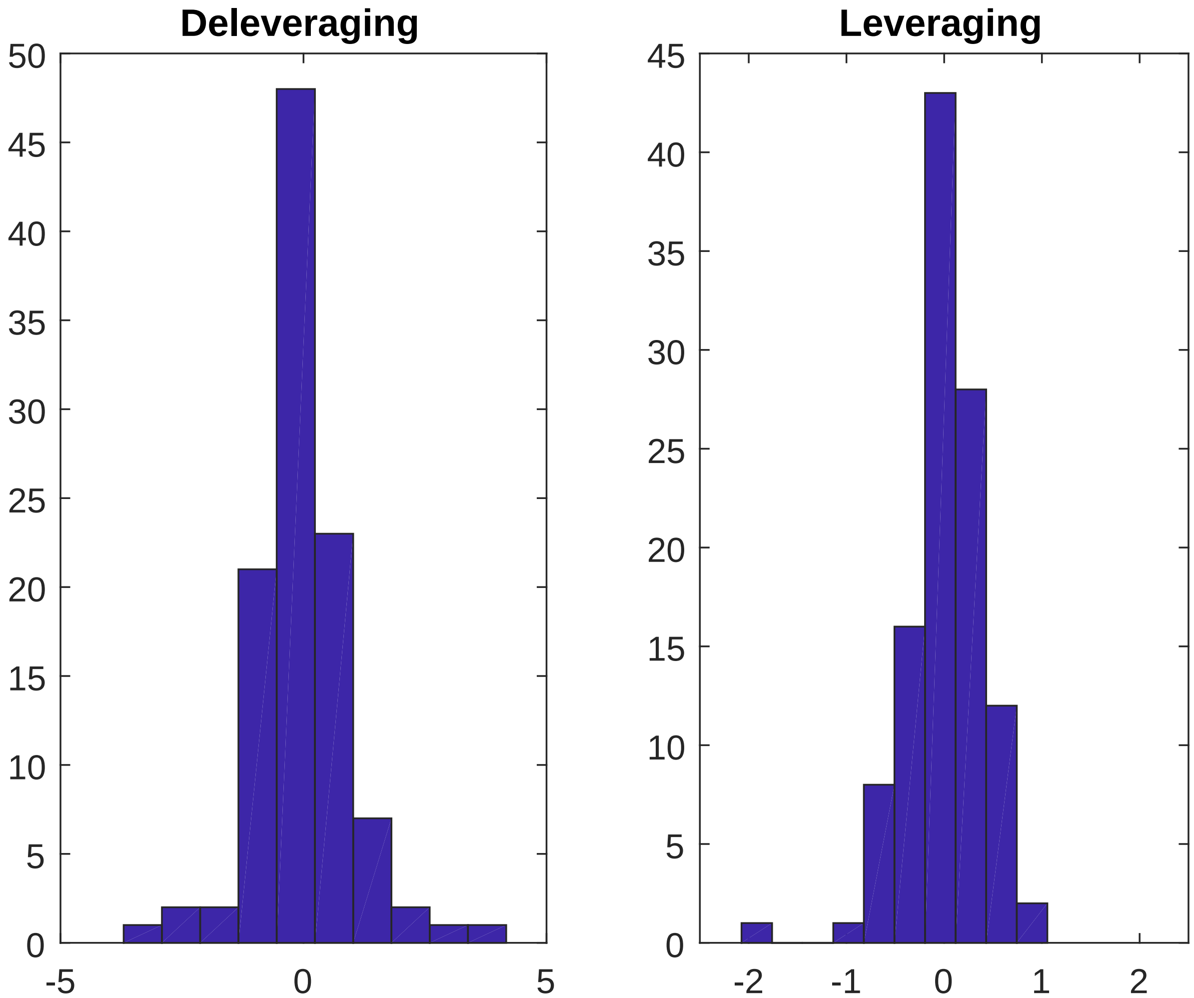
A3 Additional figures

Figure A1: Nonlinear Romer and Romer (2004) Shocks (GDP responses)



