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The costs of macroprudential deleveraging in a liquidity trap*

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Abstract

What are the effects of different borrower-based macroprudential tools when both real and nominal interest rates are low? We study this question in a New Keynesian model featuring long-term debt, housing transaction costs and a zero lower bound constraint on policy rates. We find that the long-term costs, in terms of output losses, of all the macroprudential tools we consider are moderate. However, the short-term costs differ substantially between tools. Moreover, the costs vary depending on the current state of economy and monetary policy. Specifically, a loan-to-value tightening is more than three times as contractionary compared to a loan-to-income tightening when debt is high and monetary policy cannot accommodate.

JEL: E52, E58
Keywords: Household debt, Zero lower bound, New Keynesian model, Collateral and borrowing constraints, Mortgage interest deductibility, Housing prices.

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1 Introduction

A decade after the unfolding of the Global Financial Crisis (GFC), low nominal and real interest rates have contributed to soaring debt and house prices in many advanced economies like Australia, Canada and several European countries as shown in Figure 1. While record-low interest rates currently imply debt-service-to-income ratios at – or even below – historical levels, policy makers around the world have expressed concerns about households' vulnerability to higher interest rates.[1] Various macroprudential policies – such as caps on loan-to-value (LTV), loan-to-income (LTI) and debt-service-to-income (DSTI) ratios – and fiscal policies – for example reduced or removed mortgage interest deductibility (MID) and higher property taxes – have been put forth to stem the perceived imbalances.[2]

The extraordinary events of 2020 made the issue even more pressing. The COVID crisis has led central banks in advanced economies to cut already low policy rates to – or close to – the effective lower bound (ELB) and embark on a new round of asset purchases. The Federal Reserve has announced a flexible average inflation targeting framework to strengthen its communication that interest rates will remain low for an extended period and other central banks are likely to follow suit and keep interest rates low for a prolonged period. In this low rate environment, leading policy institutions like the IMF (see Adrian (2020)) have recommended countries to remain vigilant and use macroprudential policies as necessary to contain vulnerabilities related to household indebtedness.

Against this background, the aim of this paper is to quantify the short- and long-term output losses associated with different policies that equally reduce household debt in the long term in a low interest rate environment. When quantifying these costs two observations are key. First, as shown in Figure 1, aggregate debt-to-income ratios are highly elevated relative to historical values. Second, as noted earlier, monetary policy is either at, or close to, the effective lower bound. These two facts, which both plausibly are driven by a persistently low equilibrium real interest rate, must be properly taken into account in any rigorous analysis of this issue.

[1] See Hoffmann et al. (2018).

[2] One indication of the activity within borrower-based macroprudential regulation is the fact that 58 different such measures have been implemented in various EU countries in the current decade according to ESRB (2019).

Because current economic conditions are extra-ordinary from a historical perspective, a purely empirical approach to address the question will be of limited value (a large degree of extrapolation would be required because few data points cover the situation we are currently facing). Therefore, we use a structural macroeconomic model to perform the analysis. Specifically, we use the workhorse Iacoviello and Neri (2010) two agent New Keynesian (TANK) model with housing and a collateral constraint, augmented to incorporate long-term debt, housing transaction costs and a broader set of macroprudential instruments. Furthermore, we explicitly take into account the zero (or effective) lower bound constraint on monetary policy. The new elements we introduce have been studied in isolation before, but to the best of our knowledge not jointly yet. Taken together these elements have a considerable impact on the monetary transmission mechanism and allow us to consider an initial position with simultaneously elevated debt levels and monetary handcuffs.

For the countries (except the US) in Figure 1, we observe roughly a doubling of households' loan-to-income ratios since the 1990s. In our model framework, four factors account for this phenomenon. First, we assume that an increased desire to save has reduced the equilibrium real rate from 3 to 0.5 percent. Such a fall is well in line with the mortgage rate time series in Figure 1 as well as with point estimates from a voluminous empirical literature which aims at measuring equilibrium real interest rates (see e.g., Sajedi and Thwaites (2016), Holston et al. (2017), Lisack et al. (2017), Del Negro et al. (2018) and Fries et al. (2018)). The reduction in the long-term real interest rate contributes to a sizeable decline in the user cost of housing and drives up the real price of houses. The rise in house prices implies a roughly proportional increase in debt and the loan-to-income ratio accordingly rises sharply in our model. The fall in equilibrium real and nominal rates alone accounts for over half of the increase in household indebtedness. Second, we introduce an explicit role for expanded credit supply by loosening the LTV requirement on new loans. This is consistent with the loosening in credit conditions as documented before the GFC. Third, as shown in Figure 1, inflation rates are lower in the 2010's than in the 1990's and this further contributes to the increase in LTI in our setting with long-term nominal debt. However, these three factors together cannot fully account for the doubling of debt, and we therefore allow for the possibility of a slight increase in home equity extraction to account for the remainder of the increase.[3]

In our model, low real rates also contribute to a substantial increase in the long-run residential investment as a share of GDP (from 3 to 5 percent of GDP). When the relative price of housing – the user cost – declines, demand for housing increases. Such an increase in demand leads to a surge in residential investment. Interestingly, this increase in residential investment is consistent with the data for several of the countries included in Figure 1. For instance, in Sweden residential investment has risen from less than 2 percent after the housing crisis in the early 1990s to about 7 percent in 2017. Such a structural change and the implied higher exposure to a volatile housing market is a crucial component of the transmission mechanism of macroeconomic disturbances in our framework and poses challenges for stabilization policies. Specifically, in a high debt environment the economy is more volatile not only because the expanded borrowing capacity makes borrowers' consumption more responsive but also because residential investment constitutes a larger share of output.

Our main findings are as follows. First, the long-term output costs of all the macroprudential actions in our study are moderate, regardless of whether we consider a steady state with normal (mid-1990s) or elevated debt levels (the current state).[4] Second, the short-term effects of various macroprudential tools depends critically on the initial debt level and the scope for the central bank to provide accommodation. When monetary policy is unconstrained and the initial debt level is low, the short-term output costs will be small (i.e. output does not fall much in response to a macroprudential policy tightening). But in an environment with elevated debt levels and little scope for central banks to cut rates, macroprudential actions may be associated with a significant drop in output and consumption. Specifically, an LTV tightening triggers a large initial decline in the house price, "overshooting" the long-run effect. The fall in house prices generates a negative feedback effect on borrowing capacity as house prices are part of the LTV constraint. Equally important in our model is that lower house prices triggers an adverse impact on aggregate demand and the potential real rate – over and above this feedback effect – which can only be offset if the

[3] See Mian and Sufi (2011) for microdata evidence on the importance of home equity extraction for the surge in U.S. mortgage debt.

[4] Our focus here is mainly on the macroeconomic costs of different borrower-based measures in terms of output. Van der Ghote (2020) takes into account the beneficial effects of macroprudential policy on the natural rate when relaxing macroprudential policy in financial crises.

central bank is able to accommodate an LTV tightening with a lower policy rate. LTI or DSTI tightenings do not lead to this type of overshooting through the fall in house prices and are more efficient tools to curb household debt at lower output cost. We find that the short-term contraction of output (inflation) is more than three times (twice) as large under an LTV tightening compared with an LTI or DSTI tightening. Taken together, our findings stress that when selecting between various macroprudential tools aimed at stemming household debt, it is important to consider room for monetary policy accommodation.

To rationalize the use of macroprudential policy (MPP henceforth) to reduce indebtedness, we analyze welfare in a nonlinear formulation of our model. Our simulations show that a lower LTV is optimal (welfare-maximizing) when accounting for the constraint that the zero lower bound (ZLB) imposes on monetary policy. Specifically, an LTV at 70 percent is welfare maximizing in the high debt scenario. The presence of a ZLB constraint on the nominal interest rate is a crucial driver behind this finding – disregarding the ZLB constraint yields an optimal LTV close to 85 percent (our baseline calibration). We show that the ZLB constraint is an important reason to restrain household indebtedness as it increases the economy's vulnerability to disturbances and reduces the ability of the central bank to accommodate shocks. The welfare analysis illustrates the quantitative significance of the theoretical papers by Lorenzoni (2008), Korinek and Simsek (2016), Davila and Korinek (2018) and Farhi and Werning (2016) which argue that demand and pecuniary externalities associated, respectively, with the zero lower bound and the collateral constraint, provide a rationale to restrain household debt.

