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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. The model features long-term fixed-rate borrowing and lending across two types of households, and differentiates between the flow and the stock of household debt. We use Bayesian methods to estimate parameters related to model dynamics, while level parameters are calibrated to match key ratios in the U.S. data. We find that monetary tightening is able to reduce the stock of real mortgage debt, but leads to an increase in the household debt-to-income ratio. 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. 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.

JEL classification: E52, E62, R38
Bank classification: Housing; Transmission of monetary policy; Financial system regulation and policies; Economic models

Résumé

Dans cette étude, les auteurs construisent un modèle d'équilibre général dynamique et stochastique intégrant le logement et la dette des ménages, et comparent l'efficacité de diverses mesures (politique monétaire, fiscalité relative au logement et réglementation macroprudentielle) pour réduire l'endettement des ménages. Le modèle incorpore les emprunts et les prêts à taux fixe à long terme se rapportant à deux types de ménages, et établit une distinction entre les flux de crédit et l'encours de la dette. Les auteurs utilisent des méthodes bayésiennes pour estimer les paramètres liés à la dynamique du modèle, et les paramètres de niveau sont calibrés de manière à ce qu'ils correspondent aux ratios clés calculés à partir de données sur l'économie américaine. Ils constatent que le resserrement de la politique monétaire peut induire une baisse de l'encours de la dette hypothécaire réelle, mais entraîner une augmentation du ratio de la dette au revenu des ménages. Parmi les mesures prises en considération, la réduction de la déduction fiscale au titre des intérêts hypothécaires et la diminution du rapport prêt-valeur réglementaire sont les plus efficaces et les moins coûteuses pour faire baisser la dette des ménages, devant l'impôt foncier et le resserrement monétaire. Bien que la réduction de la déduction au titre des intérêts hypothécaires ait une plus grande portée que la diminution du rapport prêt-valeur réglementaire et puisse par conséquent causer des pertes de production plus importantes, il s'agit d'une mesure efficace pour abaisser la dette hypothécaire totale, car elle atteint également les prêts sur la valeur nette d'une maison.

Classification JEL : E52, E62, R38
Classification de la Banque : Logement; Transmission de la politique monétaire; Réglementation et politiques relatives au système financier; Modèles économiques

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.

Preventing 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]

For policy-makers, it is important to assess the effectiveness of these policies in reducing household debt, and evaluate their side effects on macroeconomic variables such as output and inflation. This is what we set out to do in this paper using a dynamic stochastic general-equilibrium (DSGE) model with housing and household debt. 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, regulatory LTV generally applies to regular mortgages on new home purchases, rather than loans based on withdrawals of existing home equity. Thus, such tools may not be effective in reducing 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 they only have a direct effect on the housing sector, but they 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 of the new policy. Thus, mortgage interest deduction may potentially have a greater adverse impact on the economy, but it can also be more effective in terms of limiting home equity loans.[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]

[1] In the United States, 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, 2013).

[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.

[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 refinancings, which are 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)

Note that all four above-noted 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 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 types of effects in real terms. In particular, consider the following law of motion for household debt (also featured in our model in section 2):

$$D_t = (1 - \kappa) D_{t-1} + L_t, \tag{1}$$

where κ is the amortization rate for existing debt, and D_t and L_t are the stock and flow of nominal household debt, respectively. Dividing through by the price level, P_t, the above law of motion can be written as

$$d_t = (1 - \kappa) \frac{d_{t-1}}{\pi_t} + l_t, \tag{2}$$

where π_t is the inflation rate, 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.[5] 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.

In this paper, we build a DSGE model with housing and household debt, and consider the effectiveness of the four policies listed in Table 1 in reducing household indebtedness, paying special attention to the effects of monetary policy in light of Svensson's criticism.[6] Our model features borrowing and lending across two

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 monetary policy, which cannot be applied in a more targeted manner.

[5] 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.

[6] We do not try to model the underlying reasons as to why elevated levels of household debt may pose financial stability risks. Our focus is rather in analyzing the effectiveness of each policy tool in reducing household debt (in terms of output loss per unit decrease in the debt level). How the level of household debt would then be related to financial risks (such as affecting the frequency or magnitude of financial crises) is not explicitly modelled. Thus, given our set-up, it may not be optimal to try to reduce the level of household debt in the first place. Nevertheless, our current set-up captures an important macroeconomic

types of households, as in Iacoviello (2005), but mortgage loans are amortized over the long term, similar to Kydland et al. (2012) and Garriga et al. (2013), 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, and new mortgage loans are modelled as fixed rate. Nevertheless, 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 new mortgage loans in the real world are adjustable-rate, and some fixed-rate mortgages are refinanced before the end of their amortization period.[7] 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. This feature is 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.[8] The rest of the model features are standard. We endogenize the supply of housing by considering residential investment producers who face investment adjustment costs as in Justiniano et al. (2013). Following Christiano et al. (2005) and Smets and Wouters (2007), the model features nominal frictions in the form of price and wage stickiness and indexation, as well as real frictions such as habit formation and capital utilization costs. We estimate parameters determining model dynamics using Bayesian likelihood methods and U.S. data, while matching the steady-state relationships in the model to their data counterparts through calibration of level parameters.

Using the model, we first analyze the effects of monetary policy on household debt. Given our benchmark parameters, 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 is even perverse) when it comes to households' mortgage debt, which remains an area of major financial stability concern in many countries.

We conduct several sensitivity analyses on key parameters to investigate the importance of model features in generating our baseline results on monetary policy. In particular, reducing the duration of the interest rate on mortgage loans (equivalent to reducing the refinancing rate or the share of adjustable rate mortgages) limits the ability of monetary policy to reduce the level of real mortgage debt. Conversely, the effects of monetary policy on real household debt strengthen when the mortgage rate adjusts faster, since the pass-through from the policy rate to the mortgage rate faced by borrowers is larger. Reduction in home equity withdrawals does not seem to generate a large change in the effects of monetary policy, although this significantly increases the relative effectiveness of regulatory LTV. Other key factors determining the response of household debt to monetary policy are the slope of the New Keynesian Phillips curve and adjustment costs in housing. A steeper New Keynesian Phillips curve results in a larger decline in inflation, π_t, and hence, a smaller decline

trade-off; in particular, the externality due to the fact that house prices affect the borrowing constraint of all borrowers may lead to overborrowing and this may lead to higher volatility in output (Bianchi and Mendoza, 2010). We do not explore the optimal policy implications of this externality.

[7] 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 adjustable-rate mortgages (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). Also, about 37 percent of all outstanding mortgages are refinancing of a previous mortgage loan, and most refinancings are undertaken to reduce interest payments.

[8] 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 refinancings) are about 7 percent of existing home equity on an annual basis.

(or even an increase) in real household debt, d_t, with monetary policy tightening (see equation (2)). Similarly, larger adjustment costs in the housing stock result in smaller declines in new mortgage lending, l_t, reducing the impact of monetary tightening on household debt.

In section 4.2, we compare the effectiveness of fiscal and macroprudential tools in reducing household debt relative to monetary policy. 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 in the previous paragraphs. 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 its direct impact on home equity loans.

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), Justiniano et al. (2013), Gelain et al. (2013), Rubio and Carrasco-Gallego (2013), and Iacoviello (forthcoming). Our paper differs from the above mainly by featuring long-term debt in our model; hence, LTV policy applies only to new loans and not to the whole stock of mortgage debt. Note that the effects of regulatory LTV may potentially be exaggerated if applied to all outstanding mortgages, especially in the short run.[9]

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.[10]

Third, Kydland et al. (2012) and Garriga et al. (2013) analyze the effects of fixed-rate mortgages for business cycles and the transmission of monetary policy in a general-equilibrium setting. Our set-up is most similar to these papers, although there are several important differences. In our paper, we also allow savers to accumulate housing similar to Iacoviello (2005), which is more consistent with the data, since a substantial proportion of homeowners have full equity in their houses. We also differentiate between the duration of the loan itself and the duration of the interest rate on the loan; this helps us capture the effects of adjustable-

[9] LTV policy may also affect existing loans if agents fully exploit the increase in home equity and withdraw to the regulatory LTV limit each quarter. Data in Greenspan and Kennedy (2005, 2007) imply that although home equity withdrawal activity is important, it is far less than the regulatory LTV ratio. Aggregate data also reveal that the average LTV on new mortgage loans is around 0.91, while the average LTV on all existing mortgages is around 0.66 (see section 3 on parameterization of the model). Thus, in aggregate, borrowers have built up equity over time and have not fully withdrawn equity up to the LTV limit each period.

[10] In the Appendix, we also run VARs with our data while identifying shocks through recursive short-term restrictions. Our VAR analysis suggests that innovations in the monetary policy shock lead to a decline, not an increase, in the stock of real mortgage debt, consistent with our DSGE model. Note, however, that the VARs imply a larger decline in household debt, leading to a decrease in the household debt-to-income ratio as well. This is in contrast to our findings from the DSGE model.

rate mortgages and refinancing of existing loans. We also 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. Our focus is also different than the aforementioned papers; in particular, we focus on the impact of monetary policy on household debt, while their focus is on business cycle dynamics. In addition, we consider the effects of alternative policy tools such as fiscal and macroprudential policies in our paper, and estimate model parameters related to dynamics, rather than calibrate them.[11] Gelain et al. (2014), in simultaneous but independently developed work, also use the long-term debt structure introduced in Kydland et al. (2012) to analyze the effects of monetary policy on household debt. Our paper differs from theirs in several respects as well. They use a borrowing constraint that depends on the stock of housing similar to the original Iacoviello (2005) set-up, whereas we impose the borrowing constraint on the flow, not the stock, of household debt. As argued before, in the data, increases in home equity do not translate into new loans in the same proportion as the LTV ratio on new loans. Thus, using a binding borrowing constraint for the stock of debt in our set-up would generate stronger responses from regulatory LTV policy as it would apply to all existing loans as well as new mortgages. Gelain et al. (2014) focus on Norway, and their model features only adjustable-rate mortgages with a long amortization period, while we concentrate on the U.S. economy and take into account the effects of fixed-rate mortgages. Furthermore, we estimate our model parameters related to dynamics instead of calibrating them, as well as consider the effects of alternative policies to monetary policy, while their focus is on the role of irrational expectations in driving house price booms and household debt.

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 results, and section 5 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 mortgages, differentiate between the flow and the stock of household debt, and impose the borrowing constraint on the flow of household debt instead of on the stock, following Kydland et al. (2012) and Garriga et al. (2013). We extend their set-up in several directions: (i) the interest rate on mortgages can be adjusted more frequently than the full amortization of the loan, thus capturing the effects of adjustable-rate mortgages and refinancing in the data; (ii) new mortgage loans finance not only the residential investment of borrowers, but also their consumption expenditures through home equity withdrawals; and (iii) the model features housing-related taxation (i.e., mortgage interest deduction and property taxation), as in Alpanda and Zubairy (2013), and LTV regulation alongside monetary policy.