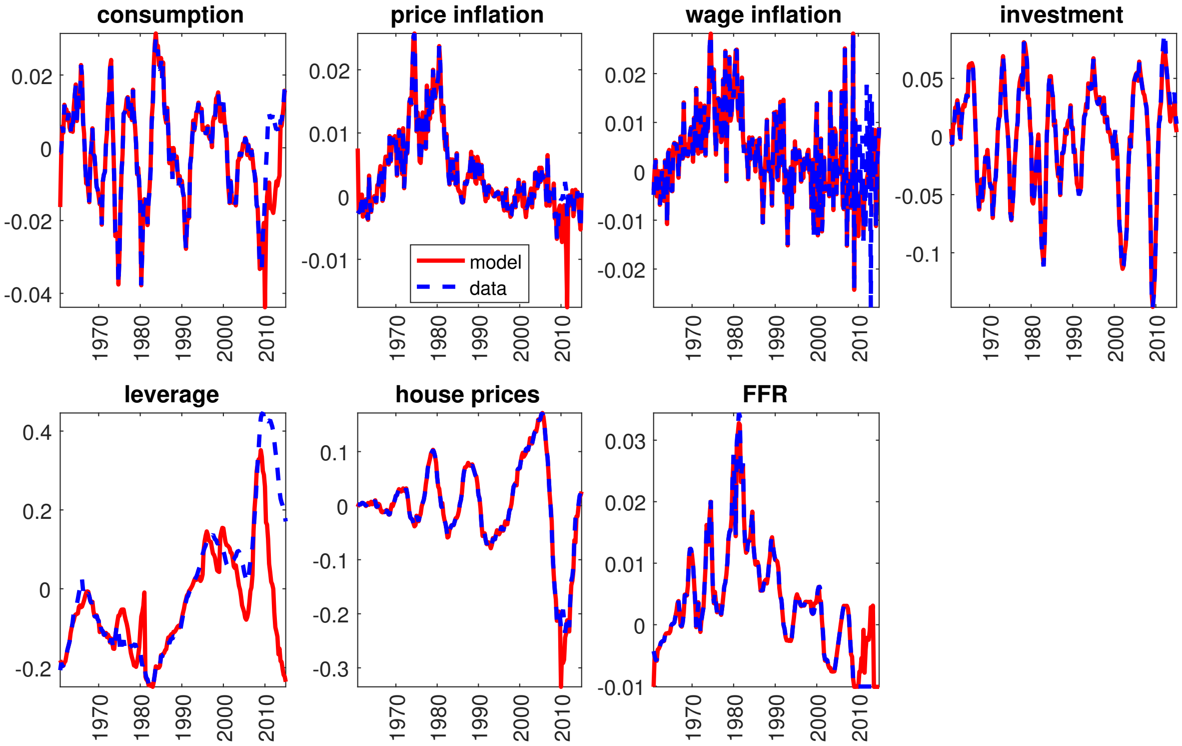
Notes: The first column shows the impulse responses of a of a monetary policy shock on GDP in a household deleveraging state. The second column shows the impulse responses of a monetary policy shocks on GDP in a leveraging state. The shaded areas indicate 90% confidence bands based on Newey and West (1987) standard errors. The dashed line shows the impulse responses from the baseline estimation.

Figure A2: Distribution of Monetary Policy Shocks



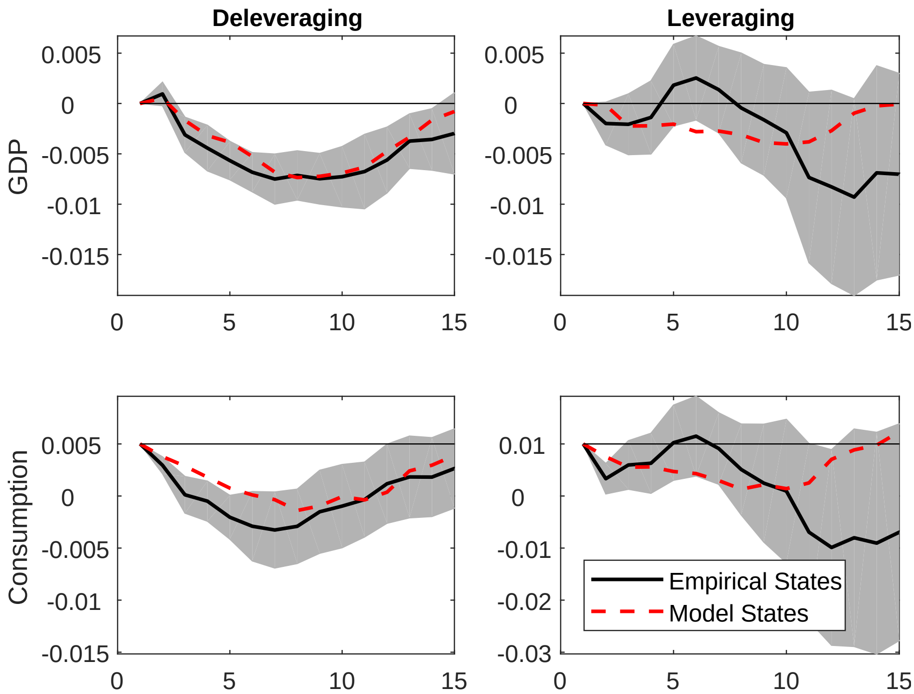
Notes: Distribution of monetary policy shocks from baseline specification under deleveraging and leveraging states.

