Addressing Household Indebtedness: Monetary, Fiscal or Macroprudential Policy?

Sami Alpanda*
University of Central Florida

Sarah Zubairy†
Texas A&M University

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Abstract

In this paper, we build a dynamic stochastic general-equilibrium model with housing and household debt, and compare the effectiveness of monetary policy, housing-related fiscal policy, and macroprudential regulations in reducing household indebtedness. Excessive household debt arises due to exuberance shocks on house price expectations, which drive a wedge between the actual and the underlying fundamental value of houses. The estimated model also features long-term fixed-rate borrowing and lending across two types of households, and differentiates between the flow and the stock of household debt. Our main findings can be summarized as follows: (i) Monetary tightening is able to reduce the stock of real mortgage debt, but leads to an increase in the household debt-to-income ratio. (ii) Among the policy tools we consider, tightening in mortgage interest deduction and regulatory loan-to-value (LTV) are the most effective and least costly in reducing household debt, followed by increasing property taxes and monetary tightening. (iii) Although mortgage interest deduction is a broader tool than regulatory LTV, and therefore potentially more costly in terms of output loss, it is effective in reducing overall mortgage debt, since its direct reach also extends to home equity loans. (iv) Lowering regulatory LTV and mortgage interest deductions from their current levels would be welfare improving, while we find weak support for systematic leaning against household imbalances through monetary policy.

Keywords: Household debt, monetary policy, housing-related fiscal policy, regulatory LTV.

JEL Classification: E52, E62, R38.

*Department of Economics, College of Business Administration, University of Central Florida, 4336 Scorpius Street, Orlando, FL 32816. Phone: (407) 823-1575, e-mail: sami.alpanda@ucf.edu.

†Department of Economics, Texas A&M University, 4228 TAMU, College Station, TX, 77843. Phone: (979) 845-7382, e-mail: szubairy@tamu.edu.

1 Introduction

The elevated levels of household debt during the mid-2000s posed significant financial stability and macroeconomic risks to the U.S. economy. Since the rise in household debt was accompanied by a decrease in mortgage underwriting standards and exuberant expectations regarding future house price gains, the U.S. financial system was exposed to a sudden reversal in housing markets. Once the exuberance in housing waned, the decline in house prices and the resulting increase in mortgage defaults put the balance sheets of financial institutions in danger, since many were directly or indirectly exposed to the housing sector. The economic fallout resulting from the financial crisis was also more painful and prolonged relative to a standard recession, as households and financial institutions engaged in a long deleveraging process following the crisis.

How best to prevent household debt from reaching unsustainable levels remains a critical issue of discussion among economists. Policy-makers already possess a suite of tools with the potential to address concerns related to household indebtedness. First, *macroprudential regulations* can be tightened to ensure a decline in household credit; for example, the regulatory loan-to-value (LTV) ratio on new mortgage lending can be reduced. Second, in the fiscal realm, *housing-related tax policies* could be tightened; for example, the statutory or effective property tax rates on residential properties can be increased or the tax deductibility of mortgage interest can be curbed.[1] Finally, and arguably as the last line of defense, *monetary policy* can be tightened to induce an increase in mortgage rates and discourage new lending.[2]

In this paper, we assess the effectiveness of the aforementioned policies in reducing household debt, and evaluate their side effects on macroeconomic variables such as output and inflation, using a dynamic stochastic general-equilibrium (DSGE) model with housing and household debt. Table 1 lists the four policies we consider, along with the scope of each policy for addressing household indebtedness. As is well known, macroprudential tools such as regulatory LTV are more targeted toward the housing sector, and therefore potentially have smaller adverse impacts on the rest of the economy. On the other hand, the regulatory LTV ratio applies to regular mortgages on new home purchases, but is generally not binding for loans based on withdrawals of existing home equity. Thus, such a tool may not be effective in reducing overall household debt if home equity withdrawals make up a large part of new mortgage lending. In other words, LTV policy is perhaps too targeted, or not broad enough, to adequately address high household indebtedness.

Housing-related tax policies are also targeted in that their direct effects are only on the housing sector, but these policies may be broader in terms of their reach relative to regulatory LTV. In particular, a reduction in the tax deductibility of mortgage interest would (likely) apply to all existing mortgage borrowers, including those that borrowed in periods prior to the implementation

[1] In the U.S., property taxation is conducted at the state level; therefore, it may be difficult to implement this policy in a coordinated manner. Nevertheless, similar effects can be obtained by reducing the deductibility of property taxes from personal income tax at the federal level (see Alpanda and Zubairy, 2016).

[2] See Crowe et al. (2011) for a detailed list of policy tools that have been used by different countries in dealing with real estate booms.

of the new policy. Thus, this policy may potentially have a greater adverse impact on the economy relative to LTV, but on the other hand, this policy may also be more effective in terms of limiting home equity loans, since interest on these loans are also largely deductible when paying income taxes.[3] Similarly, an increase in property taxes would impact all homeowners, including those that have no outstanding mortgage debt; property taxes therefore are even broader in their scope relative to mortgage interest deduction rules. Finally, monetary policy is the broadest tool among the policies discussed here, since a tightening would directly impact the non-housing sectors of the economy and the flow of credit for purposes other than housing.[4]

In this paper, we build a DSGE model with housing and household debt, and consider the effectiveness of the aforementioned policies in reducing household indebtedness. Our model features borrowing and lending across two types of households, as in Iacoviello (2005), but mortgage loans are fixed-rate and are amortized over the long term, similar to Kydland et al. (forthcoming), thereby allowing us to differentiate between the flow and the stock of household debt. This is key for differentiating the effects of policies that apply only to new lending (e.g., regulatory LTV) as opposed to all existing mortgage debt (e.g., mortgage interest deduction). The constraint on borrower households is imposed on the flow rather than the stock of household debt. New mortgage loans finance not only the residential investment of borrower households, but also partly their consumption expenditures, by allowing them to withdraw a portion of their existing home equity each period. Unlike the existing literature, we let the home equity extraction rate be lower than the LTV on new mortgages.[5] Thus, households do not increase their borrowing up to the LTV limit when house prices increase, which implies that household leverage is countercyclical in our model, consistent with the empirical evidence in Adrian and Shin (2010). This feature is also key to dilute the effectiveness of regulatory LTV in addressing household debt, since LTV policy mainly affects new regular mortgages, but not home equity loans taken on top of existing debt. The rest of the model features are standard.

In the model, excessive household debt can be detrimental, and active policy could potentially be welfare improving, due to the presence of exuberance shocks on the house price expectations of agents, which drive a wedge between the actual value of housing and its underlying fundamental value (Bernanke and Gertler, 1999). Since the house price is a key determinant of the tightness of the borrowing constraint faced by borrowers, exuberance in asset prices leads to overborrowing

[3] In the United States, mortgage interest deduction applies to all first and second mortgages and to the first $100,000 of home equity loans. In the model, home equity loans partly reflect cash-out refinancing, which is also eligible for the mortgage interest deduction.

[4] Similar to monetary policy, the two fiscal policies mentioned above (i.e., mortgage interest deduction and property taxes) can also directly impact capital accumulation, if the changes in these policies also apply to commercial real estate and mortgages financing them. Here, we implicitly assume that these fiscal policies can be applied in a more targeted fashion so as to directly affect residential real estate only. This is unlike conventional monetary policy, which cannot be applied in a more targeted manner.

[5] Given the data reported in Greenspan and Kennedy (2005, 2007), home equity withdrawals (i.e., standard home equity loans taken on top of first liens as well as cash-out refinancing) are about 7 percent of existing home equity on an annual basis, far below the regulatory LTV ratio on new mortgages. Aggregate data reveal that the average LTV on *new* mortgage loans is significantly higher than the average LTV on all *existing* mortgages. Thus, in the aggregate, borrowers have built up equity over time and have not fully withdrawn from their equity up to the LTV limit each period.

in the model.[6] Our focus in the paper is to analyze the effectiveness of different policy tools in reducing household debt, as well as the welfare implications of implementing these policies. In our estimated model, we find that monetary tightening is able to reduce the stock of real mortgage debt in the short run; in particular, a 100 basis points (bps) tightening in the policy rate results in a peak decline of about 0.2 percent in the real stock of debt. Given that the response of output to monetary policy is stronger, however, our model implies an increase in the household debt-to-income ratio after monetary tightening. Thus, our baseline results suggest that, while monetary policy may be a good last line of defense against the buildup of certain financial imbalances, it is not that effective (or can even have perverse effects) when it comes to households' mortgage debt, which remains an area of major financial stability concern in many countries.[7]

In many countries, the policy debate for reducing household indebtedness has revolved around permanently tightening mortgage rules and regulations, rather than following a countercyclical approach. To that end, we compare the effects of permanently tightening fiscal and macroprudential tools in our setup, and compare their effects to a monetary tightening.[8] Among the policy tools we consider, we find that reducing mortgage interest deduction and regulatory LTV are the most effective and least costly in reducing household indebtedness, followed by increasing property taxes, and lastly monetary tightening. This ranking is generally consistent with the scope of each policy in targeting new household loans versus other aspects of the economy, as discussed before. The only exception is mortgage interest deduction, which is a broader tool than regulatory LTV, and therefore is potentially more costly in terms of output loss. Nevertheless, reducing mortgage interest deduction is slightly more effective in reducing mortgage debt relative to regulatory LTV in our baseline case, because of the former's direct impact on home equity loans.

Finally, we analyze the optimal values for regulatory LTV and mortgage interest deductibility from a welfare perspective. Higher steady-state levels of regulatory LTV and mortgage interest deductibility lead to higher levels of debt and output, but this comes at the expense of generating higher output volatility. Borrowers prefer higher levels of regulatory LTV and mortgage interest

[6] The model also features a pecuniary externality arising from the borrowing constraint and the financial accelerator mechanism. In particular, an increase in asset prices relaxes the borrowing constraints of all borrowers, but this side effect is not internalized by a single agent who is deciding whether to purchase more housing through additional borrowing. Thus, overborrowing can arise in the model when asset prices rise. See Lorenzoni (2008), Korinek (2009), and Bianchi and Mendoza (2010) for more on this pecuniary externality. Note that in these papers, the borrowing constraint is occasionally binding, so active policy has an additional benefit of increasing the amount of time that the borrowing constraint is kept slack. We do not capture this margin in our set-up, and assume the borrowing constraint binds at all times in our estimation and simulations.

[7] We abstract from other financial stability risks emanating from excessive debt, such as an increase in the frequency and severity of crisis events. The role of monetary policy in the financial stability realm can be slightly more important in the presence of these risks. The results in Svensson (2013), Ajello et al. (2015) and Alpanda and Ueberfeldt (2015) suggest that this channel is not quantitatively important. We also abstract from the risk-taking channel of monetary policy whereby "low-for-long" monetary policy may lead to increased risk-taking by financial intermediaries. When this is the case, monetary tightening could also help lower household debt through its curbing impact on reduction in bank credit supply to riskier (i.e., subprime) borrowers.

[8] Note that we are considering only a temporary shock to monetary policy, but increasing the persistence of monetary shocks does not significantly improve the trade-off with respect to reducing household debt per unit of output. This is because more persistence in the interest rate also leads to a larger decline in inflation, which increases the real value of existing debt brought from the previous period. See Section 4 for more on this issue.

deductibility, while savers prefer lower values. Considering a social welfare measure based on the weighted average of patient and impatient households' welfare indicate that lowering regulatory LTV and mortgage interest deductions from their current levels would be welfare improving. We also consider systematic monetary leaning against household debt, and find only weak support for this type of countercyclical policy in terms of enhancing overall welfare.

1.1 Related literature

Our work is related to a few different strands of the literature. First, there are several papers that consider the effects of monetary policy and changes in regulatory LTV in a DSGE setting similar to Iacoviello (2005). A non-exhaustive list includes Basant Roi and Mendes (2007), Christensen et al. (2009), Christensen and Meh (2011), Crowe et. al (2011), Kannan et. al (2012), Gelain et. al (2013), Justiniano et. al (2015), Lambertini et. al (2013), Rubio and Carrasco-Gallego (2014), and Iacoviello (2015). Our paper differs from the above mainly by featuring long-term and fixed-rate debt in our model. Note that the effects of regulatory LTV and monetary policies may potentially be exaggerated if applied to all outstanding mortgages, especially in the short run.

Second, there are several empirical papers that consider the effects of monetary policy on household credit and the appropriateness of "monetary leaning" against financial imbalances. More recent work includes Laseen and Strid (2013), who conduct vector autoregression (VAR) analysis using Swedish data and find that monetary policy shocks are able to reduce real household debt and the debt-to-income ratio. Robstad (2014) uses Bayesian VARs with Norwegian data and finds that monetary policy tightening has a small negative effect on household credit, but leads to an increase in the household debt-to-income ratio, in line with our findings using the DSGE model. In a recent paper, Bauer and Granziera (2016) run a panel VAR of eighteen advanced countries, and find that the debt-to-GDP ratio rises in the short run, but falls in the long-run, following an unexpected tightening in monetary policy.

Third, Kydland et al. (forthcoming) and Garriga et al. (2013) analyze the effects of fixed-rate mortgages (FRMs) and adjustable-rate mortgages (ARMs) for business cycles and the transmission of monetary policy in a general-equilibrium setting. Our set-up is most similar to these papers, but we extend their set-up in several directions. In particular, we allow borrowers to take out home equity loans in order to finance their consumption expenditures, on top of the financing for their residential investment outlays.[9] Our model features FRMs only, but we differentiate between the amortization duration of the loan itself versus the duration of the interest rate on the loan, thereby capturing the effects of refinancing.[10] Our focus is also different than the aforementioned two papers; in particular, we focus on the impact of monetary, fiscal and macroprudential policies on household

[9] Home equity extraction is a common feature in DSGE models that follow the Iacoviello (2005) setup as well. Note however that these models implicitly treat the home equity extraction rate as being equal to the LTV ratio, thereby implying that agents borrow a large fraction of their existing home equity when house prices rise. As mentioned before, in the data, home equity extraction rates are much lower than the LTV rates on new mortgages.

[10] Later versions of Garriga et al. (2013) also feature refinancing of FRMs, modelled as an asymmetric optimal choice. In our paper, refinancing is exogenous and applies to all outstanding mortgages at a constant rate each period.

debt, while their focus is on business cycle dynamics.[11] Gelain et al. (2015), in simultaneous but independently developed work, also use the long-term debt structure introduced in Kydland et al. (forthcoming) to analyze the effects of monetary policy on household debt dynamics. They find that, while a monetary tightening would lead to a short-run increase in the debt-to-GDP ratio, there is a reversal in the medium-term as debt levels fall below steady-state. The authors show that this latter effect is mainly due to the increase in the average amortization rate of loans following monetary tightening, which is absent in our set-up since we assume a constant amortization rate. Our paper primarily differs from theirs in terms of our focus on the effects of housing-related fiscal and macroprudential policies in addition to monetary policy.

Finally, our paper is related to the empirical literature analyzing the effects of housing-related fiscal policy. Poterba and Sinai (2008) use household-level data from the Survey of Consumer Finances to analyze how reforms to the tax treatment of mortgage interest deduction would influence the effective cost of housing services as well as the distribution of tax burdens. Kuttner and Shim (2013) use panel data from 57 countries to evaluate the effectiveness of non-interest rate policy tools (including housing-related taxes and regulatory LTV) in stabilizing household credit. They find that housing-related taxes have a discernible impact on house price appreciation, but less effect on household credit growth rates.

The next section introduces the model. Section 3 discusses the data and estimation of the model, section 4 presents the baseline results, section 5 conducts a welfare analysis, and section 6 concludes.