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

On the production side, goods producers rent capital and labor services to produce an output good that can be used for consumption, non-residential and residential investment, and government purchases. There is wage stickiness in the labor market, and price stickiness in the goods market. The model also features investment-goods producers to generate fluctuations in the relative price of assets, as well as monetary, fiscal and macroprudential policies in the form of rules. In what follows, we analyze the agents in the model in blocks.

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:

$$E_t \sum_{\tau=t}^{\infty} \beta_P^{\tau-t} \upsilon_\tau \left[\log \left[c_{P,\tau}(i) - \zeta c_{P,\tau-1} \right] + \xi_{h,\tau} \log h_{P,\tau}(i) - \xi_n \frac{n_{P,\tau}(i)^{1+\vartheta}}{1+\vartheta} \right], \tag{3}$$

where t indexes time, $\beta_P < 1$ is the time-discount parameter, ζ is the external habit parameter for consumption, and ϑ is the inverse of the Frisch-elasticity of labor supply. $\xi_{h,t}$ and ξ_n determine the relative importance of housing and labor in the utility function, and the former, which can be interpreted as a housing preference shock, is specified as an exogenous AR(1) process:

$$\log \xi_{h,t} = (1-\rho_h) \log \xi_h + \rho_h \log \xi_{h,t-1} + \varepsilon_{h,t}. \tag{4}$$

The preference shock, υ_t, also follows an AR(1) process as

$$\log \upsilon_t = \rho_\upsilon \log \upsilon_{t-1} + \varepsilon_{\upsilon,t}. \tag{5}$$

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

$$n_{P,t}(i) = \left(\frac{W_{P,t}(i)}{W_{P,t}} \right)^{-\eta_{n,t}} n_{P,t}, \tag{6}$$

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

$$\log \theta_{w,t} = (1-\rho_w) \log \theta_w + \rho_w \log \theta_{w,t-1} + \varepsilon_{w,t}, \tag{7}$$

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

The patient households' period budget constraint is given by

$$
\begin{aligned}
& c_{P,t}(i) + q_{h,t}\widetilde{i}_{hP,t}(i) + q_{k,t}\widetilde{i}_{k,t}(i) + \frac{B_t(i)}{P_t} + \frac{L_t(i)}{P_t} \\
& \quad \leq (1-\tau_n)\frac{W_{P,t}(i)}{P_t} n_{P,t}(i) + (1-\tau_k) r_{k,t} k_{t-1}(i) + \tau_k \delta_k k_{t-1}(i) + (1+R_{t-1})\frac{B_{t-1}(i)}{P_t} + \frac{M_t(i)}{P_t} \\
& \quad \quad + tr_{P,t} + \frac{\Pi_t}{P_t} - \tau_{p,t}(1-\tau_n) q_{h,t} h_{P,t-1}(i) - \text{adj. costs},
\end{aligned} \tag{8}
$$

where $q_{h,t}$ and $q_{k,t}$ are the relative prices of housing and capital, respectively, and $\widetilde{i}_{hP,t}$ and $\widetilde{i}_{k,t}$ denote the patient households' new investment in these real assets. The laws of motion for patient households' housing and capital stock holdings, $h_{P,t}$ and k_t, are given by

$$
h_{P,t}(i) = (1-\delta_h) h_{P,t-1}(i) + \widetilde{i}_{hP,t}(i), \tag{9}
$$

$$
k_t(i) = (1-\delta_k) k_{t-1}(i) + \widetilde{i}_{k,t}(i), \tag{10}
$$

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 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

$$
\frac{M_t(i)}{P_t} = \left[R^M_{t-1}(i) + \kappa\right]\frac{D_{t-1}(i)}{P_t}, \tag{11}
$$

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. κ denotes the amortization rate for determining the principal payments out of the stock of mortgage debt; hence, the law of motion for the stock of debt is given by

$$
\frac{D_t(i)}{P_t} = (1-\kappa)\frac{D_{t-1}(i)}{P_t} + \frac{L_t(i)}{P_t}. \tag{12}
$$

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

$$
R^M_t(i) = (1-\Phi)\left(1 - \frac{L_t(i)}{D_t(i)}\right) R^M_{t-1}(i) + \left[\frac{L_t(i)}{D_t(i)} + \Phi\left(1 - \frac{L_t(i)}{D_t(i)}\right)\right] R^F_t. \tag{13}
$$

Note that when $\Phi = 1$, all mortgages are refinanced every period, and the above expression, coupled with the law of motion of debt in (12), implies that the effective mortgage rate is identical to the current mortgage rate at all times (i.e., $R^M_t = R^F_t$). As we show later, $\Phi = 1$ also implies (using the Euler condition for short-term government debt) that the current mortgage rate, R_t^F, is equal to the policy rate, R_t, for all t as well. Therefore, as Φ approaches 1, the model gets closer to an economy with only adjustable-rate mortgages, while when Φ is 0, the model features only fixed-rate mortgages whose rates are fixed for the whole amortization duration of the loan. Note also that if we have one-period debt (i.e., $\kappa = 1$), equation (12) 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 again be equal to the interest on government bonds, R_t.[12]

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

$$\frac{\kappa_w}{2}\left(\frac{W_{P,t}(i)/W_{P,t-1}(i)}{\pi_{t-1}^{\varsigma_w}\pi^{1-\varsigma_w}}-1\right)^2 \frac{W_{P,t}}{P_t} n_{P,t}, \tag{14}$$

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.[13] 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.

Optimality conditions 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 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)

$$q_{h,t} = \xi_{h,t}\frac{c_{P,t}-\zeta c_{P,t-1}}{h_{P,t}} + E_t\left[\left(\beta_P\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\right)\left[1-\delta_h-\tau_{p,t+1}(1-\tau_n)\right]q_{h,t+1}\right]. \tag{15}$$

Similar to housing, 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)

$$q_{k,t} = E_t\left[\left(\beta_P\frac{\lambda_{P,t+1}}{\lambda_{P,t}}\right)\left[(1-\delta_k)q_{k,t+1}+(1-\tau_k)r_{k,t+1}+\tau_k\delta_k\right]\right]. \tag{16}$$

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

$$\widehat{\pi}_{wP,t}-\varsigma_w\widehat{\pi}_{t-1} = \beta_P E_t\left[\widehat{\pi}_{wP,t+1}-\varsigma_w\widehat{\pi}_t\right] - \frac{(\eta_n-1)(1-\tau_n)}{\kappa_w}\left(\widehat{w}_{P,t}-\widehat{MRS}_{P,t}-\widehat{\theta}_{w,t}\right), \tag{17}$$

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

$$\widehat{\pi}_{wP,t}-\widehat{\pi}_t = \widehat{w}_{P,t}-\widehat{w}_{P,t-1}. \tag{18}$$

[12] 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.

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

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:

$$1 = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{1 + R_t}{\pi_{t+1}} \right]. \tag{19}$$

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

$$1 = \Omega_{dP,t} + \Omega_{rP,t} R_t^F, \tag{20}$$

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

$$\Omega_{dP,t} + \Omega_{rP,t} R_t^M = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{R_t^M + \kappa + (1-\kappa) \left\{ \Omega_{dP,t+1} + \Omega_{rP,t+1} \left[(1-\Phi) R_t^M + \Phi R_{t+1}^F \right] \right\}}{\pi_{t+1}} \right], \tag{21}$$

and

$$\Omega_{rP,t} = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{1 + (1-\Phi)(1-\kappa) \Omega_{rP,t+1}}{\pi_{t+1}} \right], \tag{22}$$

respectively.

Note that when $\Phi = 1$, the Euler condition for the stock of debt in (21) reduces to

$$1 = E_t \left[\left(\beta_P \frac{\lambda_{P,t+1}}{\lambda_{P,t}} \right) \frac{1 + R_t^M}{\pi_{t+1}} \right], \tag{23}$$

where we have used the first-order condition with respect to new loans given in equation (20), 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 (19), 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 $\kappa = 1$).

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 less than patient households, 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

$$n_{I,t}(i) = \left(\frac{W_{I,t}(i)}{W_{I,t}}\right)^{-\eta_{n,t}} n_{I,t}, \tag{24}$$

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

$$\begin{aligned} c_{I,t}(i) + q_{h,t}\widetilde{i}_{hI,t}(i) + \frac{M_t(i)}{P_t} &\leq (1-\tau_n)\frac{W_{I,t}(i)}{P_t} n_{I,t}(i) \\ &+ \frac{L_t(i)}{P_t} + tr_{I,t} - \tau_{p,t}(1-\tau_n) q_{h,t} h_{I,t-1}(i) + I_{m,t}\tau_n R_{t-1}^M(i)\frac{D_{t-1}(i)}{P_t} - \text{adj. costs}, \end{aligned} \tag{25}$$

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 indicator 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 (11), (12), and (13), respectively. The law of motion for impatient households' housing stock, $h_{I,t}$, is given by

$$h_{I,t}(i) = (1-\delta_h) h_{I,t-1}(i) + \widetilde{i}_{hI,t}(i). \tag{26}$$

Impatient households' new borrowing in period t is given by

$$\frac{L_t(i)}{P_t} = \phi_t q_{h,t}\widetilde{i}_{hI,t}(i) + \gamma\left[q_{h,t}(1-\delta_h) h_{I,t-1}(i) - (1-\kappa)\frac{D_{t-1}(i)}{P_t}\right] + \widetilde{\varepsilon}_{l,t}, \tag{27}$$

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

$$\frac{D_t(i)}{P_t} = \phi q_{h,t} h_{I,t}(i). \tag{28}$$

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.[14]

Optimality conditions The first-order conditions of impatient households with respect to their consumption and labor are similar to those of patient households. For housing, the optimality condition equates the marginal cost of acquiring a unit of housing with the marginal utility and expected net-of-tax capital gains

[14] 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 underestimating the effects of regulatory LTV in our specification by ruling out any effect of LTV policy on home equity withdrawal.

(ignoring adjustment costs in stock of housing):

$$(1-\mu_t\phi_t)\,q_{h,t}=\xi_{h,t}\frac{c_{I,t}-\zeta c_{I,t-1}}{h_{I,t}}+E_t\left[\left(\beta_I\frac{\lambda_{I,t+1}}{\lambda_{I,t}}\right)\left[(1-\delta_h)\left[1-\mu_{t+1}\left(\phi_{t+1}-\gamma\right)\right]-\tau_{p,t+1}\left(1-\tau_n\right)\right]q_{h,t+1}\right], \tag{29}$$

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.

The optimality condition for new borrowing is given by

$$1-\mu_t=\Omega_{dI,t}+\Omega_{rI,t}R_t^F, \tag{30}$$

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

$$\begin{aligned}&\Omega_{dI,t}+\Omega_{rI,t}R_t^M \qquad (31)\\&=E_t\left[\left(\beta_I\frac{\lambda_{I,t+1}}{\lambda_{I,t}}\right)\frac{(1-I_{m,t+1}\tau_n)\,R_t^M+\kappa+\gamma\,(1-\kappa)\,\mu_{t+1}+(1-\kappa)\left\{\Omega_{dI,t+1}+\Omega_{rI,t+1}\left[(1-\Phi)\,R_t^M+\Phi R_{t+1}^F\right]\right\}}{\pi_{t+1}}\right],\end{aligned}$$

and

$$\Omega_{rI,t}=E_t\left[\left(\beta_I\frac{\lambda_{I,t+1}}{\lambda_{I,t}}\right)\frac{1-I_{m,t+1}\tau_n+(1-\Phi)\,(1-\kappa)\,\Omega_{rI,t+1}}{\pi_{t+1}}\right], \tag{32}$$

respectively. Equations (30) and (31) are instructive in distinguishing between the effects of LTV and mortgage interest deduction on borrowers. In particular, a tightening in regulatory LTV leads to an increase in the Lagrange multiplier on the borrowing constraint, μ_t, which acts similar to an increase in the interest rate paid on marginal borrowing, R_t^F, while a reduction in mortgage interest deduction is akin to an increase in the interest paid on all borrowing, R_t^M.