Figure A3: Smoothed Variables and Data



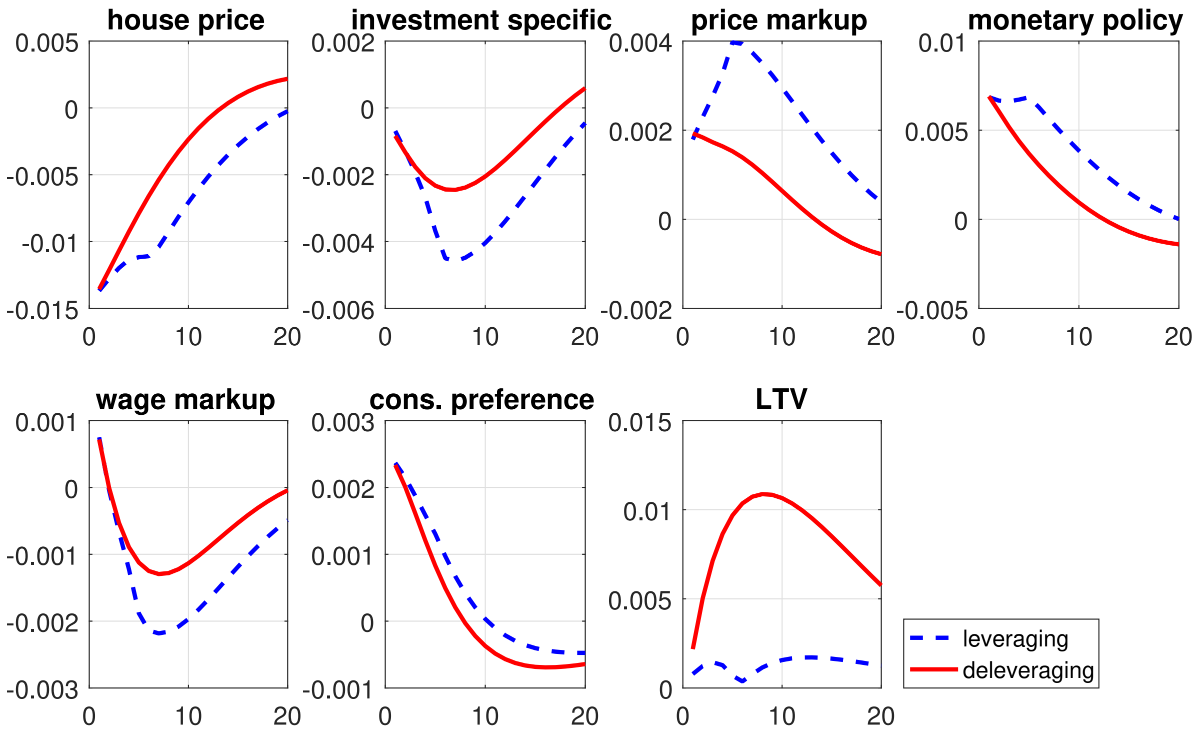
Notes: Smoothed variables from the DSGE model using the deterministic filter and data. The correlations between the two are: 0.9225 for consumption, 0.9678 for price inflation, 0.9383 for wage inflation, 0.9977 for investment, 0.7210 for leverage, 0.9913 for house prices and 0.9744 for the FFR.