2 Model

The model is a closed-economy DSGE model with housing and household debt. There are two types of households in the economy: patient households (savers), and impatient households (borrowers), similar to Iacoviello (2005). Unlike Iacoviello (2005), we consider long-term FRMs and differentiate between the flow and the stock of household debt, following Kydland et al. (forthcoming) and Garriga et al. (2013). We let the home equity extraction rate be lower than the LTV on new mortgages, which is key to generate countercyclical household leverage as in the data. We also allow the duration of the interest rate on mortgages to be lower than the amortization duration of the loan itself, thereby capturing the effects of refinancing in the data. The model also features housing-related taxation (i.e., mortgage interest deduction and property taxation), as in Alpanda and Zubairy (2016), and LTV regulations alongside monetary policy.

The rest of the model is standard, and includes various nominal and real rigidities such as price and wage stickiness, indexation of prices and wages to past inflation, habit formation in consumption, adjustment costs in investment, and costs of capital utilization. Abstracting from these features would not qualitatively alter our main results regarding the effects of monetary policy on household

[11] Also see Forlati and Lambertini (2012, 2014), who analyze the effects of long-term household debt in the presence of defaults, in a setting similar to Bernanke et al. (1999).

debt, as well as the relative effectiveness of the four policies we consider in the paper.[12] We have also highlighted the importance of some of the key features in our sensitivity analysis exercises in the result section. Nevertheless, these features are important to capture key properties of business cycle dynamics, such as hump-shaped impulse responses of model variables to shocks, and they ensure a better fit to the data, as shown in Smets and Wouters (2007).

2.1 Households

2.1.1 Patient households (savers)

The economy is populated by a unit measure of infinitely-lived patient households indexed by i, whose intertemporal preferences over consumption, $c_{P,t}$, housing, $h_{P,t}$, and labor supply, $n_{P,t}$, are described by the following expected utility function:

$$E_t \sum_{\tau=t}^{\infty} \beta_P^{\tau-t} \upsilon_\tau \left[\log \left[c_{P,\tau}(i) - \zeta c_{P,\tau-1} \right] + \xi_h \log h_{P,\tau}(i) - \xi_n \frac{n_{P,\tau}(i)^{1+\vartheta}}{1+\vartheta} \right], \tag{1}$$

where t indexes time, $\beta_P < 1$ is the time-discount parameter, ζ is the *external* habit parameter for consumption, ϑ is the inverse of the Frisch-elasticity of labor supply, and ξ_h and ξ_n determine the relative importance of housing and labor in the utility function. The preference shock, υ_t, follows an AR(1) process:

$$\log \upsilon_t = \rho_\upsilon \log \upsilon_{t-1} + \varepsilon_{\upsilon,t}. \tag{2}$$

Labor services are heterogeneous across the patient households, and are aggregated into a homogeneous labor service by perfectly-competitive labor intermediaries, who in turn rent these labor services to goods producers. The labor intermediaries use a standard Dixit-Stiglitz aggregator; therefore, the labor demand curve facing each patient household is given by,

$$n_{P,t}(i) = \left(\frac{W_{P,t}(i)}{W_{P,t}} \right)^{-\eta_{n,t}} n_{P,t}, \tag{3}$$

where $W_{P,t}$ and $n_{P,t}$ are the aggregate nominal wage rate and labor services for patient households, respectively, and $\eta_{n,t}$ is a time-varying elasticity of substitution between the differentiated labor services. To capture cost-push shocks on wages, we specify an exogenous AR(1) process on $\theta_{w,t} = \eta_{n,t}/(\eta_{n,t} - 1)$ as

$$\log \theta_{w,t} = (1-\rho_w) \log \theta_w + \rho_w \log \theta_{w,t-1} + \varepsilon_{w,t}, \tag{4}$$

where θ_w is the markup of real wages over the marginal rate of substitution at the steady state.

[12] One exception to the above statement is the adjustment costs in residential investment, which is crucial to generate endogenous changes in the relative price of housing.

The patient households' period budget constraint is given by

$$
\begin{aligned}
&c_{P,t}(i) + q_{h,t}\widetilde{i}_{hP,t}(i) + q_{k,t}\widetilde{i}_{k,t}(i) + \frac{B_t(i)}{P_t} + \frac{L_t(i)}{P_t} \\
&\quad \leq (1-\tau_n)\frac{W_{P,t}(i)}{P_t}n_{P,t}(i) + (1-\tau_k)r_{k,t}k_{t-1}(i) + \tau_k\delta_k k_{t-1}(i) + (1+R_{t-1})\frac{B_{t-1}(i)}{P_t} + \frac{M_t(i)}{P_t} \\
&\quad + tr_{P,t} + \frac{\Pi_t}{P_t} - \tau_{p,t}(1-\tau_n)q_{h,t}h_{P,t-1}(i) - \text{adj. costs}, \qquad (5)
\end{aligned}
$$

where $\widetilde{i}_{hP,t}$ and $\widetilde{i}_{k,t}$ are the patient households' new investment in housing and capital, respectively, while $q_{h,t}$ and $q_{k,t}$ denote the relative prices of these real assets.

To allow the observed house price, $q_{h,t}$, to deviate from its fundamental value, we let the agents' expectations regarding future house prices to be modified by an "exuberance shock," χ_t, which follows an AR(1) process:

$$\log \chi_t = \rho_\chi \log \chi_{t-1} + \varepsilon_{\chi,t}. \qquad (6)$$

Unlike a housing preference shock which would raise agents' marginal utility of housing (i.e., rents), the exuberance shock here raises the expected capital gains from future house price gains in a persistent manner and drives a wedge between the observed house price and its underlying fundamental value, which is the house price that would be obtained in the absence of the exuberance shock. The shock here is purely expectational and captures (irrational) exuberance on behalf of agents regarding future house price movements, similar to Bernanke and Gertler (1999), Basant Roi and Mendes (2007), Alpanda et al. (2014) and Benes et al. (2014).[13] We discuss the exuberance shock further later in this subsection when we discuss the households' optimality condition with respect to housing.

The laws of motion for patient households' housing and capital stock holdings, $h_{P,t}$ and k_t, are given by,

$$h_{P,t}(i) = (1-\delta_h)h_{P,t-1}(i) + \widetilde{i}_{hP,t}(i), \qquad (7)$$

$$k_t(i) = (1-\delta_k)k_{t-1}(i) + \widetilde{i}_{k,t}(i), \qquad (8)$$

where δ_h and δ_k are the corresponding depreciation rates.

B_t denotes the amount of one-period nominal government bonds purchased by patient households, while L_t is the amount of new lending extended to impatient households. $r_{k,t}$ denotes the rental income patient households receive from their capital holdings. Households are taxed at proportional rates of τ_n and τ_k, on their labor and capital incomes, respectively. $\tau_{p,t}$ is the (time-varying) property tax rate on housing. Note that property taxes and capital depreciation are deductible when paying income taxes.

Patient households receive transfers from the government, $tr_{P,t}$, and the profits of the goods

[13] Also see Garriga et al. (2012) and Granziera and Kozicki (2015), who also consider the role of exuberant expectations on the part of agents to account for sharp increases in house prices.

producers, Π_t, in lump-sum fashion. They also earn a predetermined nominal interest rate of R_t on their government bond holdings, and receive mortgage payments from impatient households in the amount of M_t. These mortgage payments are the sum of interest and principal payments as follows,

$$\frac{M_t(i)}{P_t} = \left[R^M_{t-1}(i) + \kappa\right] \frac{D_{t-1}(i)}{P_t}, \tag{9}$$

where D_{t-1} denotes the stock of mortgage debt carried from the previous period, and R^M_{t-1} is the effective interest on all mortgages outstanding. Here, κ denotes the constant amortization rate for determining the principal payments out of the stock of mortgage debt;[14] hence, the law of motion for the stock of debt is given by,

$$\frac{D_t(i)}{P_t} = (1-\kappa)\frac{D_{t-1}(i)}{P_t} + \frac{L_t(i)}{P_t}. \tag{10}$$

New mortgage loans, L_t, carry a fixed mortgage interest rate, R^F_t and a fraction Φ of existing loans are refinanced each period at this rate as well. Thus, the effective interest rate on the stock of mortgages, R^M_t, evolves according to

$$R^M_t(i) = (1-\Phi)\left(1 - \frac{L_t(i)}{D_t(i)}\right) R^M_{t-1}(i) + \left[\frac{L_t(i)}{D_t(i)} + \Phi\left(1 - \frac{L_t(i)}{D_t(i)}\right)\right] R^F_t. \tag{11}$$

Note that we allow the average duration of the fixed interest rate on the loan to be shorter than the full amortization duration of the loan itself. This feature captures the notion that a significant share of FRMs are refinanced before the end of their amortization period.[15] Note that when $\Phi = 1$, all mortgages are refinanced every period, and the above expression, coupled with the law of motion of debt in (10), implies that the effective mortgage rate is identical to the current mortgage rate at all times (i.e., $R^M_t(i) = R^F_t$ for all t). As we show in Appendix A, $\Phi = 1$ also implies (using the Euler condition for short-term government debt) that the current mortgage rate, R^F_t, is equal to the policy rate, R_t, for all t as well. Therefore, when Φ is equal to 1, the interest rate on mortgages change every period similar to ARMs, while when Φ is 0, there is no refinancing and the interest on the FRMs are fixed for the whole amortization duration of the loan. Note also that if we have one-period debt (i.e., $\kappa = 1$), equation (10) implies that the stock and the flow of mortgage debt would be equal to each other (i.e., $D_t = L_t$), and the effective interest rate on mortgages would

[14] Kydland et al. (forthcoming) and Gelain et al. (2015) model the amortization rate as time-varying to better match the properties of a standard mortgage. In particular, during the early years, mortgage payments consists mainly of interest payments and the amortization rate is low, while the amortization rate increases over the lifetime of the loan. Gelain et al. (2015) show that this feature is important for the medium-term dynamics of the debt level and debt-to-GDP ratio. In particular, a monetary tightening increases the average amortization rate (as new loans decline), which leads to a medium-term decline in the debt level and in the debt-to-GDP ratio below the steady-state, in contrast to the constant amortization featured in our model.

[15] According to the 2011 American Housing Survey of the Census Bureau, about 80 percent of all new mortgage loans are fixed rate, and the rest are mostly standard ARMs (i.e., "5/1 ARMs," which have a fixed rate in the first five years of the loan, and their interest rate adjusts once a year thereafter). Data in Greenspan and Kennedy (2005, 2007) imply that FRMs get refinanced on average about every 8 years.

again be equal to the interest on government bonds, R_t.[16]

Wage stickiness is introduced via a quadratic cost of wage adjustment similar to Rotemberg (1982),

$$\frac{\kappa_w}{2}\left(\frac{W_{P,t}\left(i\right)/W_{P,t-1}\left(i\right)}{\pi_{t-1}^{\varsigma_w}\pi^{1-\varsigma_w}}-1\right)^2\frac{W_{P,t}}{P_t}n_{P,t}, \tag{12}$$

where κ_w is a scale parameter, $\pi_t = P_t/P_{t-1}$ is the aggregate inflation factor, and ς_w determines indexation of wage adjustments to past inflation. There are also quadratic adjustment costs in the stocks of housing and capital, with level parameters κ_h and κ_k, respectively.[17] These adjustment costs ensure that housing cannot be sold quickly across the two types of agents, and limit the amount of substitution between the housing and non-housing sectors.

The patient households' objective is to maximize utility subject to their budget constraint and the appropriate No-Ponzi conditions. The optimality condition for housing equates the marginal cost of acquiring a unit of housing to the marginal utility gain from housing services and the discounted value of expected capital gains net of taxes, which can be written as (ignoring adjustment costs in the stock of housing)

$$q_{h,t} = \xi_h\frac{c_{P,t}-\zeta c_{P,t-1}}{h_{P,t}} + \chi_t E_t\left[\left(\beta_P\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\right)\left[1-\delta_h-\tau_{p,t+1}\left(1-\tau_n\right)\right]q_{h,t+1}\right], \tag{13}$$

where $\lambda_{P,t}$ denotes the Lagrange multiplier on the period budget constraint.

Note that the expected capital gains expression on the right hand side of (13) has an additional term, χ_t, which is the exuberance shock discussed previously. This shock is purely expectational and captures the extent of *exuberance* in the housing market by driving a wedge between the observed asset price, $q_{h,t}$, and its underlying fundamental value. This shock raises the expected capital gains from future house price gains, unlike a housing preference shock which would impact the first term on the right-hand side of equation (13) instead by raising the agents' marginal utility of housing (i.e., rents). Up to a first-order approximation, the exuberance shock has the exact same implications on model variables as would a housing preference shock. The only exception to this is regarding the implications of the two shocks on the house price-to-rent ratio. In particular, a positive exuberance shock would lead to a larger increase in current house prices relative to rents, generating an increase in the house price-to-rent ratio, consistent with the observed increase in the price-to-rent ratio prior to the recent crisis. A housing preference shock however would have a counterfactual implication on the house price-to-rent ratio, since it would generate a larger increase in rents relative to house prices (Piazzesi and Schneider, 2016).[18] An alternative way to think about the exuberance shock is to think of it as an *unrealized* news shock on future housing quality, akin to the (unrealized) capital

[16] This, however, does not render our model equivalent to the standard Iacoviello (2005) set-up, unless borrowers withdraw home equity in the same proportion as the LTV ratio on regular mortgages. See the next subsection on impatient households for more on this.

[17] These costs are specified as $(\kappa_h/2)\left[h_{P,t}\left(i\right)/h_{P,t-1}\left(i\right)-1\right]^2 q_{h,t}h_{P,t}$ and $(\kappa_k/2)\left[k_t\left(i\right)/k_{t-1}\left(i\right)-1\right]^2 q_{k,t}k_t$, respectively.

[18] Note that the two shocks would also have different implications on welfare, since the housing preference shock directly impacts the utility function in contrast to the exuberance shock.

quality shocks in Gertler and Karadi (2011). In particular, the asset pricing equation in (13) is consistent with households receiving news today regarding future housing quality and incorporating these news into their expectations of future house prices *ex-ante*, while these news are never realized *ex-post*.

The rest of the optimality conditions for the patient households are discussed in Appendix A.

2.1.2 Impatient households (borrowers)

The economy is also populated by a unit measure of infinitely-lived impatient households. Their utility function is identical to that of patient households, except that their time-discount factor is assumed to be smaller as in Iacoviello (2005); hence, $\beta_I < \beta_P$. Labor services of impatient households are also heterogeneous, and are aggregated into a homogeneous labor service by perfectly-competitive labor intermediaries using a Dixit-Stiglitz aggregator. The labor demand curve facing each impatient household is therefore given by

$$n_{I,t}(i) = \left(\frac{W_{I,t}(i)}{W_{I,t}}\right)^{-\eta_{n,t}} n_{I,t}, \tag{14}$$

where $W_{I,t}$ and $n_{I,t}$ are the aggregate nominal wage rate and labor services for impatient households, respectively.

The impatient households' period budget constraint is given by

$$\begin{aligned} c_{I,t}(i) + q_{h,t}\widetilde{i}_{hI,t}(i) + \frac{M_t(i)}{P_t} &\leq (1-\tau_n)\frac{W_{I,t}(i)}{P_t} n_{I,t}(i) \\ &+ \frac{L_t(i)}{P_t} + tr_{I,t} - \tau_{p,t}(1-\tau_n) q_{h,t} h_{I,t-1}(i) + I_{m,t}\tau_n R^M_{t-1}(i)\frac{D_{t-1}(i)}{P_t} - \text{adj. costs}, \end{aligned} \tag{15}$$

where $c_{I,t}$, $\widetilde{i}_{hI,t}$, and $tr_{I,t}$ denote consumption, residential investment and lump-sum transfers received from the government, respectively. $I_{m,t}$ is a time-varying function that determines to what extent interest payments on borrowing are deductible when paying income taxes. Impatient households also face quadratic adjustment costs on their wages and housing stock similar to patient households.