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

$$1-\mu_t=E_t\left[\left(\beta_I\frac{\lambda_{I,t+1}}{\lambda_{I,t}}\right)\frac{1+(1-I_{m,t+1}\tau_n)\,R_t}{\pi_{t+1}}\right], \tag{33}$$

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

$$1-\mu_t=E_t\left[\left(\beta_I\frac{\lambda_{I,t+1}}{\lambda_{I,t}}\right)\frac{1+(1-I_{m,t+1}\tau_n)\,R_t^M-(1-\kappa)\,\mu_{t+1}\,(1-\gamma)}{\pi_{t+1}}\right], \tag{34}$$

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.

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:

$$y_t(j) = z_t [u_t(j) k_{t-1}(j)]^\alpha \left[n_{P,t}(j)^\psi n_{I,t}(j)^{1-\psi}\right]^{1-\alpha} - f, \tag{35}$$

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

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta_{y,t}} y_t, \tag{36}$$

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 $\theta_{p,t} = \eta_{y,t}/(\eta_{y,t} - 1)$,

$$\log\theta_{p,t} = (1-\rho_p)\log\theta_p + \rho_p \log\theta_{p,t-1} + \varepsilon_{p,t}, \tag{37}$$

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

$$\frac{\Pi_t(j)}{P_t} = \frac{P_t(j)}{P_t} y_t(j) - \frac{W_{P,t}}{P_t} n_{P,t}(j) - \frac{W_{I,t}}{P_t} n_{I,t}(j) - r_{k,t} k_{t-1}(j) - \frac{\kappa_u}{1+\varpi}\left[u_t(j)^{1+\varpi} - 1\right] k_{t-1}(j) - \text{adj. costs}, \tag{38}$$

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. At the optimum, the marginal product of each input is equated to their respective marginal cost. The optimality condition for capital utilization similarly equates the marginal cost of increasing utilization at the margin with the revenue gain that arises from increased production; in log-linear form this condition is given by

$$\widehat{u}_t = \frac{1}{\varpi}\widehat{r}_{k,t}. \tag{39}$$

The first-order condition for prices yields (after log-linearization) the following New Keynesian Phillips curve for domestic goods inflation:

$$\widehat{\pi}_t = \frac{\beta_P}{1+\beta_P\varsigma_p} E_t\widehat{\pi}_{t+1} + \frac{\varsigma_p}{1+\beta_P\varsigma_p}\widehat{\pi}_{t-1} + \frac{\eta_y - 1}{(1+\beta_P\varsigma_p)\,\kappa_p}\left(\widehat{w}_{P,t} + \widehat{n}_{P,t} - \frac{1}{\theta_p}\widehat{y}_t + \widehat{\theta}_{p,t}\right), \tag{40}$$

Due to market power, domestic producers set the price of their goods at a markup relative to marginal cost. The adjustment costs in price-setting, as well as exogenous markup shocks, introduce variation in these markups with a long-run adjustment to the steady-state constant markup. The nominal rigidities in price-setting imply that shocks that alter the marginal cost of production feed into domestic goods inflation slowly.

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). The investment-goods producers' objective is thus to maximize

$$E_t \sum_{\tau=t}^{\infty} \beta_P^{\tau-t} \frac{\lambda_{P,\tau}}{\lambda_{P,t}} \left[q_{k,\tau}\widetilde{i}_{k,\tau} - i_{k,t} - \frac{\kappa_{ik}}{2}\left(\frac{i_{k,\tau}}{i_{k,\tau-1}} - 1\right)^2 q_{k,\tau} z_{k,\tau} i_{k,\tau} \right], \tag{41}$$

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.

The first-order condition of capital investment producers yields an investment demand equation of non-residential investment demand, which in log-linearized form can be written as

$$\widehat{i}_{k,t} = \frac{\beta_P}{1+\beta_P} E_t\widehat{i}_{k,t+1} + \frac{1}{1+\beta_P}\widehat{i}_{k,t-1} + \frac{1}{(1+\beta_P)\,\kappa_{ik}}\left(\widehat{q}_{k,t} + \widehat{z}_{k,t}\right). \tag{42}$$

Residential investment producers are modelled 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 similar demand equation for residential investment, which in log-linearized form can be written as

$$\widehat{i}_{h,t} = \frac{\beta_P}{1+\beta_P} E_t\widehat{i}_{h,t+1} + \frac{1}{1+\beta_P}\widehat{i}_{h,t-1} + \frac{1}{(1+\beta_P)\,\kappa_{ih}}\left(\widehat{q}_{h,t} + \widehat{z}_{h,t}\right). \tag{43}$$

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:

$$\log R_t = \rho \log R_{t-1} + (1-\rho)\left(\log R + a_\pi \log \frac{\pi_t}{\pi} + a_y \log \frac{y_t}{y}\right) + \widetilde{\varepsilon}_{r,t}, \tag{44}$$

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.

The total tax revenues of the government are given by

$$tax_t = \tau_n \left(\frac{W_{P,t}}{P_t} n_{P,t} + \frac{W_{I,t}}{P_t} n_{I,t} - I_{m,t} \frac{R^M_{t-1}}{\pi_t} d_{t-1}\right) + \tau_k \left(r_{k,t} - \delta_k\right) k_{t-1} + \tau_{p,t} \left(1-\tau_n\right) q_{h,t} h_{t-1}. \tag{45}$$

Aggregate transfer payments to households are determined by

$$tr_t = \Xi y - \varrho_b \frac{B_{t-1}}{P_{t-1}}, \tag{46}$$

where Ξ is a level parameter, and ϱ_b determines the response of transfers to government debt.[15] 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

$$\frac{B_t}{P_t} = R_{t-1} \frac{B_{t-1}}{P_t} + g_t + tr_t - tax_t, \tag{47}$$

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

$$\log g_t = (1-\rho_g) \log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}. \tag{48}$$

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

$$c_t + i_t + g_t = y_t - \text{adj.costs}, \tag{49}$$

where total consumption is $c_t = c_{P,t} + c_{I,t}$, and total investment is $i_t = i_{k,t} + i_{h,t}$.

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.

[15] 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).

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 what follows, we describe the data used and the estimation methodology.

3.1 Data

In our estimation, we use 10 quarterly data series from the United States for the period 1984Q1 to 2007Q4. We start our sample from the Great Moderation period to capture the more recent monetary policy stance against inflation, and exclude the post-crisis period where 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).

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).[16]

3.2 Bayesian estimation

We estimate the parameters that mainly affect the dynamics of the model, and calibrate the parameters that determine the steady state. In particular, 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). Table 2 lists these calibrated parameter values and Table 3 reports the main ratios at the steady state of the model versus the data targets. Tables 4 and 5 list the estimated structural and shock parameters, respectively.

3.2.1 Steady-state targets and other restrictions imposed on the estimation

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-

[16] 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.

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. 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.[17] 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).[18] 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.

RFS data report that the median first mortgage loan to house purchase price ratio is 91%; we therefore set the steady-state LTV ratio on new regular mortgages, ϕ, equal to 0.91. The data of 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.[19] According to the AHS data, the average for the ratio of outstanding mortgage loans to house value (i.e., loan-to-value on all outstanding debt), d/h_I, is 0.66. Based on this data target, and the steady-state relationship

$$\frac{d}{h_I} = \frac{\phi\delta_h + \gamma\left(1-\delta_h\right)}{1-\left(1-\gamma\right)\left(1-\kappa\right)/\pi}, \tag{50}$$

we calibrate the amortization rate for mortgage loans, κ, to 0.0186.[20] This amortization rate implies that the duration of mortgage loans in the model is around 73.8 quarters (i.e., 18.5 years).[21] 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 between 1991 and 2005, implying an interest rate duration of around 7.8 years.[22] 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 adjustable-rate mortgages do not get refinanced and have a lower interest rate duration than the

[17] 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.

[18] 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 unaltered if we estimate this parameter instead.

[19] 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.

[20] The above steady-state relationship is obtained by combining the law of motion for debt (12), the law of motion of housing of impatient households (26), and the expression for new mortgage loans (27) at the steady state.

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

[22] Note that these refinancing payments include those from adjustable-rate mortgages, which at times get refinanced as a fixed-rate mortgage.

average mortgage loan.[23] In section 4, we conduct sensitivity analysis on our calibration choices for these key parameters regulating mortgages.

Based on FOF data, the ratio of mortgage debt owed by all households 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%, based on the 50-State Property Tax Comparison Study conducted by the Minnesota Taxpayers Association (2011). 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.

3.2.2 Prior distributions

Tables 4 and 5 report the prior distributions used for each estimated parameter, and corresponding posterior mean estimates (along with the 10th and 90th percentiles of the posterior 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

$$\kappa_p = \frac{\left[10\left(\theta_p - 1\right) + 1\right]\kappa_p^{est}}{\left(1-\kappa_p^{est}\right)\left(1-\beta_P\kappa_p^{est}\right)}, \text{ and } \kappa_w = \frac{\left[10\left(\theta_w - 1\right) + 1\right]\kappa_w^{est}}{\left(1-\kappa_w^{est}\right)\left(1-\beta_P\kappa_w^{est}\right)}. \tag{51}$$

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 was 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

[23] According to AHS, about 80% of all new mortgages are fixed rate and 20% are adjustable rate. For the adjustable-rate mortgages, the majority are "5/1 ARMs." Assuming that half of adjustable-rate mortgages 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 mortgage loans.

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).

3.2.3 Posterior estimates

The mode, the mean, and the 5th and 95th percentiles of the posterior distributions of the parameters are reported in Tables 4 and 5.[24] The data are quite informative about most of the parameters, and the estimates are, on the whole, standard. The habit parameter, ζ, has a posterior mean equal to 0.88. ϑ has a posterior mean of 3.19, 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 4.1 and 2.6, respectively. Similarly, the stock adjustment cost parameters, κ_k and κ_h, are estimated as 11.4 and 0.8, 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 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 0.73, 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.

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. In the second portion of the results section, we compare the effectiveness of fiscal and macroprudential tools in reducing mortgage debt relative to monetary policy.

[24] 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 26.8%.

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 10%. 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. In particular, output falls by about 51 bps at the peak, while inflation is reduced by about 13 bps (annualized).

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. The stock of real debt declines below its steady state with a peak impact of about 0.18 percent. 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.