Literature Review. Our work is related to different strands of the growing literature using structural macroeconomic models to analyze housing, monetary policy and its interaction with other stabilization policies. Starting with Iacoviello (2005), several papers have explored the linkages between housing, household credit conditions and the macroeconomy (see e.g. Iacoviello and Neri (2010) and Justiniano et al. (2015)). Garriga et al. (2017) show how the presence of multi-period mortgage contracts can enhance the traditional interest-rate transmission mechanism of monetary policy. Differently from ours, their model abstract from nominal rigidities to insulate the effect of the long-term nominal contract aspect of mortgages. Gelain et al. (2017) study the effects of monetary policy in new Keynesian environments with long-term debt. Both of the aforementioned studies abstract from the interaction between monetary and other stabilization policies such as MPP.

A number of empirical papers corroborates some of our findings. Our results mirror the empirical work in Calza et al. (2013), which shows that countries with more developed mortgage markets and high mortgage debt-to-GDP feature larger responses to monetary policy shocks. In their study, the possibility of mortgage equity release and the prevalence of adjustable rate mortgage (ARM henceforth) contracts turns out to be crucial for the response of consumption. Similarly, using household data for the US and the UK, Cloyne et al. (2018) show that mortgagors' consumption reacts more strongly than other households' consumption to monetary policy shocks. Flodén et al. (2018) find that highly indebted Swedish households cut their non-housing expenditures more than less indebted households following changes in the policy rate. In contrast, using state dependent local projections methods Alpanda and Zubairy (2018) show that monetary policy is less effective when the debt is high. They rationalize their findings in a partial equilibrium model where highly indebted households cannot further increase borrowing in response to interest rate cuts. However, taking into account also general equilibrium effects, Walentin (2014) finds opposite results, i.e. the impact of monetary policy is stronger when the level of debt is higher. Richter et al. (2018) provide empirical evidence on the contractionary effects of LTV tightenings, but do not differentiate between situations when monetary policy is constrained and when it is unconstrained (away from the ZLB). They find that a 10 percentage point tightening of the LTV induces a 1.1% reduction in output, although output effects are concentrated in emerging economies. This result is consistent with ours as it is in-between what we find for constrained and unconstrained monetary policy settings. Using a large sample of 63 countries over the period 1991 to 2016, Alam et al. (2019) find that macroprudential tightening through LTV has a significant negative impact on house prices whereas a DSTI/LTI tightening does not have entail any significant effects. This finding provides strong support for our core mechanism that LTV tightenings are more contractionary through their adverse impact on house prices.

Our work also contributes to the growing literature on the interaction between monetary policy and macroprudential regulations (see e.g. Angelini et al. (2014), De Paoli and Paustian

(2017), Gelain and Ilbas (2017), Ferrero et al. (2018) and Lambertini et al. (2013)). Like us, Alpanda and Zubairy (2017) build on Iacoviello (2005), but we extend their work by considering the supply side of housing and the ZLB constraint on monetary policy. Their main finding is that monetary policy is too blunt a tool to stabilize households' debt compared to other more tailor-made housing-related policies. Finocchiaro et al. (2016) and Chen and Columba (2016) both study the long-run effects of deleveraging in models with housing and a banking sector. On the normative side, both De Paoli and Paustian (2017) and Ferrero et al. (2018) derive a welfare-based loss function in models featuring credit markets frictions. The latter shows that, during boom-bust episodes in housing markets macroprudential policy can help avoid zero lower bound episodes by alleviating debt leveraging. Both Lambertini et al. (2013) and Rubio and Yao (2018) study optimal (countercyclical) LTV rules, for a given average level of LTV. The latter paper shows in a simple stylized model that the macroprudential authority needs to use its instrument more aggressively to stabilize financial cycles when interest rates are low.[5] Differently from these studies, we focus on a positive analysis of the output-debt sacrifice ratio for several macroprudential tools in a quantitatively relevant model with strongly elevated household indebtedness and increased exposure to housing markets. Moreover, in line with empirical evidence on how borrower-based MPP is conducted (see ESRB (2019)), we consider permanent changes in MPP tools rather than countercyclical rules.[6]

Our results are consistent with the findings of Mendicino et al. (2018) for bank capital-based macroprudential measures. In their framework, when monetary policy hits the lower bound, it loses the ability of dampening the macroeconomic effects of a (bank) capital requirement increase. Conversely, we focus on borrower-based macroprudential measures and stress the importance of taking into account initial conditions, i.e. the level of debt, to properly assess the trade-offs associated with different tools.

The remaining part of the paper is organized as follows. Section 2 describes our main mechanism in a stylized model. Section 3 presents the quantitative model environment. Section 4 documents the drivers of the increased indebtedness evident in the data. Section

[5] Rubio and Yao (2018) perform their analysis in a model that abstracts from long-term debt, housing investment and business investment. Lambertini et al. (2013) abstract from the ZLB.

[6] None of the 58 cases documented in ESRB (2019) is state contingent.

5 then reports the long-term and short-term macroeconomic effects of the various MPP instruments we consider. Section 6 verifies the robustness of our results in a multiconstraint setting. Section 7 evaluates welfare for different LTV levels accounting for liquidity traps with endogenously determined durations. Finally, Section 8 concludes.

2 Macroprudential deleveraging: inspecting the mechanism

This section illustrates the mechanisms behind our main result, i.e. the stronger near-term contractionary effects of an LTV tightening, in a bare bones version of our model. Our focus here will be on agents with high marginal propensity to consume, i.e. constrained borrowers, whose consumption decisions are crucial for aggregate demand fluctuations. For the ease of exposition, we will abstract from uncertainty, capital accumulation and monetary policy.

Consider a two-period economy where a continuum of identical households with unit measure can borrow from abroad at a rate R, receive a fixed wage every period (normalized to one), and consume housing services (h) and non-durable goods (c). Agents' preferences over consumption, housing and hours worked (n) are described by

$$\sum_{t=1}^{2} \beta^{t-1} \left(c_t + \log\left(h_t\right) - \frac{n_t^2}{2} \right),$$

where in line with a borrower-saver framework we assume $\frac{1}{1+R} < \beta < \frac{1}{R}$. Households face the following budget constraint

$$c_t + q_t \Delta h_t + R b_{t-1} = n_t + b_t,$$

where $\Delta h_t \equiv h_t - h_{t-1}$, for given h_0, $b_0 = 0$ and b_2.

We consider two set-ups with different specifications for the borrowing limit in the first period. When contracting debt households are either subject to an LTV constraint

$$b_1 \leq \theta q_1 h_1,$$

which ties borrowing to the value of housing (see Iacoviello (2005), Farhi and Werning (2016)), or an LTI constraint

$$b_1 \leq \theta^{LTI} n_1,$$

which sets the borrowing limit to a fraction of labor income, with $\theta < \beta$.[7] In order to make the two economies comparable in the long-run, we further assume that $\theta^{LTI} = \theta$ and that $b_2 = \theta$.[8] Finally, aggregate housing is in fixed supply, so that in a symmetric equilibrium

$$h_t = \bar{H}, \ \forall t.$$

We are now ready to characterize the remaining equilibrium conditions in the LTV and LTI economies. Note that our real rate assumption together with the linearity of utility in consumption cause the borrowing constraints to bind in both environments

$$\mu = 1 - \beta R > 0,$$

where μ is the Kuhn-Tucker multiplier on the borrowing constraint.[9]

When the LTV constraint is imposed, house prices, debt and consumption decrease over time. Houses are valued less in the last period since they lose their collateral value. Households' labor supply is unaffected by the borrowing limit and is constant over time.

When borrowing instead is tied to labor earnings, housing does not have any collateral value and it is less valued compared to the LTV economy. Under an LTI constraint households instead supply more labor in the first period to be able to borrow more.

2.1 Macroprudential tightening

To evaluate the effects of an MPP tightening, we consider a permanent change in θ

$$\theta' = x\theta,$$

where variables with prime refer to the economy which experiences a tightening by setting $x < 1$.