Mortgage payments and the laws of motion for the stock of debt and the effective interest on mortgage loans are given by (9), (10), and (11), respectively. The law of motion for impatient households' housing stock, $h_{I,t}$, is given by

$$h_{I,t}(i) = (1-\delta_h) h_{I,t-1}(i) + \widetilde{i}_{hI,t}(i). \tag{16}$$

Impatient households' new borrowing in period t is given by

$$\frac{L_t(i)}{P_t} = \phi_t q_{h,t}\widetilde{i}_{hI,t}(i) + \gamma\left[q_{h,t}(1-\delta_h) h_{I,t-1}(i) - (1-\kappa)\frac{D_{t-1}(i)}{P_t}\right] + \widetilde{\varepsilon}_{l,t}, \tag{17}$$

where ϕ_t is the regulatory LTV ratio on new regular mortgages, γ is the ratio of existing home equity that is withdrawn, and $\widetilde{\varepsilon}_{l,t}$ is an exogenous AR(1) process with zero mean. When mortgage loans are fully amortized every period (i.e., one-period debt with $\kappa = 1$), and the equity withdrawal rate is the same as the LTV ratio on regular mortgages (i.e., $\gamma = \phi$), the above expression reduces to the more familiar borrowing constraint on the stock of debt as

$$\frac{D_t(i)}{P_t} = \phi q_{h,t} h_{I,t}(i) . \tag{18}$$

Note that with this specification, the effects of house price increases on the debt stock would be larger, as households rush to take out new loans based on the increase in the equity value of their existing homes up to the constraint imposed by the LTV ratio.[19] Furthermore, household leverage is rendered constant in this set-up, while our more general specification allows household leverage to be countercyclical, consistent with the empirical evidence presented in Adrian and Shin (2010).

For housing, the impatient households' optimality condition is given by (ignoring adjustment costs in stock of housing):

$$\begin{aligned}(1-\mu_t\phi_t)\, q_{h,t} = {} & \xi_h \frac{c_{I,t} - \zeta c_{I,t-1}}{h_{I,t}} \\ & + \chi_t E_t \left[\left(\beta_I \frac{\lambda_{I,t+1}}{\lambda_{I,t}} \right) \left[(1-\delta_h) \left[1 - \mu_{t+1} \left(\phi_{t+1} - \gamma \right) \right] - \tau_{p,t+1} \left(1 - \tau_n \right) \right] q_{h,t+1} \right] ,\end{aligned} \tag{19}$$

where μ_t is the Lagrange multiplier on the borrowing constraint. Note that the marginal cost of purchasing a unit of housing today is dampened by the shadow gain from the relaxation of the borrowing constraint with the increase in the level of housing. Since the borrowing constraint is on the flow and not on the stock of housing, the marginal gain next period is also dampened by the borrowing constraint tomorrow, because today's housing purchase increases the housing level tomorrow, thereby reducing the need to invest in housing further next period. On the other hand, today's house purchase also partly relaxes tomorrow's borrowing constraint due to its impact on home equity loans. Note also that the exuberance term on house prices, χ_t, impacts the expectations of impatient households as well.

Note that when the equity withdrawal rate is the same as the LTV ratio on new regular mortgages (i.e., $\gamma = \phi$), and there are no property taxes or exuberance shocks, the above expression reduces to

$$(1-\phi\mu_t)\, q_{h,t} = \xi_h \frac{c_{I,t} - \zeta c_{I,t-1}}{h_{I,t}} + E_t \left[\left(\beta_I \frac{\lambda_{I,t+1}}{\lambda_{I,t}} \right) (1-\delta_h)\, q_{h,t+1} \right] , \tag{20}$$

similar to the pricing expression for housing in models that follow the set up in Iacoviello (2005). The rest of the optimality conditions for the impatient households are discussed in Appendix A.

[19] As stated earlier, the data of Greenspan and Kennedy (2005, 2007) suggest that annual mortgage equity withdrawals (i.e., home equity loans and cash-out refinancings) constitute only about 7 percent of the existing equity of borrowers, far less than the regulatory LTV ratio. We may nevertheless be slightly underestimating the effects of regulatory LTV in our specification by ruling out any effect of LTV policy on home equity withdrawal.

2.2 Production

2.2.1 Goods production

There is a unit measure of monopolistically competitive goods producers indexed by j. Their technology is described by the following production function:

$$y_t(j) = z_t \left[u_t(j) k_{t-1}(j)\right]^{\alpha} \left[n_{P,t}(j)^{\psi} n_{I,t}(j)^{1-\psi}\right]^{1-\alpha} - f, \tag{21}$$

where α is the share of capital in overall production, and ψ denotes the share of patient households in the labor input. u_t denotes the utilization rate of capital, and f is a fixed cost of production. The aggregate productivity shock, z_t, follows an AR(1) process.

Goods are heterogeneous across firms, and are aggregated into a homogeneous good by perfectly-competitive final-goods producers using a standard Dixit-Stiglitz aggregator. The demand curve facing each firm is given by

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta_{y,t}} y_t, \tag{22}$$

where y_t is aggregate output, and $\eta_{y,t}$ is a time-varying elasticity of substitution between the differentiated goods. We specify an exogenous AR(1) process on $\theta_{p,t} = \eta_{y,t}/(\eta_{y,t} - 1)$,

$$\log \theta_{p,t} = (1 - \rho_p) \log \theta_p + \rho_p \log \theta_{p,t-1} + \varepsilon_{p,t}, \tag{23}$$

where θ_p is the markup of price over marginal cost at the steady state.

Firm j's profits at period t is given by

$$\begin{aligned} \frac{\Pi_t(j)}{P_t} &= \frac{P_t(j)}{P_t} y_t(j) - \frac{W_{P,t}}{P_t} n_{P,t}(j) - \frac{W_{I,t}}{P_t} n_{I,t}(j) - r_{k,t} k_{t-1}(j) \\ &\quad - \frac{\kappa_u}{1+\varpi}\left[u_t(j)^{1+\varpi} - 1\right] k_{t-1}(j) - \frac{\kappa_p}{2}\left(\frac{P_t(j)/P_{t-1}(j)}{\pi_{t-1}^{\varsigma_p}\pi^{1-\varsigma_p}} - 1\right)^2 y_t, \end{aligned} \tag{24}$$

where κ_u and ϖ are the level and elasticity parameters in the utilization cost specification. Similar to wage stickiness, price stickiness is introduced through quadratic adjustment costs, where κ_p is the level parameter, and ς_p captures the extent to which price adjustments are indexed to past inflation.

A firm's objective is to choose the quantity of inputs, output and its own output price each period to maximize the present value of profits (using the patient households' stochastic discount factor) subject to the demand function they are facing with respect to their output from the goods aggregators.

2.2.2 Investment-goods producers

There is a unit of perfectly-competitive capital investment-goods producers who purchase $i_{k,t}$ units of the new capital investment goods from final-goods firms at a relative price of 1, and turn it into $\widetilde{i}_{k,t}$

effective units of investment goods that can be purchased by end-users at the installed capital price of $q_{k,t}$. This production is akin to investment-specific technological change where $\widetilde{i}_{k,t} = z_{k,t} i_{k,t}$, but investment-goods producers are also subject to adjustment costs in the change in investment similar to Christiano et al. (2005) and Smets and Wouters (2007).[20] The investment-goods producers' objective is thus to maximize

$$E_t \sum_{\tau=t}^{\infty} \beta_P^{\tau-t} \frac{\lambda_{P,\tau}}{\lambda_{P,t}} \left[q_{k,\tau} \widetilde{i}_{k,\tau} - i_{k,t} - \frac{\kappa_{ik}}{2} \left(\frac{i_{k,\tau}}{i_{k,\tau-1}} - 1 \right)^2 q_{k,\tau} z_{k,\tau} i_{k,\tau} \right], \tag{25}$$

where κ_{ik} is the investment adjustment cost parameter, and future profits are discounted using the patient households' stochastic discount factor. Note that the investment-specific technological change shock (investment shock, for short), $z_{k,t}$, follows an AR(1) process.

Residential investment producers are modeled analogous to capital investment producers. These firms purchase the total housing investment goods, $i_{h,t} = i_{hP,t} + i_{hI,t}$, from final-goods firms at a relative price of 1, and turn it into $\widetilde{i}_{h,t}$ effective units of housing investment goods that can be purchased by households at the installed capital price of $q_{h,t}$. The first-order condition for residential investment producers yields a demand equation for residential investment, which in log-linearized form can be written as

$$\widehat{i}_{h,t} = \frac{\beta_P}{1+\beta_P} E_t \widehat{i}_{h,t+1} + \frac{1}{1+\beta_P} \widehat{i}_{h,t-1} + \frac{1}{(1+\beta_P)\,\kappa_{ih}} \left(\widehat{q}_{h,t} + \widehat{z}_{h,t} \right). \tag{26}$$

where κ_{ih} is the housing investment adjustment cost parameter, and $z_{h,t}$ is a residential investment shock following an AR(1) process. Note that when investment adjustment costs are large, the housing supply becomes relatively more inelastic, and, therefore, house prices become more responsive to shocks.

2.3 Monetary, fiscal and macroprudential policy

The central bank targets the nominal interest rate using a Taylor rule:

$$\log R_t = \rho \log R_{t-1} + (1-\rho) \left(\log R + a_\pi \log \frac{\pi_t}{\pi} + a_y \log \frac{y_t}{y} \right) + \widetilde{\varepsilon}_{r,t}, \tag{27}$$

where ρ determines the extent of interest rate smoothing, R is the steady-state value of the (gross) nominal policy rate, and a_π and a_y are the long-run response coefficients for inflation and the output gap, respectively. $\widetilde{\varepsilon}_{r,t}$ denotes the monetary policy shock, and follows an AR(1) process.

[20] Adjustment costs in residential and non-residential investment are key to generate endogenous changes in the relative prices of capital and housing. Note that, in the absence of these shocks, these relative price changes would all be attributed to exogenous investment-specific technological change shocks.

The total tax revenues of the government are given by

$$tax_t = \tau_n \left(\frac{W_{P,t}}{P_t} n_{P,t} + \frac{W_{I,t}}{P_t} n_{I,t} - I_{m,t} \frac{R_{t-1}^M}{\pi_t} d_{t-1} \right) + \tau_k \left(r_{k,t} - \delta_k \right) k_{t-1} + \tau_{p,t} \left(1 - \tau_n \right) q_{h,t} h_{t-1}. \quad (28)$$

Aggregate transfer payments to households are determined by

$$tr_t = \Xi y - \varrho_b \frac{B_{t-1}}{P_{t-1}}, \quad (29)$$

where Ξ is a level parameter, and ϱ_b determines the response of transfers to government debt.[21] Aggregate transfers are distributed to patient and impatient households in proportion to their labor shares. The law of motion for government debt accumulation is given by

$$\frac{B_t}{P_t} = \left(1 + R_{t-1} \right) \frac{B_{t-1}}{P_t} + g_t + tr_t - tax_t, \quad (30)$$

where government expenditure, g_t, follows an exogenous AR(1) process given by

$$\log g_t = \left(1 - \rho_g \right) \log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}. \quad (31)$$

For the baseline case used in the estimation, we set the property tax rate to a constant (i.e., $\tau_{p,t} = \tau_p$), and assume full deductibility of mortgage interest (i.e., $I_{m,t} = 1$). We also set the regulatory LTV to its steady-state value (i.e., $\phi_t = \phi$).

2.4 Market clearing conditions

The goods market clearing condition is given by

$$c_t + i_t + g_t = y_t - \text{adj.costs}, \quad (32)$$

where total consumption is $c_t = c_{P,t} + c_{I,t}$, total investment is $i_t = i_{k,t} + i_{h,t}$, and all quadratic adjustment costs are subtracted from output.[22]

The model's equilibrium is defined as prices and allocations such that households maximize the discounted present value of utility, all firms maximize the discounted present value of profits subject to their constraints, and all markets clear.

[21] Note that either taxes, government expenditure or transfers need to adjust to the level of debt so that the government cannot run a Ponzi scheme. We choose to make the adjustment through transfers based on the results of Leeper et al. (2010).

[22] Note that we are implicitly treating capital utilization costs incurred by goods producers as being lump-sum transferred back to the patient households.

3 Estimation

We estimate the parameters of the model using Bayesian likelihood methods (An and Schorfheide, 2007; Fernández-Villaverde, 2010) and U.S. macroeconomic and financial data. In this section, we briefly discuss the data, the estimation methodology, and the posterior estimates obtained from the estimation, while leaving details to Appendix B.

3.1 Data

We use 10 quarterly data series from the United States for the period 1984Q1 to 2007Q4 in our estimation. The sample starts from the Great Moderation period to capture the Federal Reserve's more recent stance against inflation, and excludes the post-crisis period when conventional monetary policy was restricted by the zero lower bound. The observable variables in the estimation are output (y), consumption (c), non-residential investment (i_k), residential investment (i_h), labor (n), real wage (w), GDP-deflator inflation (π), policy rate (R), house price index (q_h), and household debt (d). The data sources and details regarding the detrending of the data can be found in Appendix B.

3.2 Calibrated parameters

We only estimate the parameters that primarily affect dynamics, while calibrating the rest of the parameters that primarily determine the steady state of the model. The latter parameters are restricted within the estimation (i.e., recalibrated within each iteration), to ensure that the implied steady state of the model matches with pre-specified data target ratios from the U.S. macroeconomic and housing data. Table 2 lists these calibrated parameter values, and Table 3 reports the main ratios at the steady state of our model versus the data targets. In what follows, we briefly discuss our parameter choices for the mortgage-related features of the model. The details regarding the calibration of all other variables are provided in Appendix B.

We set the steady-state LTV ratio on new regular mortgages, ϕ, equal to 0.91, based on the 2001 *Residential Finance Survey* (RFS) of the Census Bureau, which reports the median value for the ratio of the first mortgage loan as a percent of the purchase price for 1-unit homeowner mortgaged properties as 91% (RFS 2001, Table 2.2, pg. 2-12).[23] The data provided by Greenspan and Kennedy (2005, 2007) suggest that mortgage equity withdrawals (i.e., home equity loans and cash-out refinancings) constitute about 1.72% of the existing equity of borrowers on a quarterly basis during 1991-2005; hence, we set the home equity withdrawal rate parameter, γ, to 0.0172.[24]

According to the data from the 2011 *American Housing Survey* (AHS) of the Census Bureau, the average for the ratio of outstanding mortgage loans to house value (i.e., loan-to-value on all

[23] Freddie Mac's Primary Mortgage Market Survey reports an *average* original LTV ratio, of around 0.76, for single single family mortgages. The difference between this figure and the RFS survey we use is likely due to differences in the sample of mortgages, as well as the difference between the median versus the average mortgage.

[24] In a recent paper, Mian and Sufi (2014) report a larger home equity withdrawal rate for the average borrower during 2002-06, of around 4.75% on a quarterly basis.

outstanding debt), d/h_I, is 0.66. Based on this data target, and the steady-state relationship

$$\frac{d}{h_I} = \frac{\phi\delta_h + \gamma(1-\delta_h)}{1-(1-\gamma)(1-\kappa)/\pi}, \tag{33}$$

we calibrate the amortization rate for mortgage loans, κ, to 0.0186.[25] This amortization rate implies that the duration of mortgage loans in the model is around 73.8 quarters (i.e., 18.5 years).[26] This is largely consistent with, albeit slightly less than, AHS data, which imply that the average remaining term of all outstanding loans is around 19.6 years.