In the next subsection, we conduct several sensitivity analyses on key parameters to investigate the importance of model features and parameterization in generating the above results related to the effects of monetary policy on household debt.[25]

4.1.1 Sensitivity analysis

First, we alter the parameter determining the duration of the mortgage interest rate, Φ. This parameter was calibrated to 0.0475 prior to estimation, implying an average duration of 7.1 years, given data on repayments due to refinancing and the share of adjustable-rate mortgages (see section 3.2 for more on this). In Figure 2, we consider a case where the mortgage rate adjusts every period; i.e., $\Phi = 1$, while the rest of the parameters are the same as before. In this case, the increase in the policy rate fully passes through 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 case. 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 effects on residential investment are 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 fixed-rate mortgages, 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 more rate adjustability implies a greater

[25] In what follows (Figures 2-9), we use the posterior mode estimates as our baseline, rather than the posterior means used here. The differences in the impulse responses using the posterior mean versus the posterior mode estimates are negligible (see Figures 1 and 2).

impact of monetary policy on household debt.[26]

Second, we consider the degree of price stickiness in the economy, which is one of the main factors determining the response of inflation to the monetary policy shock. In Figure 3, we consider a steeper Phillips curve by reducing κ_p^{est} from 0.89 in our baseline case to 0.5, reflecting an average price stickiness of 2 quarters in the Calvo set-up. This results in a significantly larger decline in inflation, π_t, due to monetary tightening, and a slightly smaller decline in output and new lending, l_t, relative to the baseline case. Given the sizable decline in inflation, real household debt now increases above its steady-state value following a monetary tightening.

Third, we increase the adjustment costs in the stock of housing, κ_h, to 50 (see Figure 4). Now, borrowers are not willing to reduce their level of new residential investment as much, since they face larger costs in changing their housing stock. The smaller decline in new mortgage lending, l_t, weakens the impact of monetary tightening on household debt. The decline in the inflation rate is comparable to the baseline case, but is enough to cause an increase in the real stock of household debt with a monetary tightening after several quarters.

Finally, we eliminate home equity loans (HELs) from the model by setting γ equal to 0 (see Figure 5). Note that, by itself, this change would also reduce the size of household debt at the steady state. We therefore recalibrate the loan duration parameter, κ, to 0.096 to preserve the same average LTV ratio for borrowers at the steady state, d/h_I, based on equation (50). In other words, we are considering an economy with the same level of aggregate household debt, but now all debts are regular mortgages subject to LTV regulations at origination and home equity loans are equal to zero. The results for monetary policy are similar to the baseline case, since the scope of monetary policy is not materially affected by this change.

4.1.2 Discussion

There are several caveats to our main results regarding the effects of monetary policy on household debt. First, the amortization rate, κ, is a constant in our set-up, but, in reality, the average amortization rate could evolve as a result of a change in monetary policy. If agents would like to keep their monthly payments constant, they may lengthen the duration of the loans as a result of monetary tightening (Dhillon et al., 1990). This would reduce the effectiveness of monetary policy in reducing mortgage debt even further. Conversely, however, agents may opt to shorten the duration of their loans to reduce their overall interest burden (Breslaw and Irvine, 1996). This would strengthen the effects of monetary policy on household debt.[27]

Second, the duration of the interest rate on mortgages is also an exogenously given constant, Φ, in our set-up. Thus, we are implicitly assuming that refinancing activity, as well as the share of adjustable-rate mortgages in new loans, does not depend on the stance of monetary policy. If we endogenize the refinancing decision, a monetary tightening would likely lead to a decrease in Φ, thereby weakening the effectiveness of monetary policy in reducing household debt. In the data, monetary policy tightening is generally associated with a slowdown in refinancing activity, although some refinancing activity remains in order to cash-out from

[26] We also did an experiment where we set Φ to 0, thus equating the duration of the fixed interest rate with the duration of the loan. In this case, the pass-through from the policy rate to the mortgage rate is slightly smaller than the benchmark, which in turn slightly weakens the response of new household borrowing to the monetary shock. The stock of real debt thus increases slightly more on impact and stays above steady state for a few quarters. The overall impact on real variables, though, is negligibly different than the baseline case.

[27] The latter case may be especially relevant for LTV policy, since agents may reduce the loan duration as they put more downpayment in the beginning. Note that this would render the effectiveness of regulatory LTV in reducing household debt even higher than the baseline case discussed in the next subsection. Conversely, an increase in property taxes or a decrease in mortgage interest deductions may prompt agents to lengthen the duration of the loans to even out their overall mortgage payment burden, therefore weakening the effects on household debt relative to the baseline case.

existing home equity as incomes fall (Chen et al., 2013).[28] On the other hand, an increase in mortgage rates may prompt borrowers to rely less on fixed-rate mortgages, leading to an increase in Φ, and strengthening the pass-through from the policy rate to the household borrowing rate.

Third, we assume that the home equity withdrawal rate, γ, is a constant as well. Monetary tightening leads to a fall in house prices, which could also lead to a slowdown in home equity withdrawal activity along with refinancings. Thus, we may be underestimating the effectiveness of monetary policy in reducing household debt by abstracting from this channel. Third, our analysis ignores non-mortgage household debt such as credit cards and car loans. These constitute about a fourth of all borrowing by households, and are far more short term and adjustable rate than mortgages. Including these features would potentially strengthen the impact of monetary tightening on household indebtedness, since the pass-through from the policy rate to the overall borrowing rates would increase.

Finally, our analysis ignores the risk-taking channel of monetary policy, and in particular that monetary policy itself may lead to exuberance in housing markets as well as increased risk taking by financial intermediaries. If this is indeed the case, then monetary tightening may also help lower household debt through its curbing impact on exuberance in housing markets and reduction in bank credit supply.

4.2 Effects of fiscal and macroprudential policies on mortgage debt

In this section, 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 near-permanent changes in these tools would affect household debt and other macroeconomic variables. In particular, we let the property tax rate, the tax deductibility of mortgage interest and regulatory LTV follow AR(1) processes as

$$\tau_{p,t} = (1 - \rho_\tau)\,\tau_p + \rho_\tau \tau_{p,t-1} + \varepsilon_{\tau,t}, \tag{52}$$

$$I_{m,t} = (1 - \rho_m)\,I_m + \rho_m I_{m,t-1} + \varepsilon_{m,t}, \tag{53}$$

and

$$\phi_t = (1 - \rho_\phi)\,\phi + \rho_\phi \phi_{t-1} + \varepsilon_{\phi,t}, \tag{54}$$

where the persistence parameters ρ_τ, ρ_m, and ρ_ϕ are set very close to unity (i.e., 0.9999), and the shocks result in near-permanent changes in these policies in the medium term.[29] In terms of normalizing the magnitude of these policy shocks, we pick the size of the fiscal shocks so that the peak response of output is equal to that from lowering regulatory LTV by 5 percentage points (pp).

[28] According to the 2011 American Housing Survey, the majority of refinancings took place in order to reduce the interest rate on the previous loan. Some refinancings shortened the amortization period of the loan as well, while our model assumes that the loan duration, κ, is a constant and does not respond to monetary policy.

[29] Of course, this also ensures that the model remains stationary and makes its computation feasible through perturbation methods. In Alpanda and Zubairy (2013), we had considered permanent changes in fiscal policies and had computed exact solutions for the transition paths. Near-permanent policy changes computed with log-linearization yielded very similar transition path results in the short run relative to those we got 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.

4.2.1 Increasing the property tax rate

In Figure 6, we plot 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 1.63 percent in annualized terms; hence, $\tau_{p,t}$ increases from 0.014/4 to 0.0163/4 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 (see their first-order conditions with respect to housing given in equations (15) and (29)), 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 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 7 plots the impulse responses of model variables to a 33 percent decline in the tax deductibility of mortgage interest (i.e., $I_{m,t}$ decreases from 1 to 0.67 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. This direct impact on impatient households is similar to an increase in the effective mortgage rate they face on their stock of borrowing (see equation (31)). 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 effects on output are 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 Figures 6 and 7). 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 8 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 (see first-order conditions of borrowers with respect to the flow of debt given in equation (30)). Note that there is an important difference between regulatory LTV and the mortgage interest deduction in this respect. The former presents a shadow cost that is equivalent to increasing the interest rate on new loans only (i.e., R_t^F), while the latter presents a real cost that is equivalent to increasing the effective interest rates on all existing loans (i.e., R_t^M). Furthermore, as a real cost, mortgage interest deductions also have direct adverse income effects for borrowers, unlike regulatory LTV, which has a direct impact only on the borrowing constraint and affects the budget constraint of borrowers only indirectly.

The effects of the LTV policy are qualitatively similar to those from mortgage interest deduction (see Figures 7 and 8), 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.

4.2.4 Comparing the effects of the four policies

In Figure 9, we show the effects of the four policies on the household debt-to-GDP ratio for a 50-year horizon in the baseline case and in the alternative cases considered for the sensitivity analysis described in section 4.1.1. In the baseline 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.

After normalizing output impact, 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 9, we are considering only a temporary shock to monetary policy (with its persistence parameter set to its estimated value in section 3), but increasing its persistence tends to make the trade-off regarding household debt per unit of output significantly worse. This is because more persistence in the interest rate leads to a relatively larger decline in inflation than the fall in new lending. 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.

The results are essentially the same, and the ranking of policies is preserved, when we constrain mortgage loans to be fully adjustable rate (i.e., $\Phi = 1$). A similar result is obtained 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 effectiveness of mortgage interest deduction is the implicit insurance across new and old borrowing in our 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 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 mortgages 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. Nevertheless, given that the response of output to monetary policy is stronger, 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 far more effective and less costly in reducing household debt, relative to an increase in property taxes or monetary tightening.

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 mortgage refinancing and home equity loans endogenous 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. These would allow for richer analyses of optimal policy in general (with or without coordination among the different tools), and of the role played by financial stability considerations in setting monetary policy.

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A Effects of monetary policy on mortgage debt: VAR analysis

In this appendix, we use VARs in order to find corroborating evidence on the effects of monetary policy on mortgage debt. Our baseline VAR includes the log of real GDP, the log of the GDP-deflator price level, the federal funds rate, the log of real mortgage debt stock of households, and the log of real house prices. We use the same data series as for the DSGE model's estimation (although, following common practice, we do not HP-filter the real variables for the VARs and leave them in their log-levels), and we use quarterly data for the same time period between 1984Q1 and 2007Q4. We identify the shocks, including the monetary policy shock, through recursive short-term restrictions, using the ordering of variables as listed above. This ordering reflects the notion that real GDP and the GDP deflator react to monetary policy with at least a quarter lag, while the change in interest rates can alter the level of household credit and house prices within the impact quarter as well. The lag length in our baseline VAR is set to 2 based on both the Akaike and Schwarz information criteria.