By construction, debt will be reduced by the same amount in both economies in the long-run, i.e. in period 2. Even so, the short-run effects of the tightening will differ. In both

[7] Our parameter restrictions ($\theta < \beta$ and $\beta > 1/(1+R)$) provide sufficient conditions for consumption to be positive and to simply characterize the effects of MPP. Both restrictions are in line with plausible values for the LTV limits, interest rates and discount factors.

[8] This is equivalent to imposing the constraints $b_2^{LTV} = \theta q_2 \bar{H}$ and $b_2^{LTI} = \theta \bar{n}_2$ where $\bar{H}$ and $\bar{n}_2$ are aggregate variables since in equilibrium, $q_2 = \frac{1}{\bar{H}}$ and $n_2 = 1$, i.e. $b_2^{LTV} = b_2^{LTI} = \theta$.

[9] The complete set of first-order conditions is reported in the Appendix.

economies MPP has both a direct and an indirect effect on debt. The direct effect refers to the exogenous change in the regulatory limit θ. The indirect effect is an amplification channel due to the negative endogenous response of house prices and labor supply in the LTV and LTI economy, respectively. In what follows, we show that movements in house prices are more pronounced than fluctuations in labor supply thereby implying a higher degree of financial amplification in an LTV economy in the short-term, i.e. in period 1.

In the collateral constrained economy, an LTV tightening triggers a contraction in housing demand. Since housing supply is fixed, equilibrium prices will decrease to accommodate the change in demand:

$$\Delta q_{1,LTV} = -\left[\frac{x\theta\left(1+\beta\right)\mu}{\bar{H}\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] < 0,$$

where $\Delta q \equiv q' - q$, i.e. the difference between the economy experiencing the tightening versus the economy which does not. Households' borrowing capacity and their consumption will shrink accordingly:

$$\Delta b_{1,LTV} = -\frac{\theta\left(1+\beta\right)\left(1-x\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)} < 0,$$

$$\Delta c_{1,LTV} = \Delta b_{1,LTV}.$$

Interestingly, the drop in prices and consumption is larger the higher the level of initial debt (or equivalently, initial LTV).

Let us now consider the LTI economy. In this case, house prices are unaffected by the policy change

$$\Delta q_{1,LTI} = 0,$$

that is, differently from an LTV tightening, a reduction in the LTI cap does not trigger an overshooting of house prices in the short-run, even though the two policy interventions, by construction, have the same impact on house prices and debt in the long-run. The MPP tightening has an impact on households' labor decisions, i.e. labor supply in period 1 drops:

$$\Delta n_{1,LTI} = -\mu\theta\left(1-x\right) < 0.$$

As a result, the total effect on borrowing and consumption is captured by:

$$\Delta b_{1,LTI} = -\theta (1-x)(\theta\mu(1+x)+1) < 0,$$
$$\Delta c_{1,LTI} = \Delta n_{1,LTI} + \Delta b_{1,LTI}.$$

To sum-up, the LTI tightening depresses consumption in period 1, since it has a negative impact on both households' borrowing capacity and their labor supply.

We can now tackle the question at the heart of this experiment, i.e. which of the two MPP tools is most contractionary? It can be easily shown that debt in the first period drops more after an LTV tightening:

$$\Delta b_{1,LTV} - \Delta b_{1,LTI} = -(1-x)\theta \left[\frac{\theta^2\mu^2((1-\theta\mu)x(1+x)+1)+\beta}{(1-\mu x\theta)(1-\mu\theta)}\right] < 0,$$

as a result of the sharp house price reaction to the MPP change. This translates into a more pronounced fall in consumption:

$$\begin{aligned}\Delta c_{1,LTV} - \Delta c_{1,LTI} &= (\Delta b_{LTV} - \Delta b_{LTI}) - \Delta n_{1,LTI} \\ &= -(1-x)\theta \left[\frac{\Xi+\beta-\mu+\theta\mu^2}{(1-\mu x\theta)(1-\mu\theta)}\right] < 0\end{aligned}$$

where the inequality follows from $\Xi \equiv \theta^2\mu^2\left((1-\theta\mu)x\left(1+x+\frac{1}{\theta}\right)+1\right) > 0$ and $\beta > \mu$ given our restrictions on the parameters.[10]

Hence, our simple model demonstrates that deleveraging through LTV tightening has a negative impact on house prices and, via the collateral constraint, on debt and consumption. When debt is instead tied to income via an LTI constraint, a forced deleveraging has less pronounced short-run effects as long as labor supply is relatively more inelastic than house prices to the policy change. In both cases, higher initial debt amplifies the negative responses of consumption to the MPP tightening.

To provide analytical insights, this section has abstracted from nominal rigidities in price and wage formation. However, we will show next that our key finding that an LTV tightening is more contractionary relative to income-based borrowing constraints – and therefore require stronger monetary accommodation – holds up in a full-fledged DSGE model with nominal rigidities.

[10] This last condition follows from $\frac{1}{1+R} < \beta \Rightarrow 1 - R\beta < \beta$.

3 The quantitative model

Our quantitative model builds on the Iacoviello and Neri (2010) two agent New Keynesian economy with housing, and is extended to allow for housing transaction costs, long-term household debt, as well as a ZLB constraint for the policy rate. The economy is populated by households and firms. Households consume both housing, h, and non-housing goods, c, and provide labor to both sectors. They are divided in two groups with a combined mass of unity; patient households, subscript P, and impatient households, subscript I, which discount the future at different rates, $\beta_P > \beta_I$. On the production side, the non-housing sector combines capital and labor to produce a good that can be be used for consumption, production capital or as an intermediate input in the production of housing. The housing sector combines capital, labor, land and the intermediate good to produce new housing. For ease of exposition, in what follows we describe the optimization problems faced by each agent in the economy and relegate to the Appendix the complete set of first-order conditions and technical details.

3.1 Households

3.1.1 Patient households

A continuum of identical patient households maximize the following expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} (\beta_P)^t z_t \left[\Gamma_c ln(c_{P,t} - \epsilon c_{P,t-1}) + j_{P,t} ln(h_{P,t}) - \frac{v_t}{1+\eta} (n_{c,P,t}^{1+\xi} + n_{h,P,t}^{1+\xi})^{\frac{1+\eta}{1+\xi}} \right] \tag{1}$$

where c, h, n_c, and n_h are consumption, housing, and hours worked in the consumption and housing sectors, respectively. The two shocks z and v denote disturbances to intertemporal preferences and labor supply, respectively, while j is a housing preference shock aiming to capture preference shifts towards or away from housing. In the specification of labor disutility, η is the inverse Frisch elasticity of labor supply while ξ is a measure of the labor immobility between sectors, such that $\xi > 0$ implies that households prefer to spread their working hours to both sectors (see Hovarth (2000)).[11]

[11] The scaling factor $\Gamma_c = (1 - \epsilon)/(1 - \beta)$ ensures that the marginal utility of consumption is $1/c$ in the steady state.

Patient households are the savers in the economy; they accumulate capital and houses and extend long-term loans to impatient households. Their budget constraint is

$$c_{P,t}+\frac{i_{c,t}}{A_{k,t}}+i_{h,t}+k_{b,t}+q_t h_{P,t}+p_{l,t}l_t+\frac{L_{P,t}}{P_t}+\frac{a(z_{ct})p_t^{ch}k_{c,t-1}}{A_{k,t}}+a(z_{ht})p_t^{kh}k_{h,t-1}+\phi_{P,t}=$$

$$\frac{w_{c,P,t}n_{c,P,t}}{X_{wc,t}}+\frac{w_{h,P,t}n_{h,P,t}}{X_{wh,t}}+(p_{l,t}+R_{l,t})l_{t-1}+\frac{M_{P,t}}{P_t}+R_{c,t}z_{c,t}k_{c,t-1}+R_{h,t}z_{h,t}k_{h,t-1}+p_{b,t}k_{b,t} \quad (2)$$

$$+q_t(1-\delta_h)h_{P,t-1}+Div_t$$

where k_c, i_c, δ_{kc} and k_h, i_h, δ_{kh} denote capital stock, investment and depreciation rates in the non-housing and housing sector, respectively, whereas k_b denotes intermediate inputs in housing production and l land.