Data in Greenspan and Kennedy (2005, 2007) imply that the ratio of repayments resulting from refinance originations to the stock of mortgages averaged around 4.4 percent quarterly during 1991-2005, implying an interest rate duration of around 7.8 years. Note that the data on repayments from refinance originations include, not only repayments from FRM refinancings, but also those from refinanced ARMs. We consider a slightly lower average interest rate duration of 7.1 years, and set the parameter Φ to 0.0475 accordingly, to reflect the fact that some ARMs do not get refinanced and have a lower interest rate duration than the average mortgage loan.[27] Calibrating Φ instead to match an interest duration of 7.8 years would not alter our main results in any discernible way.

3.3 Posterior estimates of parameters

Tables 4 and 5 report the prior distributions used for each estimated parameter, and corresponding posterior estimates of the mode, the mean, and the 5th and 95th percentiles.[28] Our choices for the priors are discussed in Appendix B. The data are quite informative about most of the parameters, and the posterior estimates are by and large standard.

The habit parameter, ζ, has a posterior mean equal to 0.87. ϑ has a posterior mean of 3.1, implying a labor supply elasticity of around 0.3. The estimate for the utilization parameter, ϖ^{est}, implies that the elasticity of capacity utilization with respect to the rental rate of capital is around 6. The estimates for the investment adjustment cost parameters, κ_{ik} and κ_{ih}, are 4.9 and 2.5, respectively. Similarly, the stock adjustment cost parameters, κ_k and κ_h, are estimated as 10.7 and 0.7, respectively. The relatively low estimate for κ_h implies that housing can be traded fairly easily across the two types of households in the model. Thus, in response to a tightening in policy, borrower households will be able to reduce their stock of housing, $h_{I,t}$, significantly, while saver households increase their housing holdings, $h_{P,t}$. Note that this will be accompanied by a significant fall in residential investment of borrowers, $\widetilde{i}_{hI,t}$, and their new borrowing, l_t, thereby increasing the

[25] The above steady-state relationship is obtained by combining the law of motion for debt (10), the law of motion of housing of impatient households (16), and the expression for new mortgage loans (17) at the steady state.

[26] We approximate duration by 2 times the half-life of the loan.

[27] According to AHS, about 80% of all new mortgages are fixed rate and 20% are adjustable rate. For the ARMs, the majority are *5/1 ARMs*, which have a fixed rate in the first five years of the loan, and their interest rate adjusts once a year thereafter. Assuming that half of ARMs get refinanced and the other half have an interest rate duration of one year, we arrive at an average interest duration of around 7.1 years for all outstanding mortgage loans.

[28] For the Metropolis-Hastings algorithm in *Dynare*, we used a single chain of 250,000 draws with a 45% initial burn-in phase. The acceptance rate was about 27%.

effectiveness of policies in reducing household debt. As we shall see in section 4, when κ_h is large, the decline in borrowing due to policy tightening becomes more limited in the short run, since borrowers are not able to reduce their housing stock as quickly.

The estimates for the price and wage adjustment cost parameters, κ_p^{est} and κ_w^{est}, are 0.88 and 0.81, respectively, implying high levels of price and wage stickiness in the post-Great Moderation period. The indexation parameters, ς_p and ς_w, have estimated means of 0.2 and 0.4, respectively, indicating that indexation to past inflation is not an important feature of the data, particularly for prices. The Taylor rule is fairly persistent with mean ρ equal to 0.74, and the mean estimates for the long-run reaction coefficients a_π and a_y are 1.42 and 0.13, respectively. The mean estimate for ϱ_b, the parameter determining the responsiveness of transfers to government debt, is 0.012. Finally, shock processes are estimated to be fairly persistent except for the preference, capital investment, wage markup and monetary policy shocks.

3.4 Model fit relative to alternative specifications

In this section, we investigate the extent to which some of the key features of our model contribute to the model's fit to the data. In particular, we re-estimate variants of our model with (i) ARMs only, and (ii) only one-period debt, instead of the long-term FRMs used in our baseline model, and conduct a marginal likelihood comparison of these alternative specifications relative to our baseline. For the first alternative model, we change the mortgages in our setup from FRMs to ARMs by setting the refinancing parameter, Φ to 1, and thereby ensuring that the interest rate on all mortgages adjusts every period. In the second case, we change the mortgages from long-term amortized loans to one-period loans by setting the amortization rate, κ, equal to 1.[29]

Table 6 compares the relative fit of these alternative models based on their marginal likelihoods and the associated Bayes factors based on the ratio of the marginal likelihood of each model relative to the baseline model. The marginal likelihoods were computed using the modified harmonic mean estimator proposed by Geweke (1999). The results indicate that the baseline model is preferred relative to the two alternatives based on their marginal likelihoods. Notably, the model with ARMs demonstrates an inferior fit, with the the logarithm of the Bayes factor taking a value of -5 in favor of the baseline model. This difference in model fit is quantitatively substantial according to the classification in Jeffreys (1961). In the case of the model with one-period debt, the results are even more stark with the log marginal likelihood being significantly lower relative to the baseline model. In particular, the associated log-Bayes factor is now approximately -135, suggesting a significantly poorer fit of the one-period debt model relative to the baseline case.

[29] In this exercise, we set the home equity extraction, γ, and the LTV ratio on new mortgages, ϕ, equal to each other and calibrate them 0.66 to ensure that the alternative model with one-period debt generates a steady-state average LTV ratio, d/h_I, of 0.66 as in our baseline estimation.

4 Results

In this section, we first analyze the effects of monetary policy on mortgage debt based on the benchmark estimated parameters, and conduct sensitivity analyses on our baseline results by altering key parameters. We then compare the effectiveness of fiscal and macroprudential tools in reducing mortgage debt relative to monetary policy.

Note that all the four aforementioned policies can potentially reduce the level of household debt, but their adverse side-effects on output would differ, largely based on the scope of each policy (see Table 1). In particular, the direct effects of targeted policies are more confined to the housing sector and borrowers; thus, these policies are able to reduce the quantity of new mortgage lending without leading to large spillovers to other sectors and non-borrowing households. In fact, in certain instances, the adverse effects to output from the decline in borrowers' demand can be partially offset by the increase in demand coming from saver households and the non-housing sector. For monetary policy, the direct effects generated from a tightening are more evenly spread between the housing and non-housing sectors and between the borrower and saver households; therefore, reducing household indebtedness by the same amount would potentially lead to a larger adverse effect on output.

A related issue is the effect of these four policies on inflation. This is a key determinant of household debt dynamics because mortgage loans are extended in nominal terms, and consequently are subject to debt-deflation type of effects in real terms. In particular, consider the law of motion for household debt given by Equation (10) in Section 2:

$$d_t = (1-\kappa)\frac{d_{t-1}}{\pi_t} + l_t, \tag{34}$$

where π_t is the inflation rate, κ is the amortization rate for existing debt and $d_t = D_t/P_t$ and $l_t = L_t/P_t$ denote the stock and flow of household debt in real terms. Therefore, for a policy to be successful in reducing the stock of real household debt, it needs to be able to substantially reduce new household loans, l_t, while not causing a large decline in the inflation rate, π_t.[30] This is especially true for mortgage loans, for which the amortization rate is very low, and thus, the share of new loans in the overall stock of mortgage debt is small. If a policy is too "blunt" and has large adverse spillovers to other sectors of the economy, it could cause a significant decline in the inflation rate relative to the decline in new loans, thereby leading to an *increase*, rather than a decrease, in the stock of real mortgage debt (and the debt-to-income ratio). Svensson (2013) has recently argued that monetary "leaning against the wind" in Sweden would have this perverse impact in the short run, since the price level and output would decline faster than the stock of nominal mortgage debt stock, all specified relative to a baseline.

[30] Here, we are assuming that the amortization rate, κ, is a constant, while in reality, the average amortization rate could also change as a result of policy. In particular, a decline in κ (i.e., a lengthening in the average duration of loans) would act similar to a decline in inflation, and would make it harder for the policy to reduce the stock of real debt. Conversely, a shortening in loan duration could potentially increase the effectiveness of the policy in reducing the stock of real debt. Gelain et al. (2015) show that a monetary tightening would increase the average amortization rate, and lead to a medium-term decline in the debt level and in the debt-to-GDP ratio below the steady-state.

Note also that new loans in our model are given by

$$l_t = \phi_t q_{h,t} \widetilde{i}_{hI,t} + \gamma \left[q_{h,t} \left(1 - \delta_h\right) h_{I,t-1}\left(i\right) - \left(1 - \kappa\right) \frac{d_{t-1}}{\pi_t} \right], \tag{35}$$

thus, a change in inflation also affects new loans, l_t, through its effect on home equity value. In particular, a decrease in inflation would increase home equity, all else equal, and would therefore lead to a slight increase in new loans. Although in general equilibrium, a monetary tightening leads to a decline in new loans, l_t, this effect would be stronger in the absence of this debt-deflation effect.[31]

4.1 Effects of monetary policy on mortgage debt

Figure 1 plots the impulse responses to a 100 bps (annualized) innovation in the monetary policy shock. The pass-through from the policy rate, R_t, to the long-term mortgage rate is incomplete, since the policy rate is expected to slowly decline from its peak. The fixed rate on new mortgages, R_t^F, increases by 25 bps, and the overall effective interest burden faced by all borrowers on their existing mortgages, R_t^M, increases by about 4 bps at the peak. Faced with higher rates, impatient households reduce their new borrowing through regular mortgages by about 9%. The decline in the demand for housing also leads to a fall in house prices, $q_{h,t}$, which in turn leads to a fall in the home equity of borrowers, and therefore their new borrowing through home equity withdrawals (by about 3.3% on impact). The increase in discounting of future returns by patient households leads to a decline in their consumption, housing and capital purchases as well. Thus, non-residential investment, $i_{k,t}$, declines along with the price of capital, $q_{k,t}$. The overall decrease in demand leads to a reduction in production and wages, leading to a fall in aggregate output, y_t, and inflation, π_t.

Given our benchmark estimates, we do not find evidence that monetary policy has perverse effects on the stock of household debt, d_t, due to the muted response of inflation to the monetary policy shock, along with the relatively sizable decline in new borrowing. Note, however, that the decline in output is stronger than the decline in the real stock of mortgage debt; thus, our model predicts an increase in the household debt-to-income ratio with monetary tightening.

4.1.1 Sensitivity analysis

In Figure 2, we conduct several sensitivity analyses to investigate the importance of model features and parameterization in generating the above results related to the effects of monetary policy on household debt.[32]

In Figure 2, we show that monetary policy could have had perverse effects on the level of debt as well if the estimation had pointed to a steeper Phillips curve or a higher adjustment costs in

[31] On the other hand, if the collateral value of housing depended on the future value of house prices as in the original Iacoviello (2005) set up, then the decline in current inflation could have potentially lowered home equity, leading to a further decline in new loans, l_t.

[32] In what follows, we use the posterior mode estimates as our baseline, rather than the posterior means depicted in Figure 1. The differences in the impulse responses using the posterior mean versus the posterior mode estimates are negligible.

housing. For example, if κ_p^{est} is reduced from 0.89 in our baseline case to 0.5 (reflecting an average price stickiness of 2 quarters in the Calvo set-up), monetary tightening leads to a significantly larger decline in inflation, π_t, which results in an increase in the level of real household debt in the short run (first row of Figure 2). Similarly, if we increase the adjustment costs in the stock of housing, κ_h, to 50, borrowers are not willing to reduce their level of new residential investment as much, causing a smaller decline in new mortgage lending, l_t (second row of Figure 2). The decline in the inflation rate is comparable to the baseline case, but this is enough to cause an increase in the real stock of household debt with a monetary tightening after several quarters.

The third row of Figure 2 considers a more persistent monetary shock than its estimated value in the baseline, to determine whether the main results regarding the effects of monetary policy on the household debt would be altered. In particular, we increase the monetary shock's persistence parameter, ρ_r, to 0.9 from its estimated value of 0.46. In this case, the monetary shock is longer lasting, and therefore the decline in output and inflation are much larger on impact.[33] Since the monetary authority follows a Taylor type rule, this leads the policy rate to endogenously fall below steady state a few quarters after the shock hits the economy. This explains the decline in the interest rate on long-term FRMs in this case based on the expectations hypothesis. The real debt stock falls on impact and slowly recovers to increase above its steady state after a few quarters. Given the larger drop in output relative to debt response, however, the household debt-to-income ratio still increases with monetary tightening.

In the aforementioned sensitivity analyses, we changed one key parameter while we kept all the other parameters the same as in our baseline estimates. Now, we look at the effects of monetary policy shocks in two re-estimated models mentioned in Section 3.4. First, we consider the alternative model with ARMs (fourth row of Figure 2). In this case, the increase in the policy rate now passes through fully to the mortgage rate on new and existing loans. Impatient households are forced to reduce their new borrowing through regular mortgages far more than the baseline model. They also reduce their consumption, leading to a sizable decline in aggregate consumption and output relative to the baseline case. Impatient households reduce their residential investment as well, but the slack is picked up by the patient households, who now increase their housing holdings; thus, the overall effect on residential investment is only minor. The effect on inflation is also comparable to the baseline case; therefore, the stock of household debt declines by a significantly larger amount relative to the baseline case due to the decline in new lending, l_t. Note that the debt-to-output ratio still increases in the short run. With FRMs, a smaller change in the mortgage rate has a greater impact on new lending as households are incentivized to lock-in the low rate for a long time. In our model, the interest rate pass-through effect dominates the lock-in effect, and a higher refinancing rate implies a greater impact of monetary policy on household debt.

Finally, in the last row of Figure 2, we show responses from the model re-estimated with one period debt. In this model, there is no distinction between new loans and the debt stock, and so

[33] Garriga et. al (2013) also document stronger effects of monetary policy on output as the persistence of monetary policy shocks increases.

monetary tightening has a large impact on the debt stock on impact. As a result, we see a large decline in debt-to-GDP in the short-run and an increase at longer horizons.

4.2 Effects of fiscal and macroprudential policies on mortgage debt

In this subsection, we compare the effectiveness of fiscal and macroprudential tools in reducing household debt relative to monetary policy. So far, we have kept the housing-related fiscal and macroprudential tools constant; in this section, we investigate how exogenous and permanent changes in these tools would affect household debt and other macroeconomic variables.[34]

The results are summarized in Figure 3, which plots the impulse responses of key variables in the model to tightening in the macroprudential or housing-related fiscal measures. In terms of normalizing the magnitude of these policy changes, we pick the size of the shocks so that the level of real debt, d_t, is reduced by 2.7% from the initial to the terminal steady-state in each case. In our model, this can be achieved by (i) a 0.07 percentage point (pp) increase in the quarterly property tax rate (i.e., τ_p is increased from 0.0035 to 0.0042), (ii) a 26.5 percent decline in the tax deductibility of mortgage interest (i.e., I_m is reduced from 1 to 0.735), or (iii) a 5 pp tightening in the regulatory LTV ratio (i.e., ϕ is decreased from 0.91 to 0.86).

4.2.1 Increasing the property tax rate

Figure 3 shows the impulse responses of model variables to a surprise 0.23 pp (annualized) increase in the property tax rate (i.e., the property tax rate increases from 1.4 percent to 1.67 percent in annualized terms; hence, $\tau_{p,t}$ increases from 0.014/4 to 0.0167/4 on impact). The increase in the property tax rate reduces the future returns that patient and impatient households expect to receive from investing in housing in the next period, thereby reducing the demand for residential investment goods, $i_{h,t}$, everything else constant. The relative price of housing, q_h, falls due to the decline in housing demand, but slowly reverts back to its steady-state level within five years of the shock as the effect of investment adjustment costs dissipates and the supply of housing adjusts. New household lending, l_t, declines as impatient households reduce their demand for housing and the fall in house prices reduces their home equity. Thus, the stock of real household debt, d_t, declines over time.