Figure 10 plots the impulse responses of each variable in the baseline VAR from the monetary policy shock. The monetary policy shock (which is about 50 bps at the peak) generates a peak response in the level of real output of 26 bps while the price level declines very gradually to about 30 bps, but only after eight years. Monetary policy tightening also reduces the level of real household debt by 1.4 percent at the peak after five years, and leads to a nearly 2 percent decline in house prices. Although there are differences in magnitude, the results are in line with our main finding that monetary policy tightening reduces the level of real household debt. Note, however, that the VAR predicts a stronger decline in mortgage debt relative to output, implying a decline in the debt-to-income ratio as well, in contrast to our findings in the DSGE set-up.[30]

Our baseline VAR exhibits a small and insignificant price puzzle in the first two years after the policy shock; in other words, the price level responds slightly positively at first to a monetary tightening. This may reflect the absence of variables in the VAR that capture expectations of higher inflation when monetary policy is active. An alternative explanation for the price puzzle is that the increased interest costs of borrowing firms are reflected in their marginal cost and therefore price-setting (Christiano et al., 2005). To overcome the price puzzle, we tried including an oil price index, or expected 1-year or 5-year inflation series constructed by the Federal Reserve Bank of Cleveland. None of these changes resulted in material differences from the results in the baseline case. We also tried different ordering of variables (in particular, with respect to the ordering of household debt in the VAR), excluding house prices from the VAR, starting the data sample from the 1960s, and changing the lag length of the VAR to 1 or 4. In almost all of these combinations, we found that innovations in the monetary policy shock lead to a small decline, not an increase, in the stock of real mortgage debt. The implied debt-to-income ratio typically declines in these cases as well.

[30] The baseline VAR generates reasonable (at least qualitatively) impulse responses to other shocks in the model as well. In particular, demand shocks (identified by innovations to the log GDP equation) generate an increase in output and prices, while supply shocks (identified by innovations to the GDP deflator equation) generate an increase in prices and a fall in output.

Table 1: 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	1.104, 4.367
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	τ_p	0.014/4

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)	0.8753	0.8792	0.8479	0.9111
Inverse labor supply elasticity	ϑ	G(5,2)	2.4889	3.1930	1.2496	5.2224
Utilization cost elasticity	ϖ^{est}	B(0.5,0.2)	0.1480	0.1608	0.0241	0.2828
Stock adj. cost - capital	κ_k	U(0,20)	15.1048	11.4498	4.4820	19.9932
- housing	κ_h	U(0,20)	0.7112	0.7633	0.5496	0.9825
Investment adj. cost - capital	κ_{ik}	U(0,20)	2.4287	4.0726	1.3000	6.8943
- housing	κ_{ih}	U(0,20)	1.6621	2.6494	1.1241	4.3312
Adj. cost - price	κ_p^{est}	B(0.5,0.2)	0.8710	0.8788	0.8453	0.9134
- wage	κ_w^{est}	B(0.5,0.2)	0.7830	0.8106	0.7525	0.8695
Indexation - price	ς_p	B(0.5,0.2)	0.0878	0.1958	0.0129	0.3892
- wage	ς_w	B(0.5,0.2)	0.3197	0.3609	0.0744	0.6296
Response of transfers to gov. debt	ϱ	G(0.01,0.005)	0.0083	0.0122	0.0073	0.0178
Taylor rule - persistence	ρ	B(0.5,0.2)	0.7239	0.7326	0.6758	0.7869
- inflation	a_π	G(1.5,0.2)	1.3962	1.4180	1.1688	1.6513
- output	a_y	G(0.125,0.005)	0.1264	0.1262	0.1180	0.1345

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)	0.2202	0.2563	0.0993	0.4151
- housing demand	ρ_h	B(0.5,0.2)	0.8795	0.8836	0.8368	0.9310
- productivity	ρ_z	B(0.5,0.2)	0.7969	0.7976	0.7323	0.8581
- investment (k)	ρ_{zk}	B(0.5,0.2)	0.2944	0.2392	0.0636	0.4028
- investment (h)	ρ_{zh}	B(0.5,0.2)	0.9791	0.9380	0.8679	0.9956
- price markup	ρ_p	B(0.5,0.2)	0.6802	0.5754	0.3494	0.8015
- wage markup	ρ_w	B(0.5,0.2)	0.1071	0.1364	0.0355	0.2343
- monetary policy	ρ_r	B(0.5,0.2)	0.4536	0.4490	0.3387	0.5679
- government exp.	ρ_g	B(0.5,0.2)	0.9021	0.8946	0.8240	0.9666
- loans	ρ_l	B(0.5,0.2)	0.8930	0.8765	0.8001	0.9559
St. dev. - preference	σ_v	IG(0.005,∞)	0.0470	0.0515	0.0389	0.0637
- housing demand	σ_h	IG(0.005,∞)	0.0859	0.0946	0.0650	0.1238
- productivity	σ_z	IG(0.005,∞)	0.0043	0.0043	0.0038	0.0049
- investment (k)	σ_{zk}	IG(0.005,∞)	0.1201	0.1719	0.0701	0.2723
- investment (h)	σ_{zh}	IG(0.005,∞)	0.0116	0.0163	0.0096	0.0258
- price markup	σ_p	IG(0.005,∞)	0.0312	0.0499	0.0171	0.0816
- wage markup	σ_w	IG(0.005,∞)	0.4747	0.7019	0.2558	1.1258
- 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	0.0104	0.0130
- loans	σ_l	IG(0.005,∞)	0.0047	0.0048	0.0042	0.0054

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

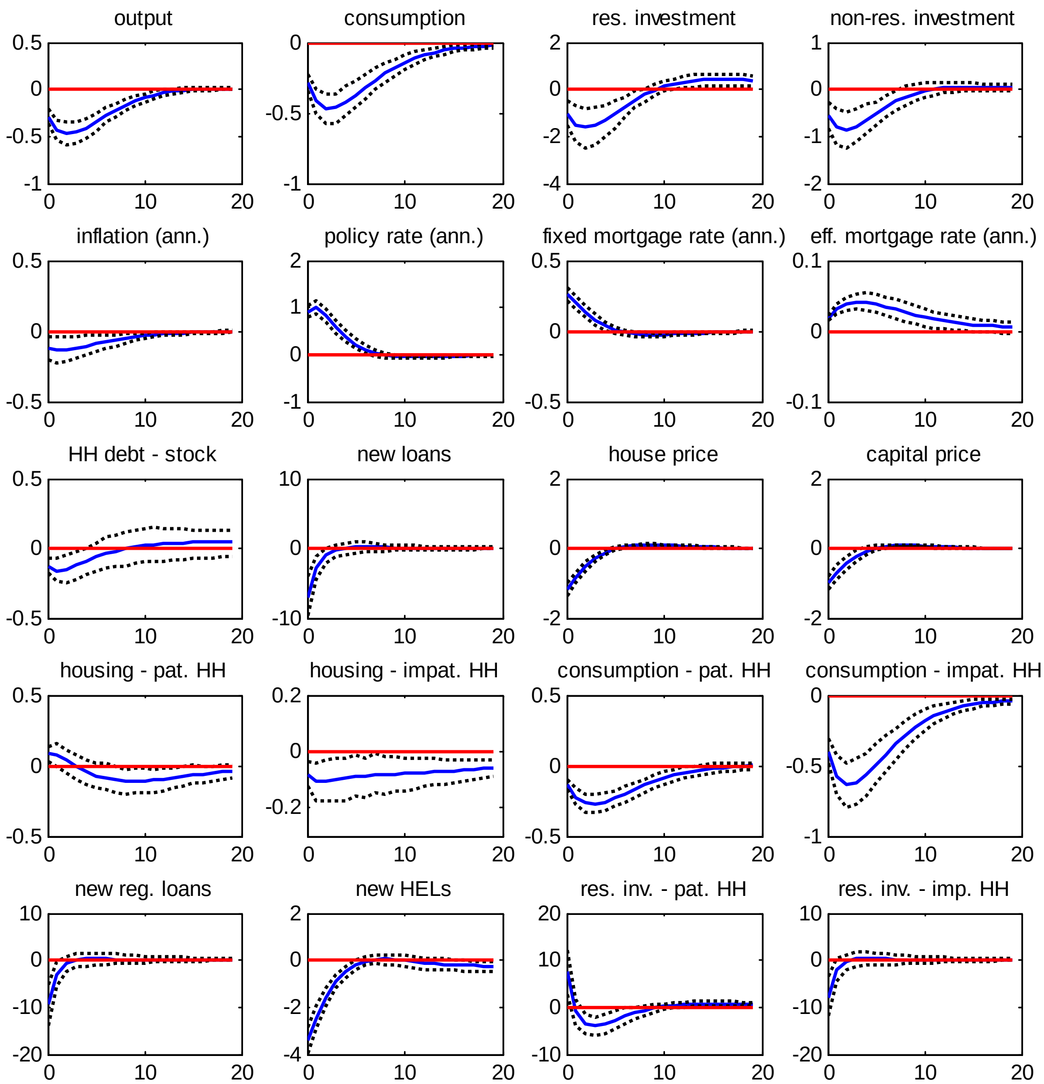

Figure 1: Impulse responses to a 100 bps (annualized) innovation in the Taylor rule. The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations. The impulse responses plotted as solid blue lines reflect the posterior mean estimates of the parameters, while the dotted black lines denote the 90th percentile confidence intervals for the impulse responses.