A_k indicates investment-specific technology in the non-housing sector. X_{wc} and X_{wh} are wage markups accruing to labor unions, Div denotes profits from retail firms and lump-sum payments from labor unions corresponding to the wage markups, R_c, R_h and R_l are rental rates, z_c and z_h capital utilization rates, $a(z_c)$ and $a(z_h)$ utilization costs in terms of capital goods (see the Appendix for functional forms for the utilization costs). The term

$$\phi_{f,t}\equiv\frac{\phi_h}{2}\left(\frac{h_t}{h_{t-1}}-1\right)^2 q_t h_{t-1} \qquad f=\{P,I\} \quad (3)$$

captures transaction costs borne by households adjusting their housing stock. The law of motion of capital in the two sectors are described by

$$k_{ct}=(1-\delta_{kc})\,k_{ct-1}+F\left(i_{ct},i_{ct-1}\right)$$
$$k_{ht}=(1-\delta_{kh})\,k_{ht-1}+F\left(i_{ht},i_{ht-1}\right),$$

where our choice of functional forms for the adjustment costs, $F(\cdot,\cdot)$, is adapted from Christiano et al. (2005), as described in the Appendix.

We follow Alpanda and Zubairy (2017) in the modelling of long-term mortgage contracts. That is, each period savers receive mortgage payments, $\frac{M}{P}$, which are the sum of interest, r^M, and constant-principal, κ, payments[12],

$$\frac{M_t}{P_t}\equiv\left(r_{t-1}^M+\kappa\right)\frac{D_{t-1}}{P_t}. \quad (4)$$

[12] See Garriga et al. (2017) and Gelain et al. (2017) for examples of time-varying amortization rates.

The total stock of debt evolves according to

$$\frac{D_t}{P_t} = (1-\kappa)\frac{D_{t-1}}{P_t} + \frac{L_t}{P_t}. \tag{5}$$

It is further assumed that new mortgage loans, L, carry a fixed interest rate, r^F, for their duration and a fixed fraction of outstanding loans, Φ, are refinanced at this rate. As a result, the effective mortgage rate r^M in eq. (4) is a weighted average of present and past rates:

$$r_t^M = (1-\Phi)\left(1-\frac{L_t}{D_t}\right)r_{t-1}^M + \left[\frac{L_t}{D_t} + \Phi\left(1-\frac{L_t}{D_t}\right)\right]r_t^F. \tag{6}$$

3.1.2 Impatient households

Impatient households' utility functional form is identical to that of patient households, but they discount the future at a higher rate, $\beta_I < \beta_P$, and assign a higher relative utility to housing $j_I > j_P$. Due to their impatience, they accumulate only the required net worth to finance the down payment on their home and borrow the rest from patient households. They do not accumulate any physical capital. Hence, their budget constraint is

$$c_{I,t} + q_t h_{I,t} + \frac{M_{I,t}}{P_t} + \phi_{I,t} =$$
$$\frac{w_{c,I,t}n_{c,I,t}}{X_{wc,t}} + \frac{w_{h,I,t}n_{h,I,t}}{X_{wh,t}} + q_t(1-\delta_h)h_{I,t-1} + \frac{L_{I,t}}{P_t} + Div_{I,t} + \tau_t r_{t-1}^M\frac{D_{I,t-1}}{P_t} - T_t \tag{7}$$

where τ captures the partial deductibility of interest payments and T are lump-sum taxes.

To analyze the effects of different borrower-based macroprudential measures, we consider alternative specifications of the borrowing constraint. Our baseline specification is that the impatient households' borrowing is constrained by the following collateral (LTV) constraint

$$\frac{L_t}{P_t} \leq \theta_t^{LTV} q_t\left[h_{It} - (1-\delta_h)h_{I,t-1}\right] + \gamma\left[q_t(1-\delta_h)h_{I,t-1} - (1-\kappa)\frac{D_{t-1}}{P_t}\right], \tag{8}$$

which is adapted from Alpanda and Zubairy (2017). Eq. (8) assumes that impatient households capacity to take up new loans is limited to a fraction θ^{LTV} of their housing investments as collateral. In addition, the households are allowed to extract a constant fraction γ of the available home equity every period.

We also consider two other borrowing constraints. First, the following loan-to-income (LTI) constraint

$$\frac{L_t}{P_t} \leq \theta_t^{LTI}\left(w_{c,I,t}n_{c,I,t} + w_{h,I,t}n_{h,I,t}\right) + \gamma\left[q_t(1-\delta_h)h_{I,t-1} - (1-\kappa)\frac{D_{t-1}}{P_t}\right], \tag{9}$$

implying that the value of impatient households' new loans cannot exceed a certain multiple, θ_t^{LTI}, of their total income (recall that they do not have any capital revenues) plus home equity extraction. Second, we consider a debt-service-to-income (DSTI) constraint

$$\frac{L_t}{P_t} \leq \theta_t^{DSTI} \frac{w_{c,I,t}n_{c,I,t} + w_{h,I,t}n_{h,I,t}}{(1-\tau_t)r_t^F + \kappa} + \gamma \left[q_t(1-\delta_h)h_{I,t-1} - (1-\kappa)\frac{D_{t-1}}{P_t} \right] \tag{10}$$

which implies that households' debt service costs on new loans (interest and amortization) cannot exceed a certain multiple of their income.

The two last constraints above capture the realistic assumption that even when borrowing is restricted by income based measures, households can still withdraw home equity. This last channel creates an incentive to accumulate housing collateral even when a LTI or a DSTI constraint binds.

For small enough shocks around the steady state, all the constraints will hold with equality. Although it would be interesting to analyze the implications of more than one of the constraints above binding simultaneously (following the work by Greenwald (2018), Grodecka (2020) and Justiniano et al. (2019)), we will assume for now that the borrowing restrictions bind only one at a time to trace out their partial implications for the effects of an MPP tightening on the economy. Section 6 will verify the robustness of our results in a multiconstraint setting where both LTV and LTI constraints bind at the same time.

3.2 Firms and technology

3.2.1 Wholesale sector

There is a perfectly competitive wholesale sector where capital and labor are inputs in the production of the non-housing good, Y_t, while new houses, IH_t, are produced with capital, labor, land and an intermediate input. Firms maximize the following profit function

$$\frac{Y_t}{X_t} + q_t IH_t - \left(\sum_{i=c,h} w_{it}n_{it} + \sum_{i=c,h} w_{it}n_{i,I,t} + R_{ct}z_{ct}k_{ct-1} + R_{ht}z_{ht}k_{ht-1} + R_{lt} + p_{bt}k_{bt} \right) \tag{11}$$

subject to the production technologies for goods and new houses, respectively

$$Y_t = \left(A_{ct} \left(n_{c,P,t}^{\alpha} \left(n_{c,I,t} \right)^{1-\alpha} \right) \right)^{1-\mu_c} \left(z_{ct}k_{ct-1} \right)^{\mu_c} \tag{12}$$

$$IH_t = \left(A_{ht} \left(n_{h,P,t}^{\alpha} \left(n_{h,I,t} \right)^{1-\alpha} \right) \right)^{1-\mu_h-\mu_b-\mu_l} \left(z_{ht}k_{ht-1} \right)^{\mu_h} k_{bt}^{\mu_b} l_{t-1}^{\mu_l} \tag{13}$$

where A_{ct} and A_{ht} are the productivity levels in the non-housing and housing sectors, respectively and α is the labor income share of patient households. The production specification above implies complementarity across labor skills from the two types of households.

3.2.2 Retailers

To model price stickiness in the non-housing sector, we assume that monopolistically competitive retailers differentiate the homogenous good. These firms buy homogenous goods at the price P_t^w and sell them at the price $P_t = X_t P_t^w$, where X_t is the markup. Retailers face Calvo frictions in their price setting, i.e. each quarter they are allowed to choose a new price with a fixed probability $1-\xi_p$. It is further assumed that the remaining fraction, ξ_p, of firms partially index their prices by a fraction ι_p to past inflation. The resulting Phillips curve for net inflation $\pi = \ln \Pi$ is:

$$\pi_t - \iota_p \pi_{t-1} = \beta(E_t \pi_{t+1} - \iota_p \pi_t) - \kappa_p \ln\left(\frac{X_t}{X}\right) + \varepsilon_{\pi,t} \tag{14}$$

where $\kappa_p \equiv (1-\beta\xi_p)(1-\xi_p)/\xi_p$ and $\varepsilon_{\pi,t}$ is an *i.i.d.* markup shock (see e.g. Smets and Wouters (2007)).