Given the adverse income effects from increased property taxes and the tightening of their collateral constraint from reduced house prices, impatient households are forced to reduce their consumption expenditures, $c_{I,t}$, as well. Patient households, on the other hand, switch their expenditures from housing to consumption and capital investment, $i_{k,t}$, but the decline in house prices in

[34] In practice, we let the property tax rate, the tax deductibility of mortgage interest and regulatory LTV follow AR(1) processes with persistence parameters close to unity (i.e., 0.9999), and consider shocks to their innovation terms. This ensures that the model remains stationary and makes its computation feasible through perturbation methods. In Alpanda and Zubairy (2016), we consider permanent changes in fiscal policies, and compute exact solutions for the transition paths. Near-permanent policy changes computed with log-linearization yield very similar transition path results in the short run relative to those we get from the exact solution under permanent changes, when the initial conditions are at the steady state and the shocks are not too large. We thus consider the stationary model here with near-permanent changes. This can also capture the notion that agents place a small probability on the reversal of these policies back to their original values in the long run.

general equilibrium cushions the decrease in their demand for housing in the short run. Aggregate consumption, c_t, decreases in the short run, reflecting the greater impact of the fall in borrowers' consumption, $c_{I,t}$, while it increases above its steady-state value after several periods given the increase in consumption demand from patient households, $c_{P,t}$. This increase in savers' consumption is also partly due to the decline in the policy rate, R_t, which is triggered by the decline in aggregate output, y_t, and inflation, π_t. The decline in the policy rate also reduces long-term mortgage rates, R_t^F, but this is not strong enough to reverse the fall in housing demand of impatient households in general equilibrium.

4.2.2 Reducing the tax deductibility of mortgage interest

Figure 3 also shows the impulse responses of model variables to a 26.5% decline in the tax deductibility of mortgage interest (i.e., $I_{m,t}$ decreases from 1 to 0.735 on impact). Unlike property taxes, which directly affect borrowers *and* savers, the direct impact of the change in mortgage interest deduction is felt solely by borrowers. Similar to property taxes, this leads to a decline in borrowers' demand for housing and mortgage borrowing, thereby leading to an overall fall in house prices. But now the decline in house prices incentivizes patient households to increase their level of housing, $h_{P,t}$. Qualitatively and quantitatively, this is the most important difference between the effects of property taxes and mortgage interest deductions. Both policies reduce the overall demand for residential investment and house prices, but the latter policy's effect on output is cushioned by the increase in housing by patient households. This ensures that for the same decline in household debt, mortgage interest deduction has a smaller output impact relative to property taxes.

Otherwise, the qualitative effects of the two policies on aggregate variables are similar (see Figure 3). Aggregate consumption, c_t, declines due to the fall in impatient households' consumption, $c_{I,t}$, which occurs mainly due to the decline in borrowers' income from the increase in their tax burden and the fall in their wages. Patient households increase consumption, $c_{P,t}$, along with the increase in housing, $h_{P,t}$, due to the fall in the policy rate, R_t, which in turn is induced by the fall in overall inflation and output. The fall in the policy rate also induces an increase in business investment, $i_{k,t}$, and an increase in capital prices, $q_{k,t}$, as well.

4.2.3 Lowering the regulatory LTV ratio on new mortgages

Figure 3 also plots the impulse responses of model variables to a 5 pp decrease in the regulatory LTV ratio (i.e., ϕ_t decreases from 0.91 to 0.86 on impact). This time, the direct effect of the policy is on the borrowing constraint of impatient households, not on their budget constraint. In particular, on impact the level of housing investment desired by impatient households is higher than the available amount of loans they can take out; thus, the Lagrange multiplier on the borrowing constraint increases significantly. This multiplier presents a shadow cost on new borrowing, working through a similar channel as an increase in the mortgage rates faced by borrowers on new loans. Note that there is an important difference between regulatory LTV and the mortgage interest deduction in this respect. The former imposes a shadow cost on new loans only, while the latter entails a real cost on all existing loans. As a real cost, the decline in mortgage interest deduction imposes a direct adverse income effect on borrowers, unlike regulatory LTV, which has a direct impact on the borrowing constraint, but affects the budget constraint of borrowers only indirectly.

The effects of the LTV policy are qualitatively similar to those from mortgage interest deduction, except for the behavior of home equity loans (HELs). Despite the fall in house prices, HELs increase with LTV policy, since the policy forces agents to build up home equity over time. Otherwise, the other variables react similarly to a change in mortgage deduction. As the borrowing constraint binds tighter due to the fall in regulatory LTV, borrowers are forced to reduce their demand for housing, which, in general equilibrium, leads to a fall in house prices and overall residential investment. Given the substitutability between housing and consumption, and the decline in their wages, $w_{I,t}$, borrowers also decrease their consumption demand. The overall impact of the LTV policy on the economy is to reduce aggregate output, y_t, which is accompanied by a decline in inflation, π_t, as the derived demand for labor declines and wages fall. The fall in inflation prompts the central bank to reduce the policy rate, R_t. This prompts patient households to increase their consumption expenditures, $c_{P,t}$, but aggregate consumption, c_t, declines nevertheless, due to the decline in impatient households' consumption, $c_{I,t}$. The decline in the policy rate also lowers the long-term mortgage interest rates, which slightly moderates the fall in housing and consumption demand of borrowers. The decline in house prices induces patient households to increase their purchases of housing, $h_{P,t}$, similar to the mortgage interest deduction.

4.3 Comparing the effects of the four policies on the debt-to-GDP ratio

In the first panel of Figure 4, we show the effects of the four policies on the household debt-to-GDP ratio for a 50-year horizon in the baseline model. In this case, reducing tax deductibility of mortgage interest is the most effective tool among the four policies we consider, in terms of reducing household debt per unit of lost output. This is followed by tightening of regulatory LTV and increasing property taxes, while monetary policy leads to an increase in the debt-to-output ratio. Note that regulatory LTV has less impact on household debt than mortgage interest deduction, despite the fact that it is a more targeted tool for the housing sector. Since LTV policy does not have a direct impact on the home equity portion of new lending, it is unable to adequately reduce the stock of household debt in the short run. LTV does impact home equity loans indirectly through its negative effect on house prices and, therefore, home equity. But, over time, house prices normalize and LTV policy induces a buildup in home equity, leading borrowers to substitute toward home equity loans while reducing regular mortgage borrowing. Mortgage interest deduction, on the other hand, is able to alter the effective cost of borrowing for all loans, including those originating from withdrawals of home equity. This comes at the expense of some additional adverse impact on output, since mortgage interest deductions apply not only to lending on the margin, but to all existing loans. Thus, the effective after-tax interest burden increases on all outstanding debt, forcing borrowers to reduce their housing and consumption expenditures further than they would have if the changes in mortgage interest deduction rules applied only to loans on the margin and not to all existing loans. This transitional cost nevertheless seems less important than the increased scope for reducing home equity loans, thereby favoring mortgage interest deduction over regulatory LTV when addressing household indebtedness.

Figure 4 also shows that property taxes have less ability to reduce the stock of household debt relative to mortgage interest deduction and LTV policies. This is because an increase in the property tax rate adversely impacts all homeowners, including saver households who have no outstanding mortgage debt. This broader scope leads to more output loss per unit of household debt reduced (in other words, less household debt can be reduced for the same output loss). Finally, compared to the other policies, monetary policy reduces real household debt only by a small amount, while having a large adverse impact on output; thus, the debt-to-GDP ratio increases. Notice that, in Figure 4, we are considering only a temporary shock to monetary policy (with its persistence parameter set to its estimated value in Section 3), and Section 4.1.1 considers the effects of increasing the persistence. Monetary policy is the broadest tool among the policies discussed here, which adversely affects capital accumulation (as well as aggregate consumption and residential investment), thereby causing a large decline in output. In comparison, the effects of property taxes are more muted as savers switch their expenditures toward consumption and capital while reducing their demand for housing. This channel is somewhat moderated by the presence of adjustment costs in the stock of patient households' housing, but not fully. In the case of mortgage interest deductions, the decline in house prices induces savers to increase their residential housing holdings as well, cushioning the impact on overall output even further. The same channel also applies to regulatory LTV. Furthermore, LTV policy does not have the direct adverse income effects related to the increase in the overall tax burden on households when fiscal tools are used. Nevertheless, its scope is limited to regular mortgages, curtailing its effectiveness in reducing household debt with less output loss.

In the first row of Figure 4, we also show the comparison of the four policies in the two alternative (re-estimated) models considered in Section 3.4. The middle panel shows that in an estimated model where we constrain mortgage loans to be adjustable rate, the results are essentially the same as in the baseline model and suggest the same relative performance of the policies in reducing household debt-to-GDP. The third panel shows the results in a model estimated with one period debt, and in this case, the results look very different. First, note that in response to a monetary shock, the household debt-to-GDP ratio now declines, rather than increases, in the short run. This is primarily driven by the response of debt, which now falls significantly more in response to the monetary shock as discussed further in Section 4.1.1. In this alternative model, there is no distinction between new loans and the debt stock, and the LTV ratio applies to all new borrowing. As a result, the tightening in LTV policy lowers the debt stock to a much greater extent, leading to a significant decline in the household debt-to-GDP ratio on impact and in the long run as well. It is important to note however that, this model has a far worse fit with respect to the data relative to the baseline model, as discussed in section 3.4.

The second row of Figure 4 shows some robustness checks when we change certain parameter values in our baseline estimated model. The results are essentially the same, and the ranking of policies is preserved, when we consider a steeper Phillips curve (i.e., $\kappa_p^{est} = 0.5$). When we increase the adjustment costs in the stock of housing (i.e., $\kappa_h = 50$), the fiscal policies are less able to reduce the stock of housing, and regulatory LTV replaces mortgage interest deduction as the most effective policy in reducing the debt-to-GDP ratio. Similarly, when we eliminate home equity loans from the model (i.e., $\gamma = 0$), regulatory LTV becomes the most effective tool in terms of reducing the debt-to-GDP ratio, since its scope is now exactly targeted to impact new loans (all of which are regular mortgages).

An important caveat for the overall effectiveness of mortgage interest deduction is the implicit insurance across new and old borrowing in our baseline set-up. In particular, mortgage interest deduction changes the effective cost of borrowing on all existing debt, prompting borrowers to substantially reduce their new borrowing in order to reduce their overall level of debt quickly. This leads to a hump-shaped decline in household debt given a reduction in mortgage interest deduction (or an increase in property taxes), as borrowers overshoot the decline in debt to reduce their overall effective interest burden. In the real world, however, new borrowers are likely not the same agents as the old borrowers. Thus, a reduction in mortgage interest deductibility would have adverse wealth effects on old borrowers, but would not prompt new borrowers to reduce their marginal borrowing more in order to reduce the effective cost on the old borrowers' existing debt. In this sense, it may be more realistic to think that household debt would decline monotonically, and not with a hump-shape, with mortgage interest deduction rules, similar to the case depicted with high adjustment costs in the housing stock. Therefore, the impact of mortgage deduction on the household debt-to-GDP ratio is likely comparable to that of LTV, and not significantly better as implied by our baseline case.

Another caveat for our comparison is the fact that only monetary policy leads to a co-movement between the housing and the non-housing sectors in the model. In particular, with housing-related fiscal policies or regulatory LTV policy, the tightening in the housing sector is partially offset by an increase in business investment due to substitution effects. However, there may be other sources of co-movement between the two sectors in the real world which our model currently ignores, and which may lead to a decline in the non-housing sectors with fiscal and macroprudential policies as well. For example, the decline in house prices may erode bank capital and have adverse effects on the credit supply to the non-housing sectors (Alpanda et al., 2014). These and other additional sources of co-movement between the housing and the non-housing sectors could render the fiscal and macroprudential policies less effective in reducing household debt relative to our baseline results, but would not, by themselves, alter the basic ranking of the four policies in terms of their effectiveness in reducing household debt.

5 Welfare implications

In this section, we analyze the optimal values for regulatory LTV and mortgage interest deductibility from a utility-based welfare perspective. We also consider whether countercyclical monetary policy with respect to household debt can improve upon the welfare of savers and borrowers.

Following Schmitt-Grohe and Uribe (2005), we compute each agent's welfare based on the second-order approximation of the model around its deterministic steady-state. The welfare of agents of type $a \in \{P, I\}$ at period t is defined as the value of their expected lifetime utility under the equilibrium path (conditional on period t information, and symmetry across all agents within a type); hence,

$$V_{a,t} = E_t \sum_{\tau=t}^{\infty} \beta_a^{\tau-t} U\left(c_{a,\tau}^*, h_{a,\tau}^*, n_{a,\tau}^*\right), \tag{36}$$

where U denotes the period utility function in (1), and the asterisks on variables denote their equilibrium values. In recursive form, the above can be written as

$$V_{a,t} = U\left(c_{a,t}^*, h_{a,t}^*, n_{a,t}^*\right) + \beta_a E_t V_{a,t+1}. \tag{37}$$

As in Rubio (2011) and Lambertini et al. (2013), we augment the set of equilibrium conditions of the model with the two equations above, and compute the theoretical stochastic means of the welfare expressions, V_P and V_I, using the second-order approximation of the model.[35] We convert these welfare measures into *lifetime consumption equivalents* ($LTCE$) by calculating λ_a for each agent type $a \in \{P, I\}$ that would satisfy

$$V_a = \frac{U\left(\left(1+\lambda_a\right)\overline{c}_a - \zeta\overline{c}_a, \overline{h}_a, \overline{n}_a\right)}{1-\beta_a}, \tag{38}$$

where the hats above variables denote their deterministic steady-state values. We report the $LTCE$ numbers relative to their values in the baseline calibration. We also construct a social welfare measure, V, as a weighted average of the two agents' welfare, where we pick the weights such that the same constant consumption stream would result in equal welfare across the two agents; hence,

$$V = \left(1-\beta_P\right) V_P + \left(1-\beta_I\right) V_I. \tag{39}$$

5.1 Varying the steady-state level of policies

We first analyze the optimal value for regulatory LTV. Figure 5 plots the first and second moments of some of the key variables, as well as the welfare measures described above, for different values

[35] Strictly speaking, we include these expressions without the asterisks on the period utility variables. Given that the equations with V_P and V_I are auxiliary to the rest of the system, in equilibrium, we can recover the welfare expressions. Also note that the theoretical stochastic means are obtained by summing the deterministic steady-state and the shift factor from to the variance of future shocks. Thus, our welfare measures are conditional on the economy being at the steady-state at time $t = 0$, whereby the deviations of all state variables from their corresponding deterministic steady-states are zero.

of the regulatory LTV ratio, ϕ. Note that these exercises do not take into account the transitional effects on welfare of changing ϕ from its initial value of 0.91; rather, we are comparing the stochastic steady-states implied by different values for ϕ. A change in the steady-state LTV ratio has both first-order (i.e. deterministic steady-state) and second-order (i.e. shift factor due to future shock variances) effects on the economy. As shown in the first row of Figure 5, higher levels of ϕ are associated with higher levels of output and household debt at the deterministic steady-state. The latter increases faster than the former, implying higher levels of the debt-to-income ratio, as we increase ϕ.[36] Notice however that the economy also becomes more volatile as we increase ϕ, since the financial accelerator effects become larger as the borrowing constraint becomes looser.