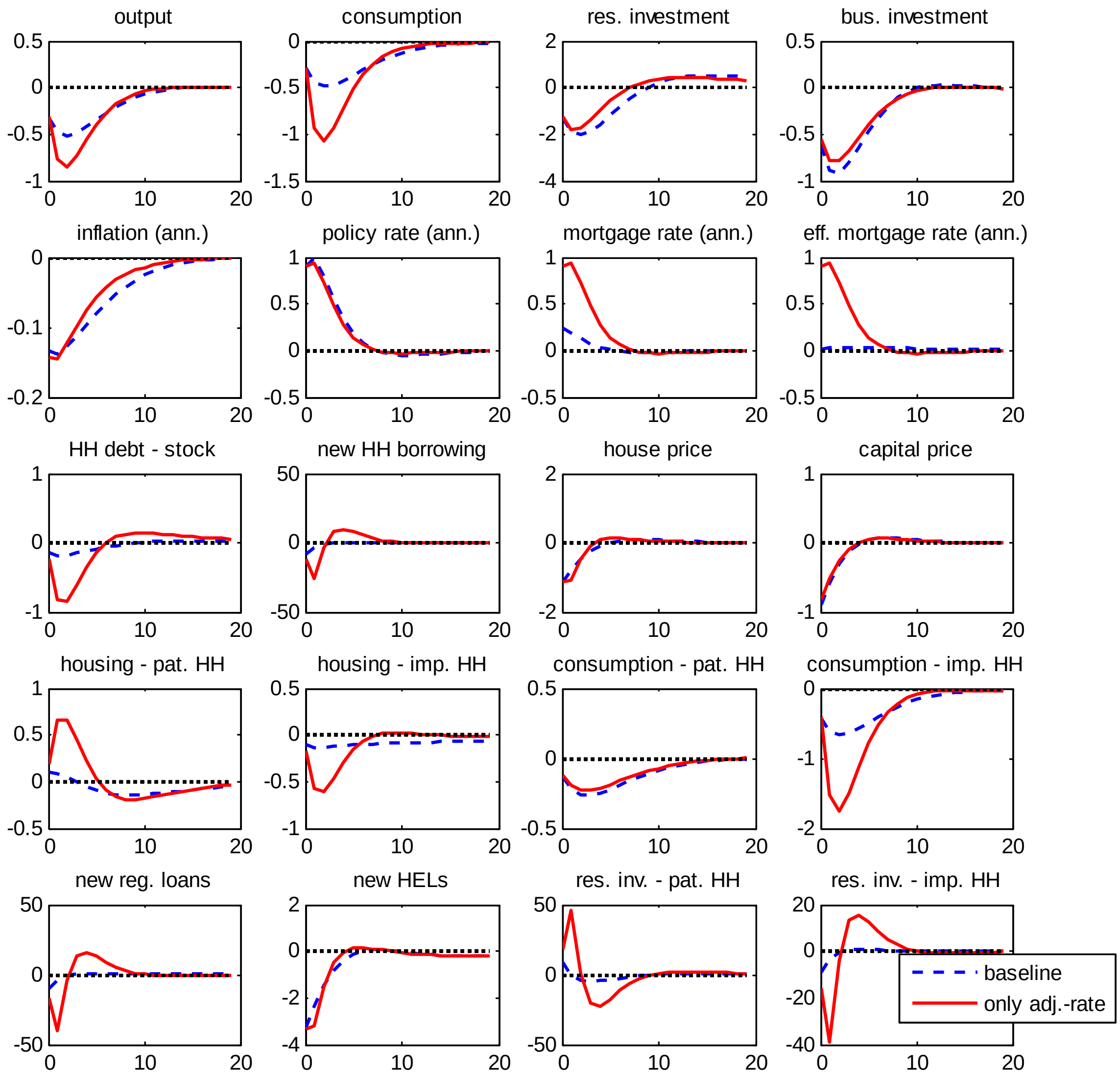

Figure 2: Comparing impulse responses to a 100 bps (annualized) innovation in the monetary policy shock in the baseline case versus a case with only adjustable-rate mortgages (i.e., $\Phi = 1$). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

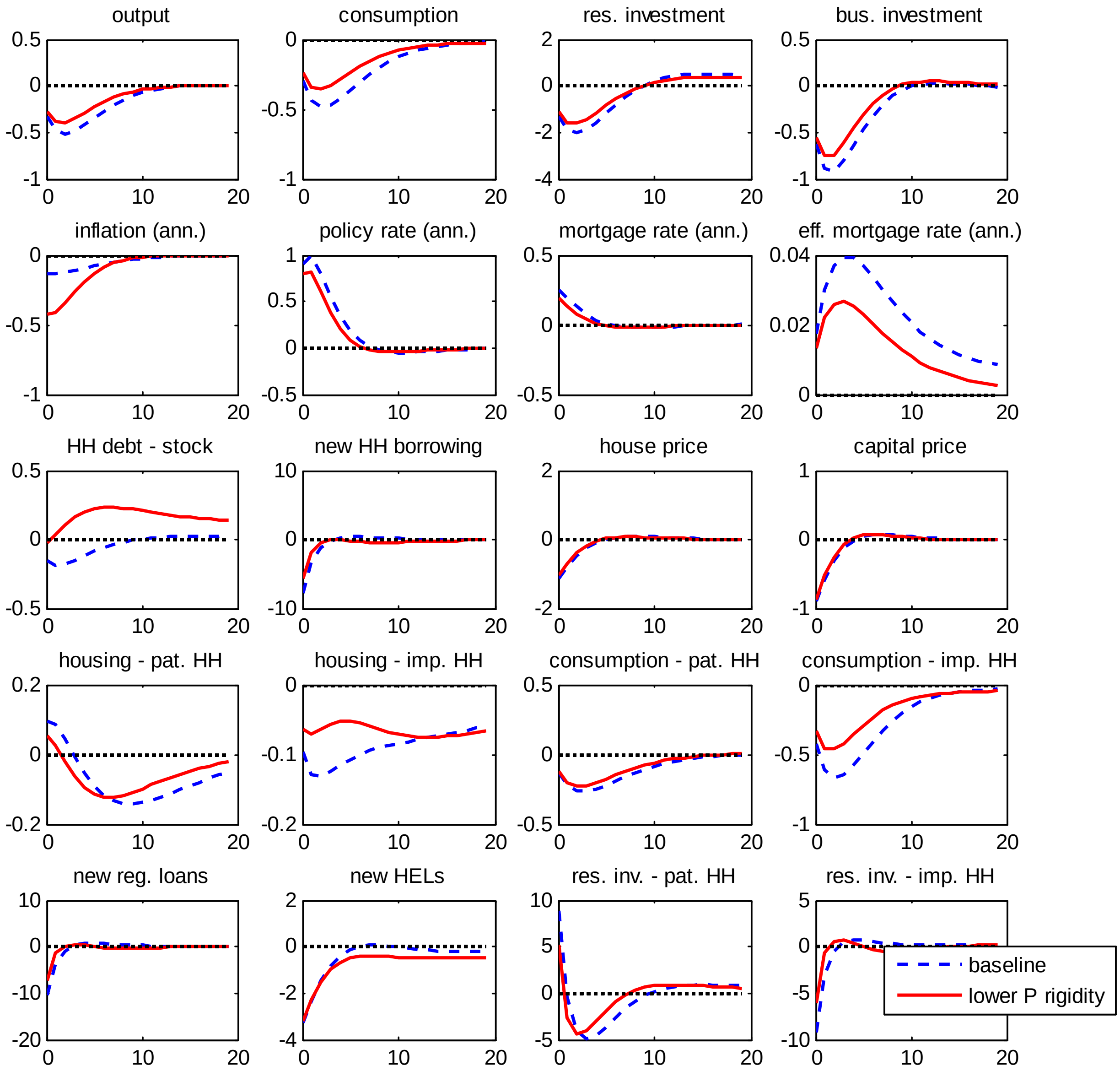

Figure 3: Comparing impulse responses to a 100 bps (annualized) innovation in the monetary policy shock in the baseline case versus a case with lower price rigidities (i.e., $\kappa_p^{est} = 0.5$). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

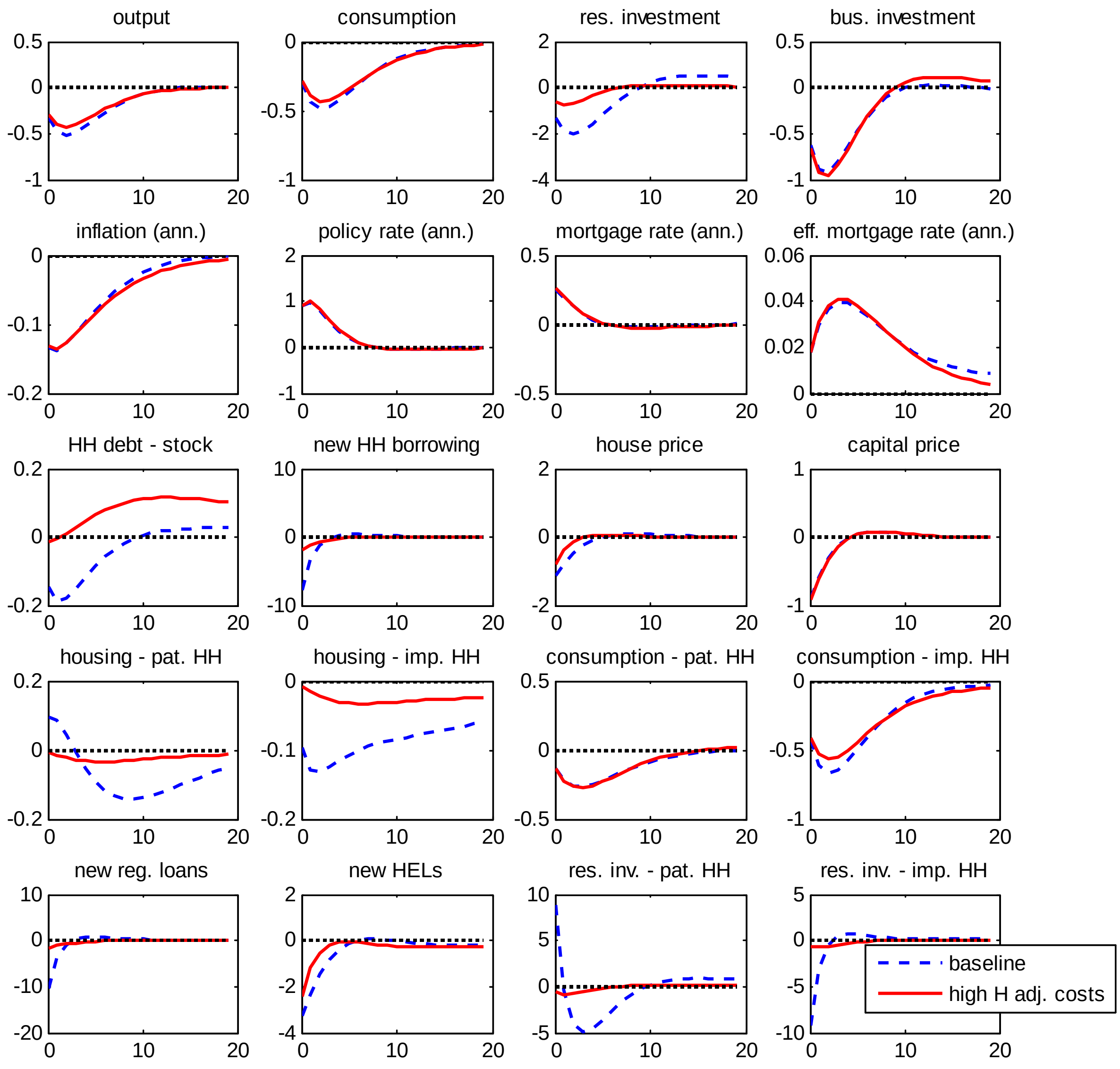

Figure 4: Comparing impulse responses to a 100 bps (annualized) innovation in the monetary policy shock in the baseline case versus a case with high adjustment costs in the stock of housing (i.e., $\kappa_h = 50$). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