Figure A4: Non-Cumulative Effects: Empirical States and Model States



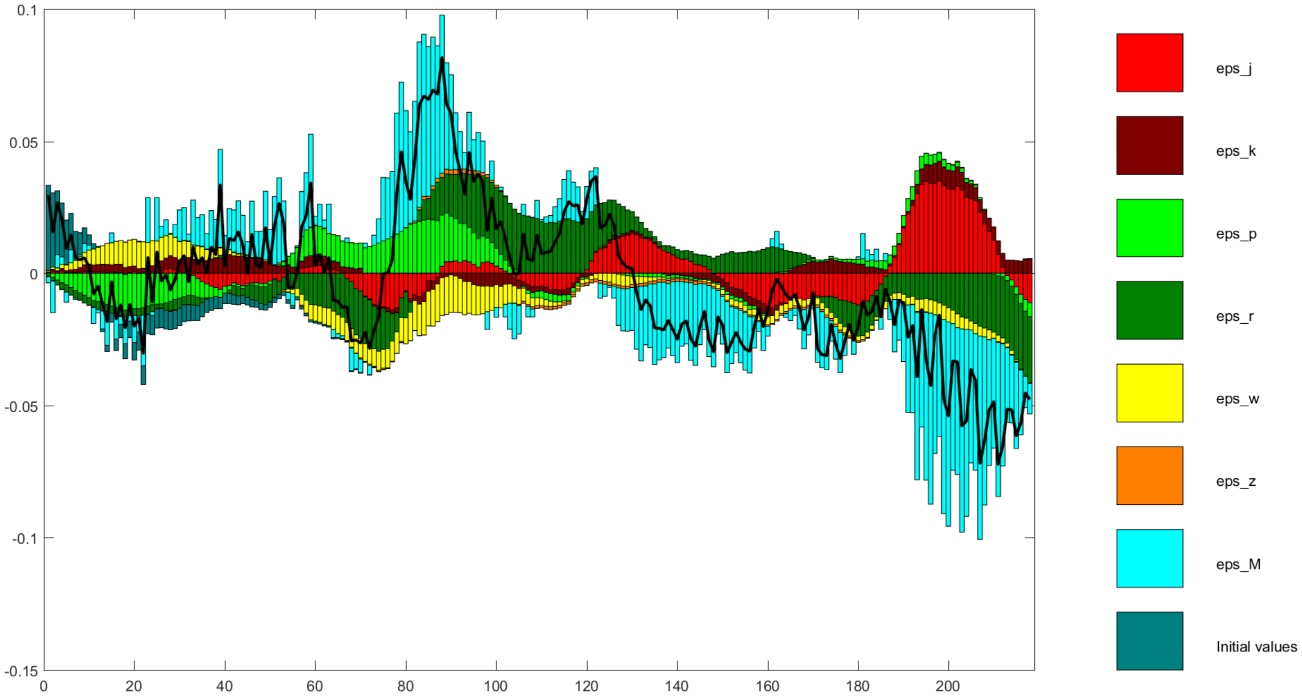
Notes: Solid lines show responses based on the baseline empirical specification. Dashed lines show responses based on the model implied states. Shaded areas indicate 90% confidence bands based on the baseline empirical specification.

Figure A5: IRFs of Leverage to all Shocks during Leveraging and Deleveraging



Notes: IRFs of leverage to a 1 standard deviation shock for all shocks. Starting from the steady state, leveraging and deleveraging states are simulated as a series of 6 consecutive positive and negative LTV shocks, respectively. After the sixth LTV shock, in period 7 the shock of interest hits. The y-axis shows leverage in percentage deviations from the steady state. The x-axis shows quarters after the shock of interest hits. House price and LTV shocks are the main drivers of leverage dynamics. However, note that when the constraint is slack LTV shocks have much smaller effects of leverage.

Figure A6: Shock Decomposition: Linear Model



Notes: Smoothed multiplier on the borrowing constraint using the Kalman filter and the linear solution of the model. The black solid line depicts the smoothed multiplier in percentage deviations from its steady state. The borrowing constraint is assumed to bind at all times and higher values of the multiplier reflect tighter borrowing constraints.