Analogously to prices, nominal wages are sticky. The resulting four wage Phillips curves, one for each sector-household pair, are documented in the Appendix.

3.3 Monetary, fiscal and macroprudential policy

Monetary policy is constrained by the zero lower bound and the gross nominal interest rate R_t follows a simple Taylor-type rule

$$R_t = \max\left\{1, \hat{R}_t\right\}, \tag{15}$$

with

$$\hat{R}_t = R_{t-1}^{\rho_R}\left(\bar{R}\left(\frac{\Pi_t}{\Pi}\right)^{r_\pi}\left(\frac{Y_t}{Y_t^{flex}}\right)^{r_Y}\left(\frac{Y_t}{Y_{t-1}}\right)^{r_{\Delta Y}}\right)^{(1-\rho_R)} \exp\left(\varepsilon_{r,t}\right), \tag{16}$$

where $\hat{R}_t$ denotes the gross notional (shadow) interest rate, $\varepsilon_{r,t}$ is an i.i.d. monetary shock, Y_t^{flex} measures flex-price-wage output (so that $\ln\left(Y_t/Y_t^{flex}\right)$ is the model consistent output gap), and $\bar{R}$ is the steady state gross nominal interest rate. In the absence of corrective subsidies, the steady state output is inefficiently low in the flex price-wage equilibrium due to the distortions in the product and labor market. Nevertheless, the presence of the output gap in eq. (16) implies that the central bank internalizes policy changes (e.g. macroprudential policy) that have an effect on potential output.

The government balances its budget period-by-period by financing the interest rate deductions with lump-sum taxes paid by impatient households,

$$T_t = \tau_t r^M_{t-1} \frac{D_{t-1}}{P_t}.$$

3.4 Market clearing

Market clearing for non-housing goods implies

$$c_{Pt} + c_{It} + i_{ct}/A_{kt} + i_{ht} + k_{bt} = Y_t.$$

Similarly, the market clearing condition for houses is given by

$$h_{Pt} + h_{It} - (1 - \delta_h)(h_{Pt-1} + h_{It-1}) = IH_t.$$

3.5 Calibration

The calibration of the parameters that apply generally, both in the high and the low debt steady state, are documented in Table 1 and motivated below.

First, parameters affecting mainly the steady state, i.e. markups, factor shares and depreciation rates, are set to conventional values in the literature. Some steady state parameters are seen as drivers of the increased household debt between the 1990's and 2010's and are described in section 4.

Second, parameters that affect only the dynamics are set to the estimated values in Iacoviello and Neri (2010) except investment adjustment cost estimates that we take from Walentin (2014).[13] There are some additional exceptions that we now describe. Motivated by the bulk of the empirical literature (see e.g. Christiano et al. (2005) and Smets and Wouters

[13] Iacoviello and Neri (2010) did not allow for investment adjustment costs. We decided to include them to ensure a conventional monetary policy transmission mechanism, which is important in our ZLB environment.

(2007)), we use higher consumption habit parameters (0.7) than estimated by Iacoviello and Neri (2010) (0.32 and 0.58) to ensure a more conventional monetary policy transmission mechanism. A voluminous literature has also documented lower sensitivity of prices to product and labor market changes observed since the onset of the financial crisis (see e.g. Del Negro et al. (2015) and Lindé et al. (2016)). We therefore consider a higher degree of stickiness in prices compared to Iacoviello and Neri. Since we want to consider a policy rule which recognizes changes to potential output after a persistent MPP tightening, we include the model consistent output gap in the policy rule. We set its parameter to 0.25, consistent with the view that the output gap carries a large weight in a liquidity trap. Such a weight also often approximates optimal policy well in New Keynesian model environments, see e.g. the seminal work by Erceg et al. (2000) and the recent paper by Debortoli et al. (2018). We also use a stronger response of the policy rate to inflation than Iacoviello and Neri (2010). The motivation behind the changes to the monetary policy rule is the basic premise that the central bank adopts a more aggressive policy rule in a low interest environment with less policy space so as to avoid persistent deflationary episodes. Finally, we set the share of savers, α, to two thirds, 0.67. This value is slightly higher than the prior used by Iacoviello and Neri, but below their posterior median (0.79). Our slightly larger share of borrowers, $(1-\alpha)$, than estimated by Iacoviello and Neri is inspired by the recent literature on wealthy hand-to-mouth consumers (see e.g. Kaplan et al. (2018)) and our desire to have a total debt to income ratio in line with the data. Our choice of α will still imply that the model underestimates the total debt to income ratio relative to the data (too many savers without any debt relative to constrained borrowers in the model), but the tension is somewhat moderated.[14]

Third, we set the parameters related to the behavior of borrowers and savers as follows.[15] The speed of amortization parameter is set to yield 46 years of amortization to be in line with Riksbank calculations on the aggregate amortization rate in recent years for Sweden and the average interest rate fixation period is set to 1 year to match the average for Swedish

[14] Specifically, our model implies an aggregate LTI ratio of 83 percent whereas the model which keeps α at 0.79 has an aggregate LTI of 53 percent. The median aggregate LTI of the countries in Figure 1 is close to 200 percent in 2017.

[15] As we have access to granular data from Sweden about the distribution of debt, this part of the calibration focuses on the Swedish case. Furthermore, Sweden appears representative of the countries included in Figure 1.

mortgages.[16] The calibration target for LTI is based on the median loan size-weighted LTI for new mortgage loans obtained by the Swedish FSA, which amounts to 433% on average for 2015-2017, when the low level of the interest rate had been established.[17] The steady state weight on housing in the utility function for patient households, j_P, is set jointly with the corresponding weight for impatient households, j_I, to yield residential investment of 3% of GDP (4% of private sector absorption) and to match LTI of borrowers of 433/2% in the 1990's.[18] The calibration of the LTI and DSTI parameters in the 1990's and the 2010's is done analogously; we simply set the LTI (DSTI) ratio parameter, θ_t^{LTI}, (θ_t^{DSTI}) to get the same LTI of borrowers as in the LTV constrained economy, while accounting for the change in the real rate and the change in the inflation rate. Our aim with this approach is to keep the LTI, DSTI and LTV constrained economies comparable.

Fourth, let us explain the parameters related to housing transactions and home equity withdrawal. The housing transaction cost parameter ϕ_h in eq. (3) is set to match the peak non-housing consumption response to a monetary policy shock for the 1990's version of our model. The target is taken from Cloyne et al. (2018). Specifically, it is the average of the U.S. and U.K. peak response for non-durable consumption of borrowers, i.e. a 0.33% response to a 25 bp monetary policy shock (their Figures 7 and 8; our Figure 6).

4 Accounting for the increased household indebtedness

We now describe how our model can account for the large increase in household indebtedness that occurred from the 1990's to the 2010's as shown in Figure 1. As noted in the introduction, we assume four key drivers: lower real interest rates, easier credit conditions, lower inflationary pressures, as well as an increase in home equity withdrawal. Table 2 reports the parametrization of these four drivers. As we have access to granular data from Sweden about household debt, the calibration focuses on the Swedish case and hence aim to explain

[16] Source: Sveriges Riksbank's own calculations using data from the Swedish FSA mortgage survey. This interest rate fixation period is likely a bit shorter than in other countries, and we have therefore checked that our results are robust with respect to this choice (especially the short-term results in Section 5; the long-term effects in Section 4.3 are unaffected by this parameter).

[17] Source: Swedish FSA mortgage survey 2015-2017.