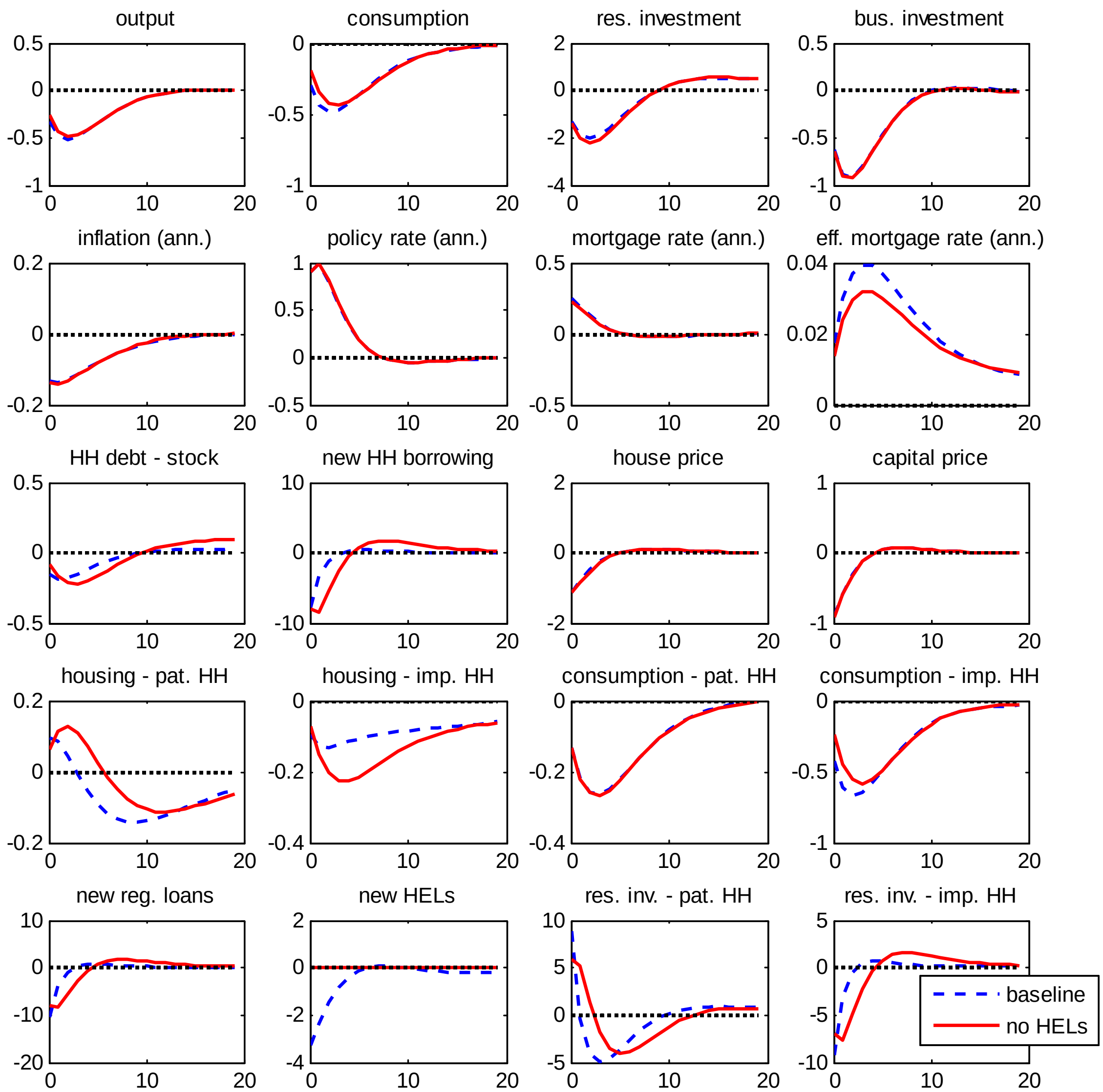

Figure 5: Comparing impulse responses to a 100 bps (annualized) innovation in the monetary policy shock in the baseline case versus a case with no home equity loans (i.e., $\gamma = 0$). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

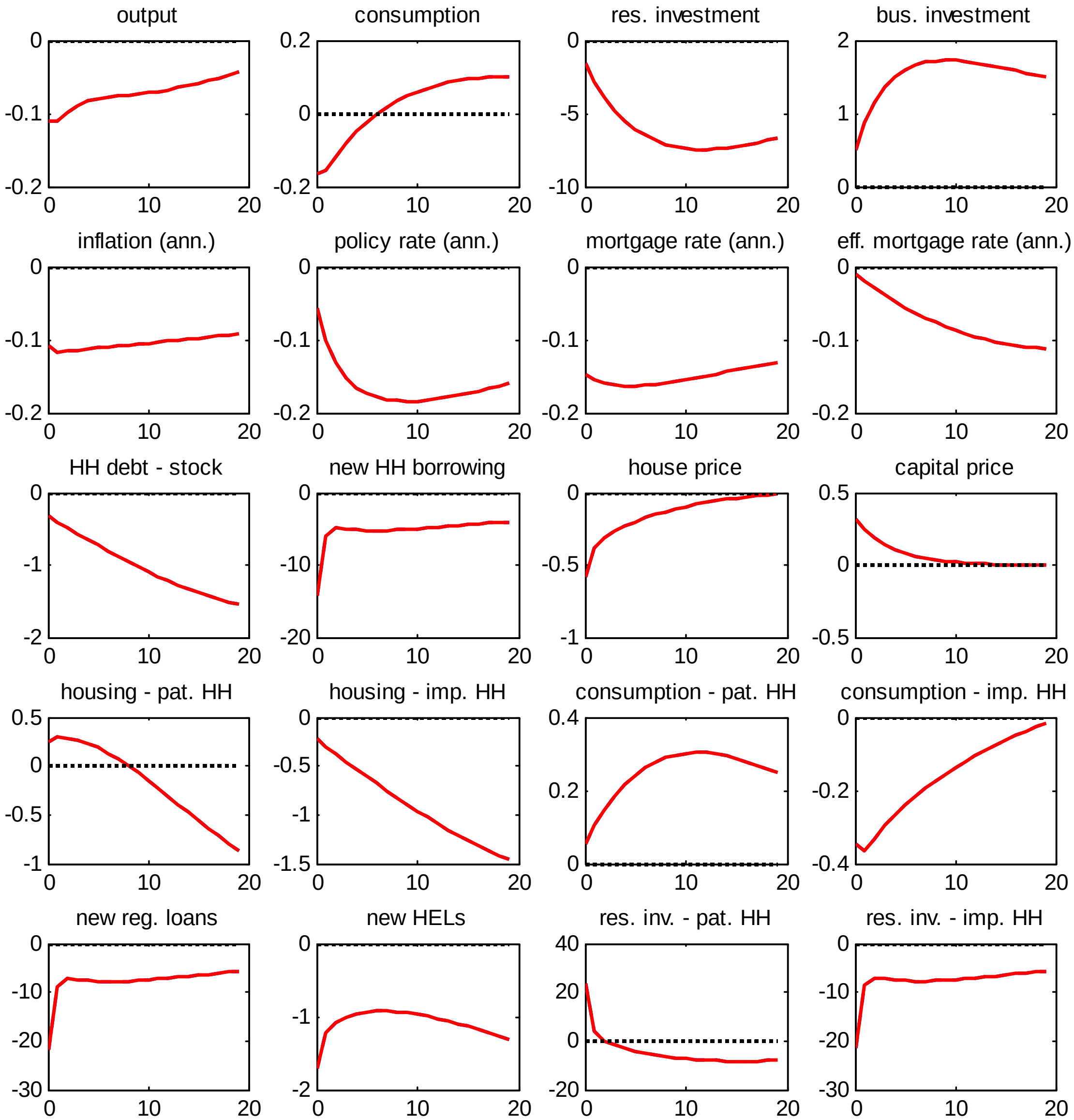

Figure 6: Impulse responses to a 0.23 pp (annual) persistent increase in the property tax rate (i.e., τ_p increases from 0.014 /4 to 0.0163/4). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

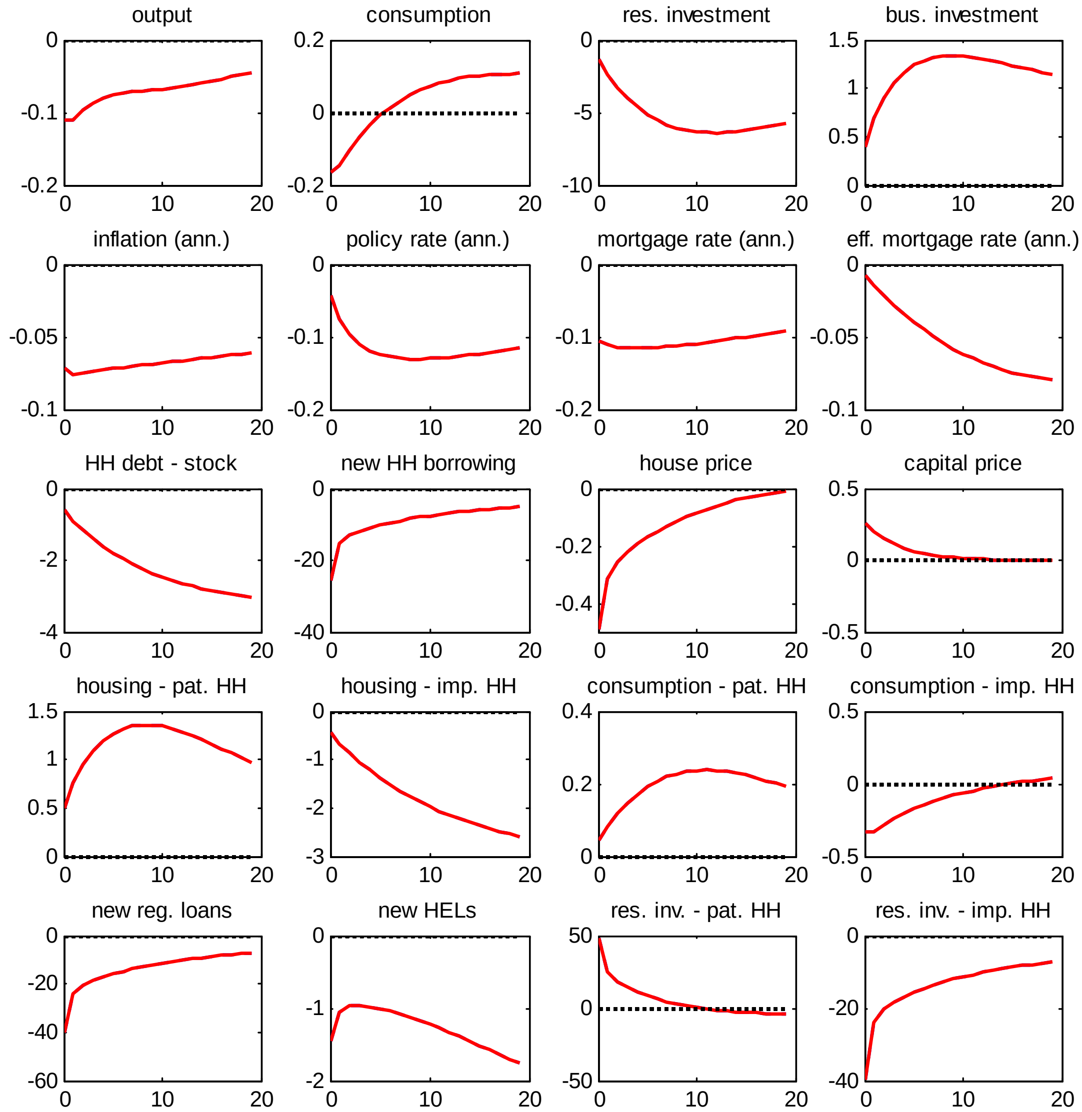

Figure 7: Impulse responses to a 33 percent persistent decline in the tax deductibility of mortgage interest (i.e., I_m is reduced from 1 to 0.67). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