The first-order effects are positive for patient households, but these effects are dominated by the adverse second-order effects. Patient households would indeed prefer higher levels of steady-state LTV if the economy was not subject to stochastic shocks; i.e., an economy with no volatility and no amplification through the financial accelerator. They would enjoy slightly higher levels of consumption and housing as ϕ increases in that case. However, in the presence of shocks, higher levels of LTV induce more volatility, which prompts the patient households to increase precautionary savings and labor supply, and slightly lower consumption and housing expenditures. The end result is a slight reduction in patient households' welfare as ϕ gets higher; in particular, an economy with $\phi = 1$ is associated with a 0.0025 percent lower $LTCE$ for patient households relative to an economy with $\phi = 0$.

On the other hand, impatient households are not as averse to the economy becoming more volatile as a result of higher levels of ϕ, since they stand to gain from the increased credit supply that results from the precautionary savings of patient households. As a result, they strictly prefer higher levels of steady-state LTV, which generates higher consumption and housing for them. An economy with $\phi = 1$ is associated with about a 0.035 percent higher $LTCE$ for impatient households relative to an economy with $\phi = 0$. Overall, there is a tradeoff between the welfare of the two types of agents. The social welfare measure based on the weighted average of patient and impatient households' welfare implies that the optimal regulatory LTV ratio is around 0.66, significantly lower than its calibrated value of 0.91. Note, however, that lowering LTV from 0.91 to 0.66 would generate a larger $LTCE$ decline for impatient households than the $LTCE$ gain for patient households.

Figure 6 repeats the same exercise for different values of the mortgage interest deduction parameter, I_m. The results are qualitatively similar to the regulatory LTV case, whereby higher mortgage interest deductibility leads to higher levels of debt and output at the deterministic steady-state, but this comes at the expense of generating higher output and inflation volatility in the presence of shocks. As before, patient households would prefer higher levels of steady-state I_m if the economy was not subject to stochastic shocks, but the adverse second-order effects are sizable enough that they prefer lower values for I_m. Borrowers on the other hand, prefer higher levels of mortgage interest deductibility as they gain from the positive effect of mortgage interest deductibility on their

[36]Note that household debt is not equal to 0 when $\phi = 0$, since impatient households can buy housing using their wage income and then borrow against their housing equity.

after-tax income as well as the slightly higher levels of precautionary savings of patient households. Nevertheless, the social welfare measure indicates that eliminating the mortgage interest deduction would result in a higher level of overall welfare.[37]

5.2 Countercyclical monetary policy

In this section, we consider the welfare implications of countercyclical monetary policy vis-a-vis household debt, also referred to as *leaning against the wind*. We implement this by augmenting the Taylor rule with a new term that makes the policy rate directly respond to the growth rate in household debt, d_t/d_{t-1}, with a long-term response coefficient a_d; thus, the augmented Taylor rule is given by

$$\log R_t = \rho \log R_{t-1} + (1-\rho)\left(\log R + a_\pi \log \frac{\pi_t}{\pi} + a_y \log \frac{y_t}{y} + a_d \log \frac{d_t}{d_{t-1}}\right) + \widetilde{\varepsilon}_{r,t}. \qquad (40)$$

Note that this policy change does not have first-order effects on welfare, since the deterministic steady-state of the model remains the same as before, but it does alter the volatility of the economy under stochastic shocks. Results in Figure 7 lend only weak support to monetary leaning against household debt. In particular, while the variance of household debt decreases with countercyclical policy, the resulting changes in interest rates also lead to an increase in the volatility of output and inflation above a threshold level of leaning, leading to a decline in overall welfare. The optimal leaning coefficient is positive for impatient households (around $a_d = 0.92$) since their consumption and housing purchases are more correlated with debt, but this effect is not large enough to reverse the pattern for the social welfare measure. The optimal monetary leaning given the social welfare criterion is found to be $a_d = 0.1$.[38]

6 Conclusion

In this paper, we build a DSGE model with housing and household debt, and consider the effectiveness of monetary policy, housing-related fiscal policy, and macroprudential regulations in reducing household indebtedness. Unlike the majority of the literature, our model features long-term FRMs, and differentiates between the flow and the stock of household debt. Given our benchmark parameters, we do not find evidence that monetary policy has perverse effects on the stock of household debt. Given that the response of output to monetary policy is stronger however, there is deterioration in the household debt-to-income ratio despite monetary tightening. We also find that reducing the tax deductibility of mortgage interest and tightening regulatory LTV would be more effective

[37] We also conducted a similar exercise for the property tax rate, τ_p, for which the optimal value which maximizes social welfare is 0. The intuition for this result is very similar to that for the mortgage interest deduction, in the sense that the property tax policy also severely hurts borrowers. In the case of property taxes, saver households' welfare is also reduced.

[38] Also note that, if we condition the Augmented Taylor rule on the household debt gap rather than debt growth, the resulting optimal leaning coefficient is 0.

and less costly in reducing household debt, relative to an increase in property taxes or monetary tightening. Based on welfare calculations, we find the socially optimal regulatory LTV to be around 66%, while we do not find support for mortgage interest deductions or systematic leaning against household imbalances through monetary policy.

In future work, we plan to extend our framework to include non-mortgage borrowing in order to obtain a more complete picture of the effects of monetary and other policies on household debt. The model can also be extended to make the refinancing and the home equity extraction rates endogenous with respect to changes in monetary policy. Future work could also feature endogenous occurrence of financial crises, and incorporate some of the underlying reasons as to why elevated levels of household debt may pose financial stability risks in this regard. These would allow for a richer analysis of optimal policy in general, and with respect to the role played by financial stability considerations in setting monetary policy.

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Table 1: Scope of different policies for addressing household indebtedness

Policies (from more to less targeted)	*Direct effect on*
Regulatory LTV	new regular mortgages (excluding home equity loans)
Mortgage interest deduction	all outstanding mortgages (including home equity loans)
Property taxes	all homeowners (including those with full equity in house)
Monetary policy	both housing and non-housing sectors

Table 2. Calibrated structural parameters

	Symbol	Value
Inflation target (gross, qtr.)	π	1.005
Discount factor	β_P, β_I	0.9926, 0.9877
Level for housing and labor in utility	ξ_h, ξ_n	1.077, 4.259
LTV ratio on new regular mortgages	ϕ	0.91
Home equity withdrawal rate (qtr.)	γ	0.0172
Interest rate adjustability of mortgages	Φ	0.0475
Amortization rate on HH loans	κ	0.0186
Share of capital in production	α	0.224
Share of patient HH in labor income	ψ	0.383
Depreciation rates	δ_h, δ_k	0.0105, 0.0176
Gross markup in price and wage	θ_p, θ_w	1.25, 1.5
Fixed costs in production	f	0.35
Utilization cost level	κ_u	0.03
Transfers	Ξ	0.024
Tax rates - labor income	τ_n	0.23
- capital income	τ_k	0.41
- property (qtr.)	τ_p	0.0035

Table 3. Model steady-state ratios versus data targets

	Symbol	Model	Data target
Total consumption / GDP	c/y	0.625	0.625
share of patient households	c_P/c	0.45	
share of impatient households	c_I/c	0.55	
Residential investment / GDP	i_h/y	0.045	0.045
share of patient households	i_{hP}/i_h	0.44	
share of impatient households	i_{hI}/i_h	0.56	
Non-residential investment / GDP	i_k/y	0.13	0.13
Government expenditure / GDP	g/y	0.20	0.20
Tax revenue / GDP	tax/y	0.224	
Transfers / GDP	tr/y	0.024	
Wage share in non-housing income	$1-\alpha$	0.776	
share of patient households	ψ	0.383	
share of impatient households	$1-\psi$	0.617	
Capital stock / GDP (qtr)	k/y	7.4	7.4
Housing stock / GDP (qtr)	h/y	4.28	4.28
share of patient households	h_P/h	0.44	0.44
share of impatient households	h_I/h	0.56	0.56
Mortgage debt / total housing value	d/h	0.37	0.37
average LTV on all outstanding loans	d/h_I	0.66	0.66
LTV on new regular loans	ϕ	0.91	0.91

Table 4. Estimated structural parameters						
			Posterior dist.			
	Symbol	Prior dist.	Mode	Mean	5%	95%
Habit in consumption	ζ	B(0.95,0.025)	0.8722	0.8736	0.8451	0.9053
Inverse labor supply elasticity	ϑ	G(5,2)	2.5617	3.0654	1.0886	4.8732
Utilization cost elasticity	ϖ^{est}	B(0.5,0.2)	0.1437	0.1509	0.0265	0.2709
Stock adj. cost - capital	κ_k	U(0,20)	12.9696	10.7274	3.4667	19.7339
- housing	κ_h	U(0,20)	0.6775	0.7170	0.5106	0.9114
Investment adj. cost - capital	κ_{ik}	U(0,20)	2.8637	4.9351	1.2775	8.6276
- housing	κ_{ih}	U(0,20)	1.6948	2.5329	1.2225	4.0126
Adj. cost - price	κ_p^{est}	B(0.5,0.2)	0.8759	0.8840	0.8479	0.9214
- wage	κ_w^{est}	B(0.5,0.2)	0.7892	0.8093	0.7544	0.8695
Indexation - price	ς_p	B(0.5,0.2)	0.0864	0.1710	0.0153	0.3351
- wage	ς_w	B(0.5,0.2)	0.3257	0.3639	0.0838	0.6307
Response of transfers to gov. debt	ϱ_b	G(0.01,0.005)	0.0084	0.0124	0.0073	0.0181
Taylor rule - persistence	ρ	B(0.5,0.2)	0.7287	0.7382	0.6843	0.7893
- inflation	a_π	G(1.5,0.2)	1.3947	1.4181	1.1800	1.6509
- output	a_y	G(0.125,0.005)	0.1265	0.1266	0.1180	0.1346

Prior distributions: B: beta, G: gamma, U: uniform, IG: inverse gamma.

Table 5. Estimated shock parameters

	Symbol	Prior dist.	Posterior dist.			
			Mode	Mean	5%	95%
Persistence - preference	ρ_v	B(0.5,0.2)	0.2145	0.2453	0.0781	0.3947
- housing exuberance	ρ_χ	B(0.5,0.2)	0.8554	0.8600	0.8166	0.9051
- productivity	ρ_z	B(0.5,0.2)	0.7988	0.7995	0.7388	0.8638
- investment (k)	ρ_{zk}	B(0.5,0.2)	0.2637	0.2227	0.0541	0.3887
- investment (h)	ρ_{zh}	B(0.5,0.2)	0.9716	0.9331	0.8653	0.9909
- price markup	ρ_p	B(0.5,0.2)	0.6854	0.5979	0.4063	0.7975
- wage markup	ρ_w	B(0.5,0.2)	0.1115	0.1400	0.0371	0.2376
- monetary policy	ρ_r	B(0.5,0.2)	0.4637	0.4587	0.3424	0.5737
- government exp.	ρ_g	B(0.5,0.2)	0.8966	0.8893	0.8163	0.9597
- loans	ρ_l	B(0.5,0.2)	0.8441	0.8373	0.7461	0.9288
St. dev. - preference	σ_v	IG(0.005,∞)	0.0443	0.0473	0.0362	0.0576
- housing exuberance	σ_χ	IG(0.005,∞)	0.0023	0.0024	0.0018	0.0031
- productivity	σ_z	IG(0.005,∞)	0.0043	0.0044	0.0038	0.0049
- investment (k)	σ_{zk}	IG(0.005,∞)	0.1299	0.1987	0.0643	0.3355
- investment (h)	σ_{zh}	IG(0.005,∞)	0.0116	0.0154	0.0096	0.0226
- price markup	σ_p	IG(0.005,∞)	0.0331	0.0527	0.0174	0.0878
- wage markup	σ_w	IG(0.005,∞)	0.5012	0.6784	0.2618	1.0558
- monetary policy	σ_r	IG(0.005,∞)	0.0012	0.0012	0.0010	0.0014
- government exp.	σ_g	IG(0.005,∞)	0.0115	0.0117	0.0103	0.0130
- loans	σ_l	IG(0.005,∞)	0.0046	0.0047	0.0041	0.0052

Prior distributions: B: beta, G: gamma, U: uniform, IG: inverse gamma.

Table 6: Model Comparison

Specification	*Marginal Likelihood*	*Bayes factor versus Baseline Model*
Baseline (long-term FRMs)	3433.5	
ARMs ($\Phi = 1$)	3428.5	-5
One-period debt ($\kappa = 1$)	3298.8	-134.7

Note: This table shows the logarithm of the marginal likelihood for the baseline model, and two alternative models with ARMs and one-period debt. The last column shows the log Bayes factor, which is the log marginal likelihood relative to the baseline model, where negative values indicate poorer fit relative to the baseline model.

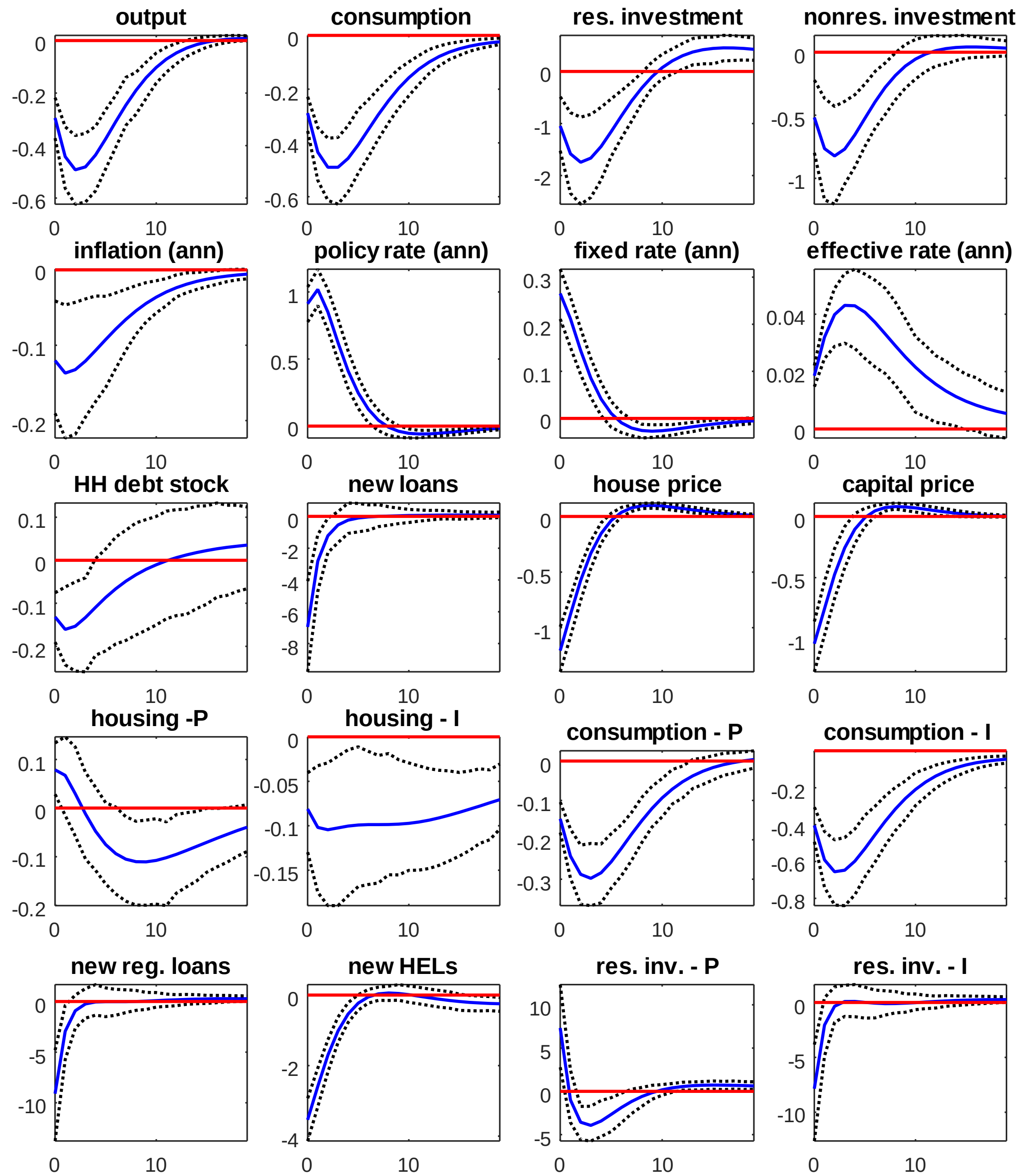

Figure 1: Impulse responses (in percent) to a 1 percentage point (annualized) innovation in the Taylor rule. The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations. The impulse responses plotted as solid blue lines reflect the posterior mean estimates of the parameters, while the dotted black lines denote the 90% probability bands.