[18] The model has no government consumption, so before presenting any ratio involving GDP we adjust for this by multiplying by private sector absorption/GDP=3/4, i.e. accounting for a government consumption of 25% of GDP.

a doubling of the aggregate LTI since the 1990's. Nevertheless, the key driving factors (e.g. lower real and nominal rates as well as increased credit supply) are shared with many other advanced economies and we hence believe that the calibration is of general interest and will note below when this might not be the case. Figure 1 shows how real mortgage rates have fallen in recent decades in many economies. This decline is more moderate for countries with a large share of fixed rate mortgage rates (such as the US and Denmark), which might explain why these two countries are not at an all-time high in terms of household indebtedness. A voluminous literature, see for instance Del Negro et al. (2018), argues that this low real rate represents a persistent new regime. Following this evidence, we assume a real interest rate in the 2010's 250bp lower than in the 1990's. In the model, such a fall in the real interest rate accounts for the majority of the indebtedness' increase in the data. Motivated by the evidence in Figure 2, we additionally assume a higher maximum LTV. More specifically, we let the LTV increase by 10 percentage points, as in the data. Figure 3 shows the LTI and LTV distributions of new loans in Sweden 2015-2017. It indicates extreme bunching at 85% LTV while no analogous bunching is visible in the LTI dimension. This observation is also consistent with the microdata in Grodecka (2020) which show that, during 2011-2015, 60% of borrowers taking on new loans in Sweden had an LTV larger than 80%, while around 26% were at their discretionary income limit.[19] We therefore choose the LTV constrained economy as our benchmark. We also note from Figure 1 that inflation rates are lower in the 2010's than in the 1990's. We account for a lower inflation rate in the current decade by calibrating the steady state inflation of the 2010's to 1.5% instead of the 2.0% in the 1990's. This further contributes to the increase in DTI in a setting with long-term nominal debt as lower inflation acts similarly to lower amortization rates. However, these three factors do not cause average indebtedness to rise quite as much as in the data. In line with evidence in Mian and Sufi (2011) we therefore let an increase in home equity withdrawal (HEW) as a fraction of available home equity soak up the residual in the doubling in indebtedness. This implies increasing the HEW share from 1.5% to 2.1% from the 1990's to the 2010's. Both these numbers are in the neighborhood of the empirical evidence for the US, 1.7%, reported

[19] The discretionary income limit (so-called KALP in Swedish) is a borrowing limit used in banking practice which takes into account borrowers after-tax income, housing expenses, a minimum level of consumption and a stressed interest rate.

by Greenspan and Kennedy (2007). Home equity withdrawal appears similar between U.S. and Sweden in terms of frequency and amounts according to Li and Zhang (2017). Jointly, these four factors double the LTI of borrowers, from 217% to 433%.

The decomposition between the debt drivers are as follows. Changing only the interest rate accounts for 54% of the increase in borrowers DTI. Changing also the LTV ratio contributes an additional 24% of the increase and the lower inflation accounts for 10% of the increase. Finally, the increased HEW accounts for 12% of the increase in borrowers' DTI.

Table 3 compares the long-run equilibrium in the low debt economy (the 1990's) and the high debt economy (the 2010's). The table shows that DSTI ratios of borrowers increase substantially less than the increase in debt (and LTI) while the pure interest payment over income (not including amortization) actually decrease slightly. The latter follows from that households wish to spend a fixed fraction of their expenses on housing due to Cobb-Douglas preferences over housing and non-housing consumption combined with the fact that the user cost of housing consists of both the real (after tax) interest rate and housing depreciation. We also note that the lower real rate increases the share of GDP accounted for by both non-residential and residential investment. The increase in the latter is most consequential as it almost doubles between the two debt levels, i.e. between the 1990's and the 2010's. As a result, the economy with a lower real rate is much more exposed to fluctuations in residential investment. This is in addition to the exposure to aggregate demand that the increased indebtedness causes.

Third, the doubling in the LTI ratio between implies an increase in real house prices of roughly one third, below the doubling of real house prices observed in the data (see Figure 1). However, the model-implied value of the housing stock relative to GDP rises by 110 percent, in line with the empirical increase in real house prices.

Fourth, a final take-away from Table 3 is that the steady state properties of the model are approximately invariant to the type of borrowing constraint.[20]

[20] Regarding the dynamics, Figure A.1 in the Appendix documents the monetary policy shock impulse responses across models (i.e. for different borrowing constraints) in a high debt environment. The main take-away from this figure is that the monetary transmission mechanism is quite similar across models, with the exception that in the LTV model borrowers' consumption contracts slightly more.

5 Effects of macroprudential tightening

In this section we characterize the effects of four borrower-based policies aimed at reducing the aggregate loan-to-income ratio by 10.2%: a tightening of the LTV, LTI and DSTI constraints, and a reduction in MID from a starting point of 30%, given an LTV constrained economy.[21]

5.1 Long-term effects

Table 4 reports the long-term effects of tightening the various macroprudential instruments. The reductions in the LTV, LTI and DSTI parameters are set to imply an identical decline in the aggregate long-run loan-to-income ratio (10.2%) as obtained when removing MID in the high-debt LTV-constrained economy. This scaling is done separately for the low indebtedness and the high indebtedness regime. In the low indebtedness regime the LTV ratio is reduced from 0.75 to 0.65 and in the high indebtedness regime it is reduced from 0.85 to 0.77.[22]

The aggregate long-term effects of all the four policies on output and consumption are moderate. Output falls in response to all debt-reducing policies under consideration, even if the mechanisms are different. When a collateral constraint is binding (LTV and MID tightening), reducing debt capacity has a small, positive effect on borrowers consumption, while housing investment and house prices instead strongly contract. The large housing decrease of borrowers in response to a tighter LTV constraint stems mainly from the decreased usefulness of housing as collateral as discussed previously in the stylized model (Section 2). When MID is removed, debt-financed housing effectively (after tax) becomes more expensive and borrowers accordingly reduce their housing stock. In the long run, borrowers instead devote a higher share of their income to non-housing consumption. The resulting fall in their marginal value of wealth induces borrowers to work less, thereby causing the observed contraction in output.

[21] Our definition of macroprudential policy is consistent with the one adopted by the ECB, which defines it as any tool which prevents the excessive build-up of risks and smooths the financial cycle over time. In the following, we treat mortgage interest deductibility as a macroprudential instrument because the way we implement the policy avoids any re-distributional effects between borrowers and savers (borrowers fully pay for the mortgage interest rate deductions by lump-sum transfers).

[22] In the low debt environment, mortgage deductibility is only reduced to 6.35% to obtain a 10.2% reduction in the aggregate loan-to-income ratio.

On the contrary, when debt is constrained by labor income (LTI and DSTI tightening), the fall in house prices and housing investment is much smaller as explained in our analysis with the stylized model in Section 2. In the high-debt economy, borrowers will also reduce their non-housing consumption in response to an LTI tightening, and their labor supply decreases as labor income loses part of its "collateral" value. Specifically, when households are allowed to borrow in proportion to their labor income, the borrowing limit has a direct, positive, impact on their labor supply as impatient households work more to be able to borrow more.

Comparing tightening of LTI and DSTI constraints, we notice that they have basically identical effects on all variables in the long run. The result reflects that the only difference between these two constraints is that DSTI takes into account the time-variation in the nominal interest rate (and neither an LTI nor DSTI change will affect the nominal rate in the long run). Finally, we note that the long-term aggregate effects on the economy of the debt reducing policies are roughly invariant, in percentage terms, to the debt level. So the basic mechanisms at work in the long-run are not contingent on the initial debt level.

5.2 Short-run effects

We now turn to analyzing the short-run effects of the various MPP tools. First, we focus on the macroeconomic effects of an LTV tightening in a low vs. high debt economy when the economy is in a liquidity trap. Next, we compare the effects of an LTV cut with those obtained for alternative borrower-based MPP tools (LTI/DSTI constraints and MID). However, we begin with explaining how we generated a baseline in which the economy is driven to the zero lower bound (ZLB).

5.2.1 Simulations set-up

The economy is assumed to be driven to the ZLB by a mix of adverse shocks which lowers inflation below the central bank's targeted rate and drives down output below its potential level. In our setting in which the only nonlinearity is the ZLB constraint, there is no need to specify which particular shock(s) have driven the economy to the ZLB. The only thing that matters is the path of the notional, or shadow rate $\hat{R}_t$ in eq. (16), as the path of this variable determines the expected duration of the ZLB which we assume is two years absent any MPP changes.[23] When we add the various MPP tools to the baseline scenario, the duration of the liquidity trap is kept unchanged. This means that we consider the marginal effects (ZLB duration fixed) as opposed to the average effect (ZLB duration extended to the extent that the MPP impacts the economy adversely). Hence, the implicit assumption is that the central bank is able to cut rates as much as needed after the two years it is constrained by the ZLB in the baseline scenario without any MPP measures.[24] Had we instead focused on the average effects and allowed the duration of the liquidity trap to change in response to the MPP actions, our results would have further strengthened as the difference between LTV and LTI/MID would be even greater. In light of this, the results we report are conservative.