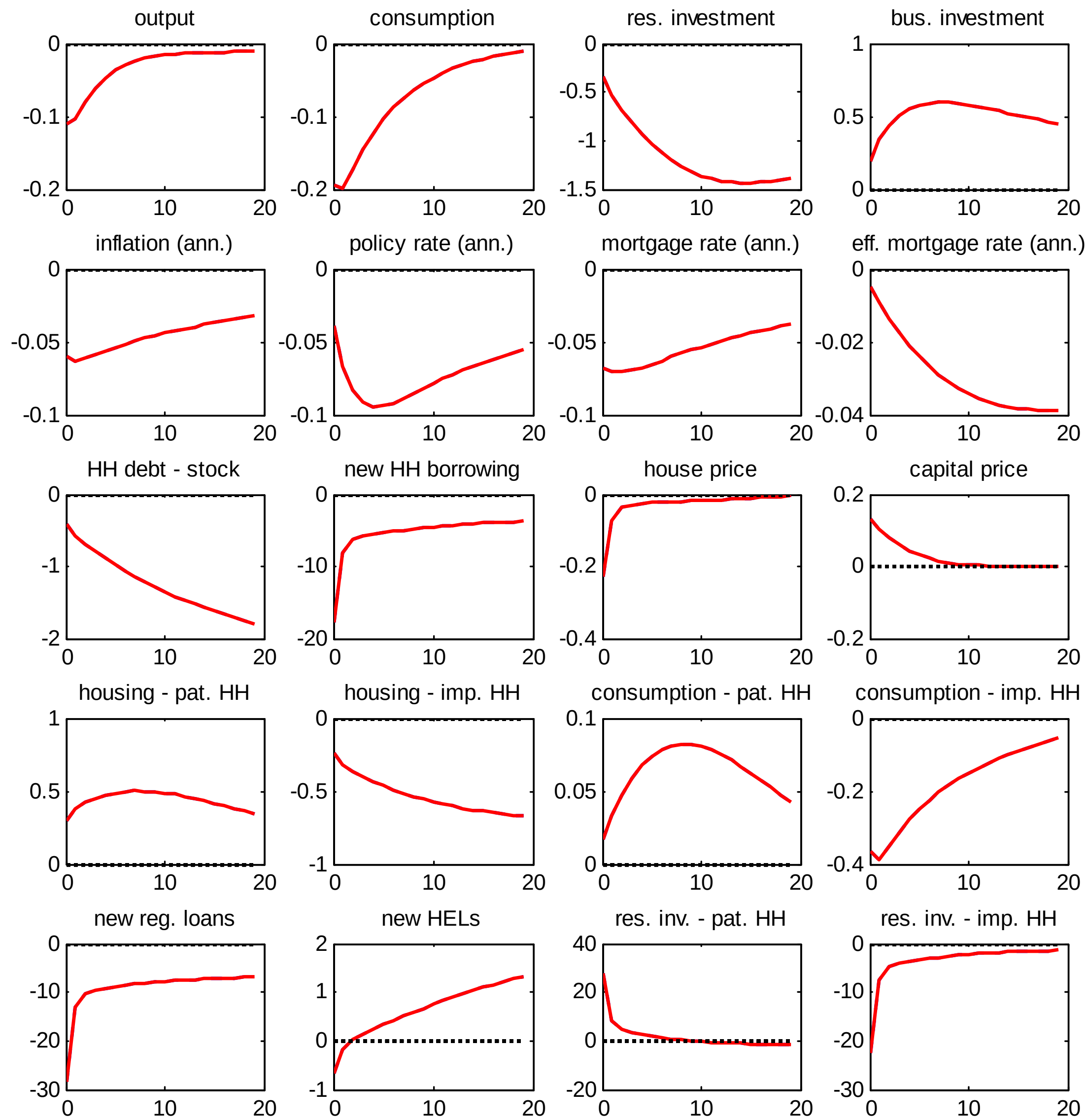

Figure 8: Impulse responses to a 5 pp persistent decline in the regulatory LTV on new mortgage loans (i.e., ϕ decreases from 0.91 to 0.86). The y-axes denote percent deviation of each variable from its steady state, except for inflation and interest rates, which are in percentage point deviations.

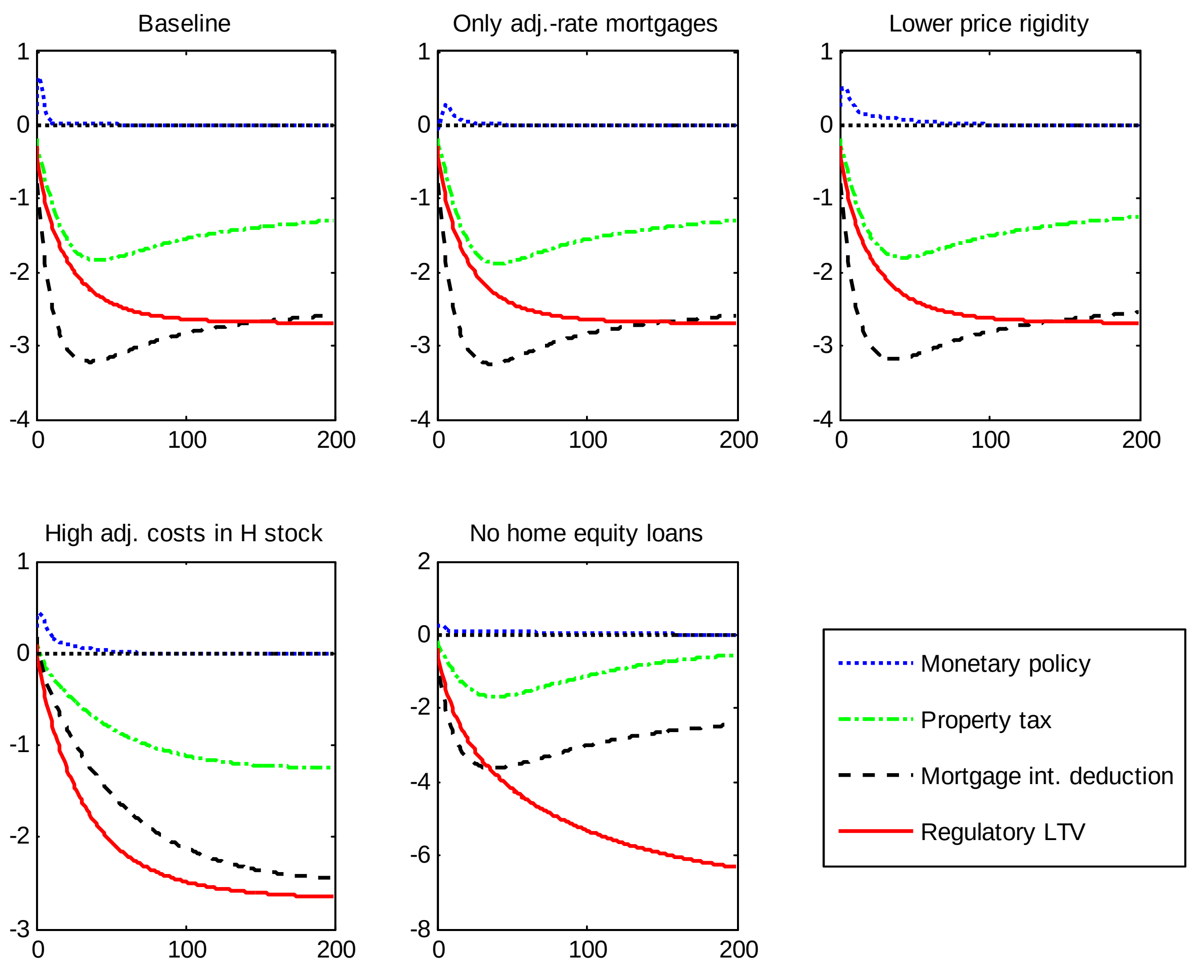

Figure 9: Comparing the effects of the four policies on household debt-to-GDP ratio. The y-axis is in percent deviation from steady state.

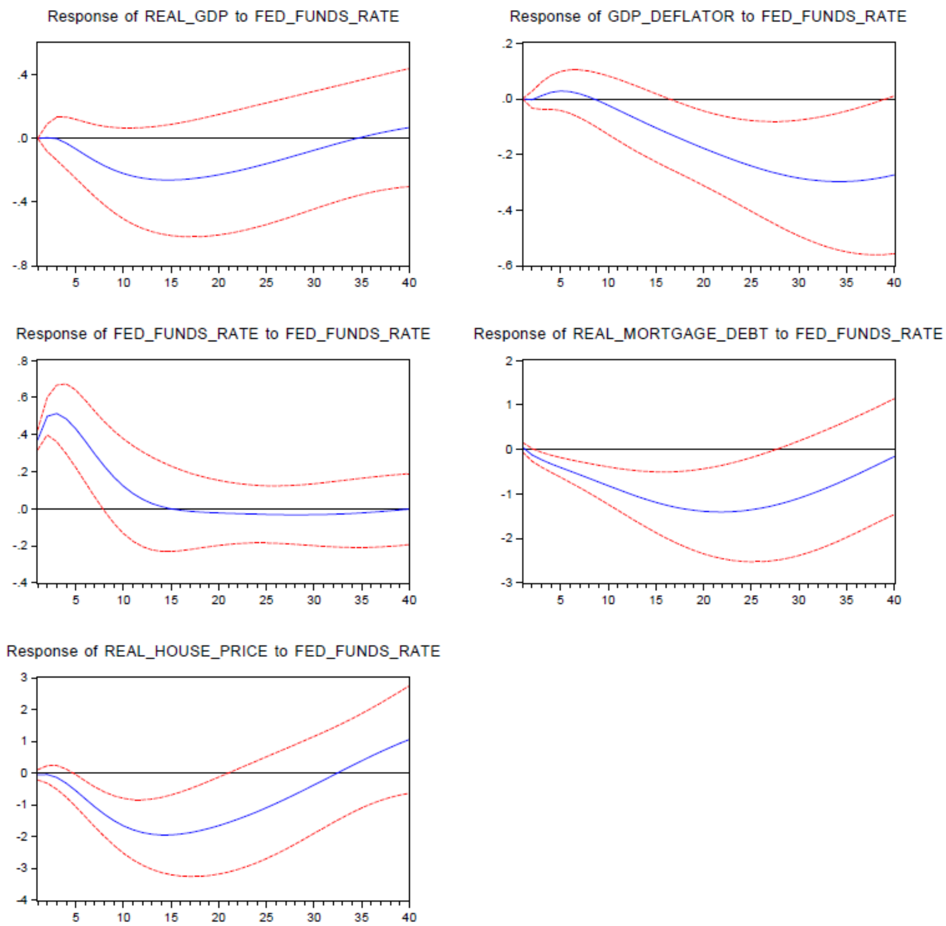

Figure 10: Impulse responses to a one standard deviation monetary policy shock in the baseline VAR on log real GDP, log GDP deflator, federal funds rate, log real mortgage debt of households, and log real house price. The VAR includes 2 lags, and shocks are identified through ordering as listed above. The y-axes denote percent deviation of each variable from its steady state, except for the policy rate, which is in percentage point deviation.