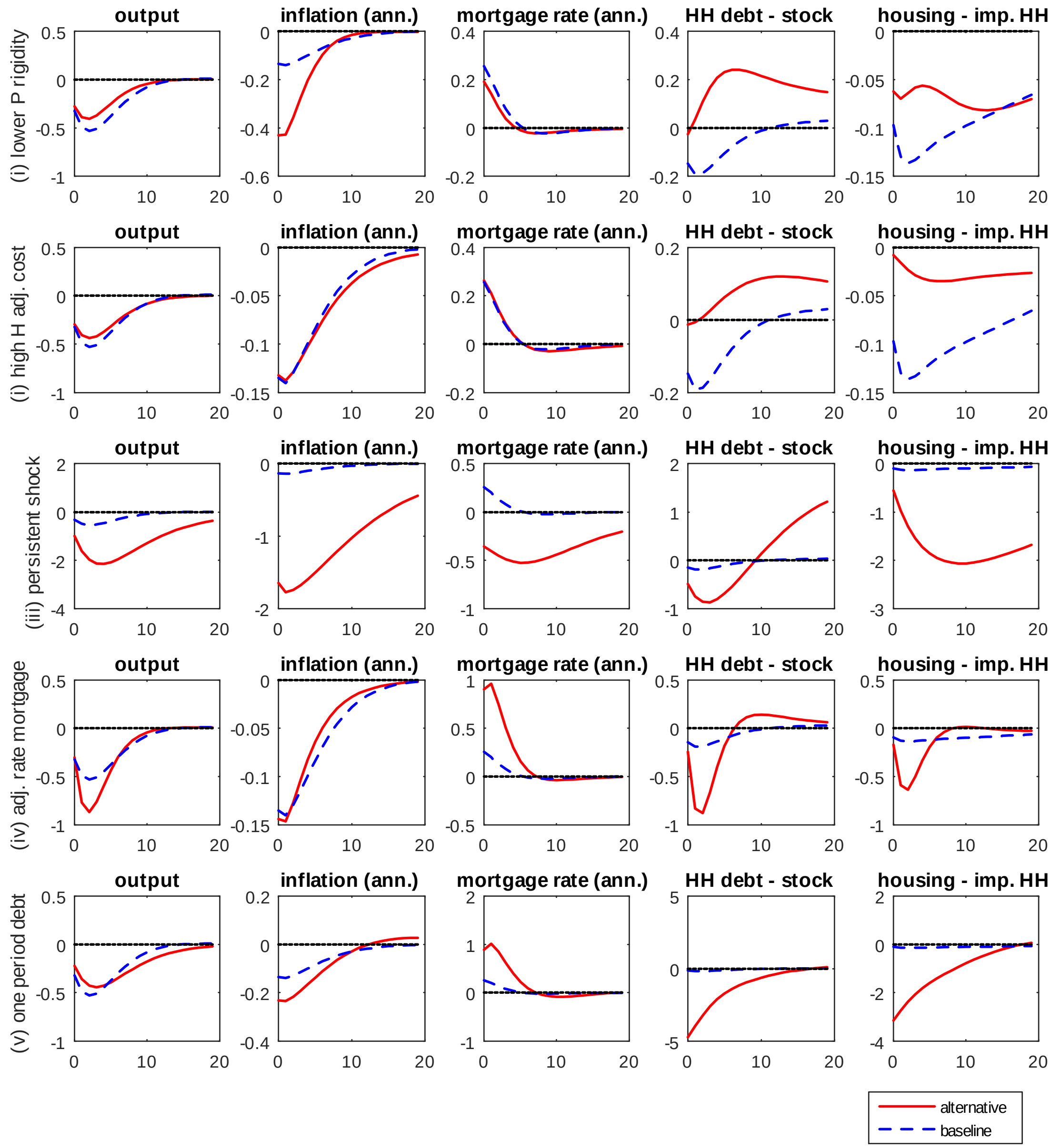

Figure 2: The effects of monetary policy under alternative parameterizations. In the first three rows, only one parameter is altered relative to the baseline estimation, while the last two rows correspond to results from re-estimated models with alternative features. In order, the rows plot results under (i) higher housing adjustment costs (i.e., $\kappa_h = 50$), (ii) more persistent monetary policy shocks, (i.e., $\rho_r = 0.9$), (iii) adjustable-rate mortgages (re-estimated model with $\Phi = 1$), (iv) one-period debt (re-estimated model with $\kappa = 1$and $\gamma = \phi = 0.66$).

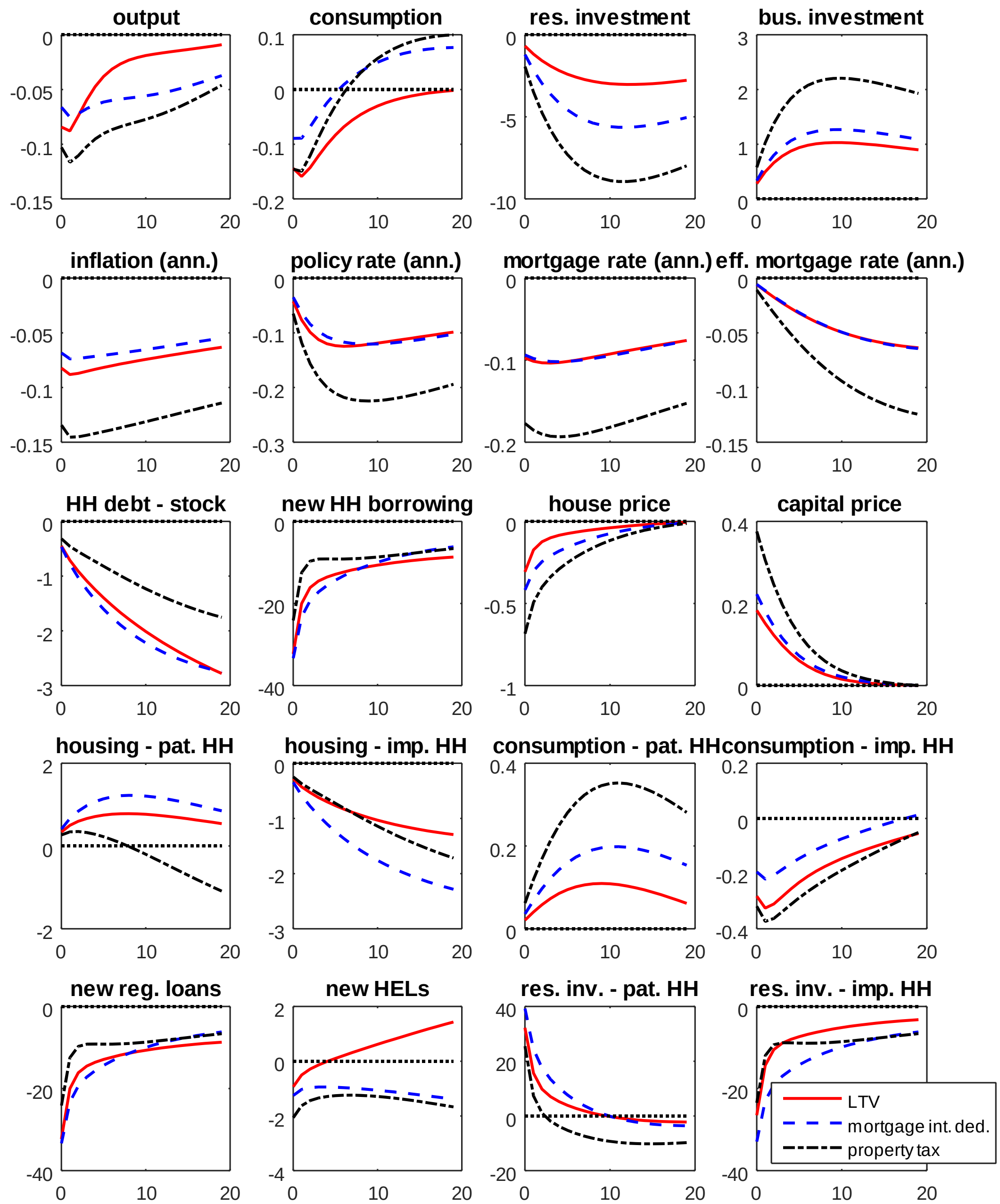

Figure 3: The short-term effects (in percent) of permanent changes in LTV and housing-related fiscal policy normalized to generate the same reduction in real debt from initial to terminal steady state. The policy changes are (i) 0.06 pp increase in the quarterly property tax rate (i.e., τ_p increases from 0.0035 to 0.0042), (ii) 26.5 percent decline in the tax deductibility of mortgage interest (i.e., I_m is reduced from 1 to 0.735), and (iii) 5 pp tightening in regulatory LTV (i.e., ϕ decreases from 0.91 to 0.86),

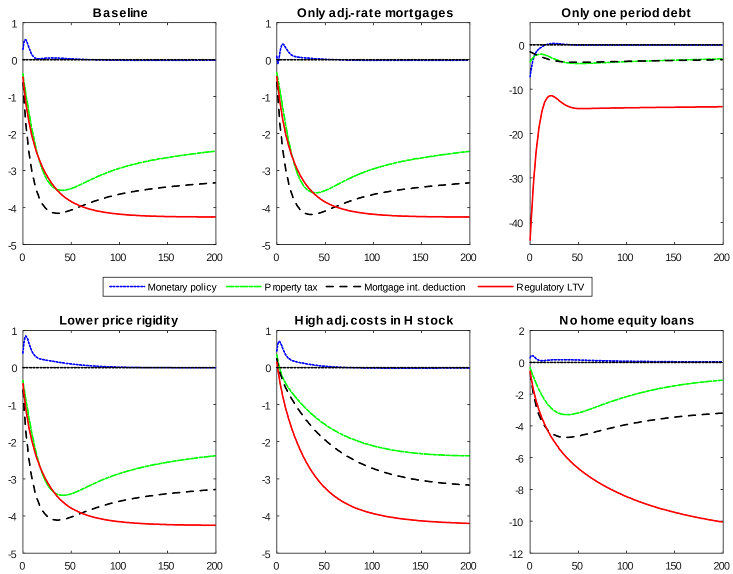

Figure 4: Comparing the effects of the four policies on household debt-to-GDP ratio. The y-axis is in percent deviation from steady state. In the top row, the three panels are obtained from re-estimations of the model with alternative specifications, while in the bottom row, the results are obtained using the parameters from the baseline estimation except for one parameter.

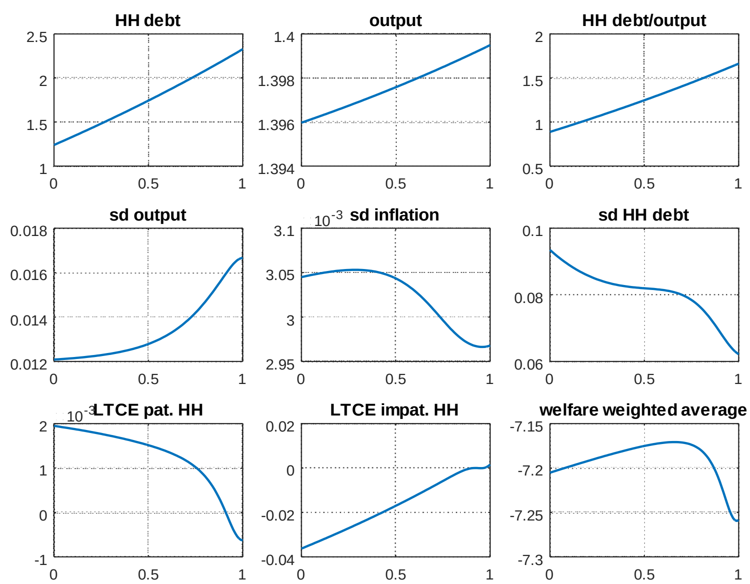

Figure 5: Model moments and welfare measures for different values for the regulatory LTV ratio, ϕ. The first row shows level changes, the second row shows standard deviations and the last row shows the welfare results, where the LTCE results are relative to the baseline calibration for the two types of agents.

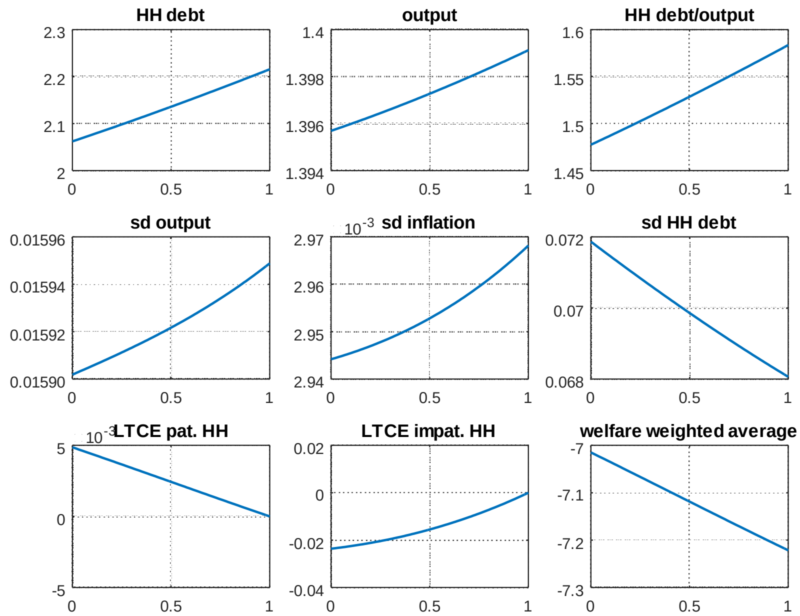

Figure 6: Model moments and welfare measures for different values for the tax deductibility of mortgage interest, I_m. The first row shows level changes, the second row shows standard deviations and the last row shows the welfare results, where the LTCE results are relative to the baseline calibration for the two types of agents.

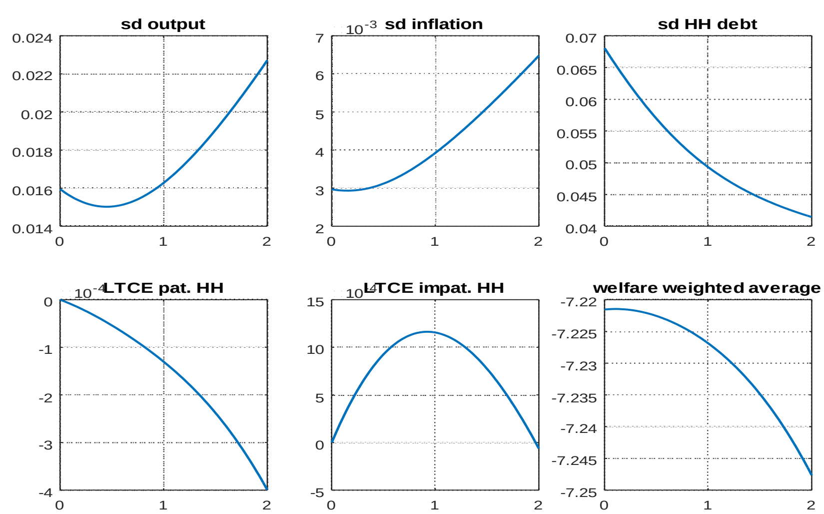

Figure 7: Welfare measures for different values of the response coefficient in the Augmented Taylor rule, a_d. The first row shows standard deviations and the second row shows the welfare results, where the LTCE results are relative to the baseline calibration for the two types of agents.