We implement the short-run experiments for debt reduction in the following way. The change in the LTV, LTI and DSTI parameters is modelled as an AR(1) with a coefficient arbitrarily close to unity. Hence, we think about these changes as structural and not driven by any rationale to fine-tune cyclical variation in indebtedness or the economy. Noting that the LTV/LTI/DSTI constraint only applies to new mortgage loans while mortgage deductibility pertains to the entire stock of outstanding loans, we use an AR(2)-process for the latter to obtain a gradual reduction of MID (τ_t) and thereby a similar path for household debt as induced by an LTV tightening. In particular, τ_t in eq. (7) follows

$$\Delta\tau_t = \rho_{\tau,1}\Delta\tau_{t-1} - \rho_{\tau,2}\left(\tau_{t-1} - \tau\right) + \varepsilon_{\tau,t},$$

where we set $\rho_{\tau,1} = 0.9$ and $\rho_{\tau,2} = 0.0000001$ to achieve a near-permanent gradual decline in τ.

5.2.2 Tightening of LTV and the importance of the debt level

Panel A in Figure 4 reports the aggregate responses to the reduction in the LTV ratio when monetary policy is constrained by the ZLB for 8 quarters, for a high and low debt economy, respectively. The message of this panel is twofold: i) The economy's transition in response to

[23] For proof, see e.g. Erceg and Lindé (2014).
[24] See Erceg and Lindé (2014) for an detailed discussion of the difference between marginal and average impulses in a liquidity trap.

an LTV tightening implies large costs in terms of inflation and output when monetary policy is constrained, and ii) these costs are roughly three times as large in the high debt economy. In particular, GDP and inflation will initially fall by about 3 and 1 percent, respectively, in the high debt economy in response to an LTV tightening that reduces LTI by 10.2% in the long run.[25] The corresponding numbers for the low debt economy is a 0.8 percent reduction in GDP and a roughly 0.3 percent reduction in inflation.

To understand the drivers behind this large contraction in the high debt economy, Figure 5 reports the disaggregate effects of the LTV cut in the setting where monetary policy is constrained by the ZLB. The LTV tightening has a direct effect on borrowers' borrowing capacity and therefore their demand. There is also an indirect strong endogenous contractionary effect on their debt capacity as house prices fall by more than 5 percent on impact (vs. 2.6 percent in the low debt economy). Note that there is "overshooting" in the reduction of the borrowing capacity. As house prices gradually recover over time so does borrowing capacity and thereby aggregate demand. In addition, there is a further endogenous reduction of borrowing capacity as borrowers reduce their housing stock by almost 1 percent on impact, and then gradually more over time. All three major components of aggregate demand fall in response to the LTV reduction. Residential investment is most adversely affected, followed by aggregate (non-housing) consumption and non-residential investment.[26] The fall in aggregate consumption is due to the large initial contraction in borrowers' consumption. We note that this reduction in borrowers' consumption is four times as large in the high debt regime whereas the reduction in borrowers' housing stock is similar across debt regimes. Quantitatively, the housing transaction costs are important for this response as they influence borrowers' willingness to off-load housing to savers in the short-run. An additional reason for the gradual decline of the borrowers' debt and housing stock is that the tightened LTV only applies to new loans.

Two main forces are behind our finding that an LTV tightening contracts GDP three times more in the high debt economy. First, the LTV tightening requires more monetary accommodation in a high debt economy. To show this, Panel B in Figure 4 reports the

[25] That is, a reduction in borrowers' LTI from 433 to about 390 percentage points in the high debt economy.

[26] The strength in the decrease in residential investment might appear extreme. But properly accounting for the volatility of this variable moderates this impression. There are many occasions is the recent history when residential investment has fallen by more than 10 percent within a year, see Figure 1.

aggregate responses to the identical LTV cut when monetary policy is unconstrained. Note that the unconstrained policy rate response is three times larger compared to the low debt economy.[27] Second, monetary policy is more potent in a high debt environment. This has the unpleasant implication that a ZLB is a particularly detrimental constraint in such an environment. To show this, Figure 6 reports the aggregate effects of a hike in the policy rate with 25 basis points for both high and low debt economies. The figure documents that the inflation response to a monetary shock is only mildly amplified in the high debt regime. Even so, output responds much more (by roughly 50%) to monetary policy shocks in the high debt regime. The reason that output responds more strongly in that regime is the greater contribution from residential investment as well as borrowers' consumption. Figure 6 reports the main demand components (in terms of their contribution to GDP) to make the responses comparable between indebtedness regimes; as documented in Table 3 both forms of investment constitute a substantially larger share of GDP in the high debt regime.

5.2.3 Short-run effects of income-based MPP tools

We now relate our previous findings to the effects of income-based MPP tools and show that the impact of the latter can differ substantially in the short-run. Specifically, when the economy is highly exposed to housing markets and monetary policy cannot accommodate, the short-term macroeconomic costs of an LTI or an DSTI tightening are substantially lower than from an LTV tightening.

Figure 7 reports the aggregate responses to various MPP tools – calibrated to achieve the same long-term LTI reduction – when monetary policy is constrained by the ZLB for two years and indebtedness is high.[28] Figure 8 quantifies these dynamics for a larger set of variables. The figures indicate that the dynamics induced by LTI and DSTI tightenings are nearly identical.[29] Moreover, Figure 7 shows that the initial output (inflation) response is more than three times (twice) as strong in the case of tightening the LTV constraint. There are two reasons for this. First, an LTV tightening triggers a negative feedback loop on

[27] We are not describing optimal monetary policy, but simply noting that the Taylor rule used seems appropriate in the sense that it trades off deviations in inflation against deviations in output in response to the LTV tightening.

[28] The figure also includes MID removal which will be discussed in section 5.2.4.

[29] This is unsurprising as the implications of tightening the DSTI constraint only differ from tightening the LTI constraint to the degree that it induces changes in the interest rate.

borrowing capacity as house prices are part of the collateral constraint (8). We demonstrated this effect qualitatively already in our simple two-period model.

Second, and equally important, lower house prices trigger an adverse impact on aggregate demand and reduces the potential real rate which can only be offset if the central bank is able to accommodate the MPP tightening with an aggressive policy rate cut. This channel further amplifies the adverse effects of the LTV tightening. The corresponding negative feedback loop is much weaker in the LTI/DSTI case as borrowers can increase their short-term labor supply so as to smooth their consumption.

Figure 9 disentangles these two channels by presenting three simulations. First, the blue solid line in the Figure reports our baseline simulation; second, the red dotted line shows a simulation aimed at parsing out the house price (q_t) feedback loop by replacing q_t with its steady state value q in the collateral constraint (8); and third, the black dashed line illustrates the response to an LTV tightening in an economy where the initial fall in q_t is limited to its long-run value (i.e. do not overshoot in the near term) due to a temporary boost in savers' housing demand. This last experiment is meant to capture the interaction between house prices and aggregate demand.[30] Panels A and B show the effects when monetary policy is at the ZLB and unconstrained, respectively.

When the aggregate effect on housing demand is muted (black dashed line in Panel A), the short-term effects of an LTV tightening are similar to the LTI/DSTI results in Figure 7. At the same time, the simulation with a constant house price q in the collateral constraint is roughly half-way between the no-overshooting case (less than 1 percent fall in output) and the baseline simulation (more than 3 percent decline in output).

From this simple exercise, we can draw two main conclusions: i) house prices play a crucial role in the transmission mechanism of an MPP tightening; and ii) about half of the additional adverse effect of an LTV tightening relative to the LTI/DSTI case is accounted for by the feedback loop in the collateral constraint while the other half is due to the aggregate demand effect. Panel B makes clear that monetary policy plays a key amplifying role (as argued earlier).

[30] We achieve this by adding a positive housing preference shocks $j_{P,t}$ for the savers (see utility functional 1).

The amplification mechanism and the related overshooting in our LTV model is not new in the literature. It is simply another incarnation of the financial accelerator outlined by Bernanke et al. (1998), Kiyotaki and Moore (1997) and Iacoviello (2005). What is new here is that we show that this mechanism is amplified considerably in a low real rate/high debt environment with monetary constraints.