A Equilibrium conditions of the model

A.1 Patient households

The patient households' objective is to maximize utility subject to their budget constraint and the appropriate No-Ponzi conditions. The first-order condition with respect to consumption equates the marginal utility gain from consumption to the Lagrange multiplier on the period budget constraint, $\lambda_{P,t}$. The optimality condition for housing is discussed in the main text. The optimality condition for capital equates the marginal cost of purchasing a unit of capital to the expected marginal gain in rental income and capital gains net of taxes, which can be written as (ignoring adjustment costs in the stock of capital)

$$q_{k,t} = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \left[\left(1-\delta_k\right) q_{k,t+1} + \left(1-\tau_k\right) r_{k,t+1} + \tau_k \delta_k \right] \right]. \tag{41}$$

The optimality conditions with respect to labor and wages can be combined to derive a New-Keynesian wage Phillips curve (after log-linearization):

$$\widehat{\pi}_{wP,t} - \varsigma_w \widehat{\pi}_{t-1} = \beta_P E_t \left[\widehat{\pi}_{wP,t+1} - \varsigma_w \widehat{\pi}_t \right] - \frac{\left(\eta_n - 1\right)\left(1-\tau_n\right)}{\kappa_w} \left(\widehat{w}_{P,t} - \widehat{MRS}_{P,t} - \widehat{\theta}_{w,t} \right), \tag{42}$$

where the nominal wage inflation, $\widehat{\pi}_{wP,t}$, and the real wage rate, $\widehat{w}_{P,t}$, for patient households are related as

$$\widehat{\pi}_{wP,t} - \widehat{\pi}_t = \widehat{w}_{P,t} - \widehat{w}_{P,t-1}. \tag{43}$$

Since households are wage-setters in the labor market, wages are marked up relative to the marginal rate of substitution (MRS) between leisure and consumption, where $MRS_{P,t} = -U_{n,t}/U_{c,t}$. Wage stickiness, along with exogenous markup shocks, provides variation in the wedge between wages and MRS with a long-run correction to the steady-state markup.

The first-order condition for government bonds equates the marginal utility cost of forgone consumption from saving to the expected discounted utility gain from the resulting interest income:

$$1 = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{1+R_t}{\pi_{t+1}} \right]. \tag{44}$$

The first-order conditions for new mortgage lending is given by

$$1 = \Omega_{dP,t} + \Omega_{rP,t} R_t^F, \tag{45}$$

where $\Omega_{dP,t}$ denotes the Lagrange multiplier with respect to the law of motion for mortgage debt, and $\Omega_{rP,t}$ denotes the Lagrange multiplier on the law of motion for the effective interest rate on mortgages. Both of these Lagrange multipliers are specified relative to the Lagrange multiplier on the budget constraint. The above condition equates the marginal loss from a unit of forgone consumption to the benefits of adding to the stock of mortgage lending at a fixed interest rate of R_t^F. In turn, the Euler conditions for the stock of mortgage debt and the effective mortgage interest rate are given by

$$\Omega_{dP,t} + \Omega_{rP,t} R_t^M = E_t \left[\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \frac{R_t^M + \kappa + (1-\kappa) \left\{ \Omega_{dP,t+1} + \Omega_{rP,t+1} \left[(1-\Phi) R_t^M + \Phi R_{t+1}^F \right] \right\}}{\pi_{t+1}} \right], \tag{46}$$

and

$$\Omega_{rP,t} = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{1 + (1-\Phi)(1-\kappa) \Omega_{rP,t+1}}{\pi_{t+1}} \right], \tag{47}$$

respectively.

Note that when $\Phi = 1$, the Euler condition for the stock of debt in (46) reduces to

$$1 = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{1 + R_t^M}{\pi_{t+1}} \right], \tag{48}$$

where we have used the first-order condition with respect to new loans given in equation (45), and the fact that $R_t^M = R_t^F$ when $\Phi = 1$. Thus, coupled with the Euler condition for government debt given in equation (44), we have $R_t^M = R_t^F = R_t$ for all t when $\Phi = 1$. The same result can be obtained when mortgage debt is fully amortized each period (i.e., one-period debt with $\kappa = 1$).

A.2 Impatient households

The first-order conditions of impatient households with respect to their consumption and labor are similar to those of patient households, and the optimality condition for housing is discussed in the main text. The optimality condition for new borrowing is given by

$$1 - \mu_t = \Omega_{dI,t} + \Omega_{rI,t} R_t^F, \tag{49}$$

where $\Omega_{dI,t}$ denotes the Lagrange multiplier with respect to the law of motion of mortgage debt, and $\Omega_{rI,t}$ denotes the Lagrange multiplier on the law of motion of the effective mortgage interest rate. The above condition equates the marginal gain from borrowing (excluding the shadow cost of tightening the borrowing constraint) to the marginal cost of adding to the stock of mortgage debt at a fixed interest rate of R_t^F. In turn, the Euler conditions for the stock of mortgage debt and the effective mortgage interest rate are given by

$$\Omega_{dI,t} + \Omega_{rI,t} R_t^M = E_t \left(\beta_I \frac{\lambda_{I,t+1}}{\lambda_{I,t}} \right) \tag{50}$$

$$\left[\frac{(1 - I_{m,t+1} \tau_n) R_t^M + \kappa + \gamma (1-\kappa) \mu_{t+1} + (1-\kappa) \left\{ \Omega_{dI,t+1} + \Omega_{rI,t+1} \left[(1-\Phi) R_t^M + \Phi R_{t+1}^F \right] \right\}}{\pi_{t+1}} \right],$$

and

$$\Omega_{rI,t} = E_t \left[\left(\beta_I \frac{\lambda_{I,t+1}}{\lambda_{I,t}} \right) \frac{1 - I_{m,t+1}\tau_n + (1-\Phi)(1-\kappa)\,\Omega_{rI,t+1}}{\pi_{t+1}} \right], \tag{51}$$

respectively.

Note that with full amortization of mortgage loans each period (i.e., $\kappa = 1$), the Euler condition for the stock of debt reduces to

$$1 - \mu_t = E_t \left[\left(\beta_I \frac{\lambda_{I,t+1}}{\lambda_{I,t}} \right) \frac{1 + (1 - I_{m,t+1}\tau_n)\,R_t}{\pi_{t+1}} \right], \tag{52}$$

similar to the standard model with one-period debt. Similarly, with only ARMs (i.e., $\Phi = 1$), the Euler condition for the stock of debt becomes

$$1 - \mu_t = E_t \left[\left(\beta_I \frac{\lambda_{I,t+1}}{\lambda_{I,t}} \right) \frac{1 + (1 - I_{m,t+1}\tau_n)\,R_t^M - (1-\kappa)\,\mu_{t+1}(1-\gamma)}{\pi_{t+1}} \right], \tag{53}$$

where the last term on the right-hand side of the expression appears, since the borrowing constraint is specified on the flow, and not on the stock, of debt. Therefore, an increase in debt this period leads to a tightening of the borrowing constraint next period as well. With full amortization, the stock and flow of debt are equivalent, hence this last term would disappear.

B Details on the Bayesian Estimation

B.1 Data Sources

All data were obtained from the FRED database of the Federal Reserve Bank of St. Louis, except for the early part of the house price series, which is from the Census Bureau. GDP and its expenditure components were deflated using the GDP deflator. For labor hours, we use the index series *Nonfarm Business Sector: Hours of All Persons*, and for real wage we use the index series *Nonfarm Business Sector: Real Compensation per Hour*, constructed by the Bureau of Labor Statistics. The policy rate refers to the Federal Funds rate, and was converted from monthly to quarterly by averaging. For the house price series, we use the *S&P/Case-Shiller National Composite Home Price Index*, but extend the early part of the series between 1984Q1-1986Q4 using the *Price Index of New Single-Family Houses Sold Including Lot Value* from the Census Bureau. The nominal house price index was also deflated using the GDP deflator. Household debt data refer to *Home Mortgages* on the liability side of the balance sheet of *Households and Nonprofit Organizations*, which was deflated as well. The inflation and interest rates were demeaned prior to estimation, while the other series were HP-filtered (which was conducted including pre-1984 and post-2007 data to reduce concerns related to endpoints with HP-filtering).[39]

[39] Our main results regarding the effects of monetary policy on household debt, as well as the relative effectiveness of the four policies we consider, are robust to filtering the data through first-differencing instead.

B.2 Calibrated parameters

We only estimate the parameters that primarily affect the dynamics of the model, while calibrating the parameters that determine the steady state. The latter parameters are restricted within the estimation (i.e., recalibrated with each iteration), to ensure that the implied steady state of the model matches with pre-specified data target ratios from the National Income and Product Accounts (NIPA; Bureau of Economic Analysis), Flow of Funds Accounts (FOF; Federal Reserve Board), the 2001 Residential Finance Survey (RFS; Census Bureau), and the 2011 American Housing Survey (AHS; Census Bureau).

The trend inflation factor, π, is set to 1.005, corresponding to 2% annual inflation. The time-discount factor of patient households, β_P, is set to 0.993 to match an annualized 3% real risk-free interest rate. The time-discount factor of the impatient households, β_I, is set to 0.988, which implies a 200 bps spread on the risk-free rate if borrowers were allowed to engage in non-mortgage borrowing.[40] The level parameter for housing in the utility function, ξ_h, is calibrated to ensure that the value of housing relative to annual GDP is 1.07, consistent with FOF data. The level parameter for labor supply, ξ_n, is calibrated to ensure that the labor supply of patient households is equal to 1 at the steady state without loss of generality.

In the data, residential and non-residential investments are about 4.5% and 13% of output, respectively, while housing-to-GDP and capital-to-GDP ratios are 1.07 and 1.85 on an annualized basis.[41] Based on these, we calibrate the quarterly depreciation rates for housing and capital stocks, δ_h and δ_k, to 1.05% and 1.76%, respectively. The share of capital in domestic production, α, is calibrated to 0.224 using the capital-output ratio and the model-implied after-tax rental rate of capital. The steady-state (gross) markups in prices and wages, θ_p and θ_w, are set to 1.25 and 1.5, similar to Smets and Wouters (2007).[42] The fixed cost of production, f, is set equal to $\theta_p - 1$ times the steady-state level of output to ensure that pure economic profits are zero at the steady state, thus eliminating the incentive for entry and exit in the long run of the stochastic economy. Similarly, the level parameter for the utilization cost specification, κ_u, is calibrated to ensure that the utilization rate is equal to 1 at the steady state without loss of generality.

The steady-state LTV ratio on new regular mortgages, ϕ, the home equity withdrawal rate parameter, γ, the amortization rate for mortgage loans, κ, and the refinancing parameter, Φ, are discussed in the main text. Based on FOF data, the ratio of mortgage debt owed by all households

[40] Given γ is close to 0 and shocks are small, the borrowing constraint in the model is always binding as long as $(1-\tau_n)\left(\frac{\pi}{\beta_P}-1\right) < \frac{\pi}{\beta_I}-1$. So we could in fact assume that borrowers have the same discount factor as patient households, or even a higher discount factor, as long as we rule out the ability of patient households to borrow and deduct mortgage interest.

[41] The capital stock reflects the tangible asset holdings of non-financial corporations, non-corporate businesses, and households minus the real estate and consumer durable holdings of households, using FOF data.

[42] Smets and Wouters (2007) actually estimate the gross markup on prices, θ_p. The identification for this parameter comes only from our assumption that the fixed cost in production is equal to the net markup at the steady state; thus, this parameter shows up in the log-linearized version of the production function. We choose to set this parameter prior to estimation, instead of forcing identification in this way. Our main results are not altered if instead we estimate this parameter.

relative to their real estate holdings, d/h, is around 0.37. Given that the LTV ratio is 0.66 for the average borrower household, we can infer that borrower households own about 56% of the total housing stock. We therefore calibrate the wage (and transfers) share of patient households, ψ, to 0.38, to hit this target. Steady-state government expenditure is calibrated to ensure that its share in output, g/y, is 20%. The labor income tax rate, τ_n, is set to 0.23, and the capital income tax rate, τ_k, is set to 0.41, following Zubairy (2014). The (quarterly) property tax rate, τ_p, is set to 0.0035, which implies an annual property tax rate of 1.4%, following Alpanda and Zubairy (2016). The level parameter for transfers, Ξ, is then calibrated as a residual to satisfy the government budget constraint (with zero government debt) at the steady state.

B.3 Prior distributions

We estimate a rescaled version of the price and wage adjustment cost parameters, κ_p and κ_w, to constrain the estimates within the unit interval, and make the estimates more comparable to the literature using Calvo (1983) type price and wage setting. In particular, we estimate κ_p^{est} and κ_w^{est}, where

$$\kappa_p = \frac{\left[10\left(\theta_p - 1\right) + 1\right]\kappa_p^{est}}{\left(1 - \kappa_p^{est}\right)\left(1 - \beta_P \kappa_p^{est}\right)}, \text{ and } \kappa_w = \frac{\left[10\left(\theta_w - 1\right) + 1\right]\kappa_w^{est}}{\left(1 - \kappa_w^{est}\right)\left(1 - \beta_P \kappa_w^{est}\right)}. \tag{54}$$

At the mean of their prior distributions (i.e., 0.5), these are analogous to assuming 2-quarter price and wage stickiness in the Calvo setting, along with more curvature in the *Kimball* aggregator functions used in Smets and Wouters (2007), instead of the standard Dixit-Stiglitz functional forms we use here. The utilization cost elasticity parameter is also rescaled as $\varpi = \varpi^{est}/(1 - \varpi^{est})$, to constrain its estimate within the unit interval.

For the parameters with a unit support, we use beta priors with mean 0.5 and standard deviation 0.2. These parameters are the utilization cost elasticity parameter, ϖ^{est}, price and wage adjustment cost parameters, κ_p^{est} and κ_w^{est}, indexation parameters, ς_p and ς_w, the Taylor rule smoothing parameter, ρ, and the shock persistence parameters. For the habit parameter, ζ, we use a more informative beta prior with mean 0.95 and standard deviation 0.025 to ensure that the estimation yields impulse responses with a significant degree of consumption persistence, in line with the related DSGE literature and VAR evidence.

For parameters with positive support (but not necessarily constrained within the unit interval), we mainly use gamma priors. In particular, for the labor supply elasticity parameter, ϑ, we use a gamma prior with mean 5 and standard deviation 2. For the Taylor rule response coefficient on inflation, a_π, we also use a gamma prior with mean 1.5 and standard deviation of 0.2, while the output gap response coefficient, a_y, has a gamma prior with mean 0.125 and standard deviation 0.05. For the parameter determining the responsiveness of transfers to government debt, ϱ_b, we use a gamma prior with mean 0.01 and standard deviation of 0.005, where the low mean value is intended to ensure that government debt does not play a major role in determining dynamics while preserving the determinacy of the model.

Since we do not have strong prior beliefs on the capital and housing stock adjustment cost parameters, κ_k and κ_h, and the investment adjustment cost parameters, κ_{ik} and κ_{ih}, we use uniform priors bounded by 0 and 20 for these parameters. Finally, for the shock standard deviations, we use inverse-gamma priors with 0.5% mean and infinite variance, as in Smets and Wouters (2007).