5.2.4 Short-run effects of an MID removal

Finally, we show that our model implies that even gradual MID removal can entail significant macroeconomic costs when interest rates are low and LTV constraints are binding.

The green lines in Figures 7 and 8 report the results of a gradual MID removal when monetary policy is constrained. This puts downward pressure on house prices as it increases the effective (after tax) user cost of debt-financed housing. Even though MID is only gradually removed, the house price fall occurs immediately due to the forward-looking nature of asset prices. The reason that the macroeconomy contracts strongly is that the fall in house prices reduces borrowing capacity because of the LTV constraint. Quantitatively the macroeconomic contraction is almost as strong as for an LTV tightening. On the contrary, a removal of MID under LTI or DSTI constraints would require no monetary accommodation and only gradually reduce output as shown in Figure A.2 in the Appendix.

The main take-away from this analysis is that removing mortgage deductibility under LTV constraints can be associated with large short-run macroeconomic costs even in a environment with low current interest rates if households are forward-looking and expects interest rates to rise within a foreseeable future.[31] So even in this case, more favorable short-term effects are instead obtained by imposing LTI or DSTI constraints when deleveraging.

6 A multiconstraint framework

So far, we have focused on scenarios where only one type of borrowing constraints binds at a time and have shown that LTI tightenings are much less contractionary than LTV

[31] Karlman et al. (2020) also find that although MID removal leads to welfare improvements in the long-run, it is costly, even welfare reducing, due to the transition it implies. In their case it is the transition costs at the individual level that is the main driver of this result. In fact output is exogenous in their model, so the demand shortages we explore are abstracted from.

cuts. Recently, a number of papers (see e.g., Greenwald (2018), Justiniano et al. (2019) and Grodecka (2020)) have shown that the monetary policy transmission mechanism and overall model dynamics may differ notably in a multiconstraint framework. As a robustness check, we therefore compare our two main macroprudential tools when the LTI and LTV constraints bind at the same time. Even so, it is important to keep in mind that LTV and LTI constraints bind jointly for only a subset of the borrowers; for Sweden Grodecka (2020) reports that the case pertains to 14 percent of the borrowers. Nevertheless, the results in this section show that our conclusions are unaffected even for this unusual case: an LTV tightening is still more contractionary than a tightening of the LTI constraint.

Consider the model described in Section 3 modified to take into account that households' debt can be constrained by equations (8) and (9) simultaneously. Now, consider a separate contraction in the LTI or the LTV limit aimed at reducing the aggregate loan-to-income ratio in the long-run by the same amount as in Section 5. As before, assume the economy is initially in a liquidity trap.

An LTV tightening $\left(\theta^{LTV}\downarrow\right)$ required to achieve the same reduction in the debt to income ratio we targeted in the other experiment makes the LTI constraint not binding in the long-run. Thus, starting from a multiconstraint framework, a 10% reduction in long-run indebtedness brings us back to the one-constraint environment analyzed in Section 5. This confirms the findings of Grodecka (2020) who shows analytically in a simple multi-constraint setting how stricter LTV limits expand the region where the income-based constraint is slack.

On the contrary, after an LTI tightening $\left(\theta^{LTI}\downarrow\right)$ both constraints remain binding even in the long-run. Figure 10 illustrates the dynamics of this policy experiment under the assumption that the economy is in a four-quarter liquidity trap. Three main lessons can be drawn from this exercise. First, the response of output in the multiconstraint economy is similar to the one in the LTI-constraint-only model. Second, inflation and house price dynamics are different, specifically an LTI tightening in a multiconstraint setting has a moderately stronger effect on house prices and is less deflationary on impact - the latter has a moderating effect on the length and severity of a liquidity trap, i.e. after four quarters the economy recovers and interest rates are well above zero. Third, the response of labor supply differs considerably in the two models. Looking closely at the disaggregated effects in Figure 11, the LTI cut triggers a weaker response of labor supply and a milder reduction in borrowers consumption in a two-constraint world. The lower labor supply compared to the one-constraint model creates inflationary pressures, thereby shortening the duration of the liquidity trap.[32] The weaker response of consumption is a reflection of the fact that even if the LTI limit is reduced, housing has collateral value and the reduction in borrowers' LTI is more gradual. As expected, the presence of a collateral constraint induce a stronger response of house prices compared to the LTI-constraint-only model, however quantitatively the effects are moderate. In Greenwald (2018), the so called constraint switching effect, from a binding income-based limit to a binding LTV limit in response to a monetary *easing* is key to generate larger movements in house prices and the resulting amplification. All else equal, a monetary tightening would make Greenwald's PTI (Payment-to-income) limit more binding. That is, the constraint switching effect is non-linear. In our set-up, both constraints bind when the LTI limit is reduced. And in this case, the effects of macroprudential policies are not amplified.

To sum-up, the results of this section confirm our previous findings, an LTI tightening remains a more efficient macroprudential policy to deleverage than an LTV tightening even when households are subject to multiple constraints. Although not shown here, this is true regardless of whether monetary policy is unconstrained or at the ZLB.

7 Welfare implications of reducing debt limits

A possible critique of our analysis so far is the absence of a welfare justification for using macroprudential tools, e.g. an LTV tightening, to reduce household indebtedness. In fact, this type of critique is often voiced in response to proposals for increased macroprudential regulation. In this section we tackle this issue and assess the welfare gains of tightening the LTV constraint, eq. (8) both for society as a whole and separately for the two types of households. We perform this exercise in our high debt (low steady state real and nominal rate) economy. To perform this analysis, we follow Schmitt-Grohe and Uribe (2007) and approximate lifetime utility up to second-order. Specifically, we compute a second-order

[32] This is the reason why we use a 4-quarter ZLB episode to illustrate the results in this section.

approximation of the model around its non-stochastic steady state and simulate the pruned system (following Andreasen et al. (2018)) for a large number of time periods (5,000) for different LTV values. Importantly, we use exactly the same innovations to all estimated shock process for each LTV value we consider. This way, we parse out the partial derivative of the steady state LTV value in the borrowing constraint.

We then consider the unconditional welfare (W_P and W_I) of the two groups of households in our economy by computing the stochastic mean of their discounted sum of utility along the equilibrium path. Following Lambertini et al. (2013), we also construct a measure of social welfare

$$W_S = (1 - \beta_P) W_P + (1 - \beta_I) W_I$$

where the chosen social weights assign equal welfare to the two groups of households for the same constant consumption stream.

Two alternative assumptions about the conduct of monetary policy are considered. As a benchmark, we assume that the central bank is unconstrained when setting policy rates. Under this assumption, the central bank can always set the policy rate as low as it deems appropriate according to the interest rate rule eq. (16), and abstract from the ZLB in eq. (15). In our second case, we assume that the central bank is constrained by an effective lower bound (zero here) on policy rates when setting the policy rate. To impose the ZLB on the second-order system, we follow Hebden et al. (2010) and add positive current and anticipated monetary policy shocks when the ZLB binds. Under this procedure, the current and expected policy rate is non-negative in each state.

The presence of a ZLB constraint amplifies the welfare costs related to high indebtedness. A higher LTV will trigger an increase in macro volatility and hence in the frequency of hitting the ZLB constraint. This last channel entails larger welfare costs and in low interest rate environment these costs are substantial.

The estimated shock processes are all adapted from Iacoviello and Neri (2010), with one exception. Since we are considering a low-interest environment (i.e. a steady state nominal interest rate of 2 percent instead of 5 percent as in Iacoviello and Neri (2010)), we allow for the possibility that the variance of the estimated monetary policy shock is lower than its historical average. Specifically, we shrink the standard deviation of the monetary policy shock by the ratio of the steady state nominal interest rate in our model and the average Federal funds rate in Iacoviello and Neri (2010)'s sample (1965-2006). In doing so we obtain a modified standard deviation of monetary policy shocks of about 34 percent of the value estimated in that paper. Had we used the historical estimated value, the welfare costs when imposing the ZLB on the policy rate would have been significantly larger and the optimal unconditional LTV value notably lower.

The results of the welfare calculations are reported in Figure 12. The upper panels show (from left to right) total, savers and borrower average welfare as function of the steady state LTV level, θ^{LTV}, in eq. (8). As noted previously, we present results when the ZLB is imposed (red line with *'s) and when the ZLB is not imposed (blue line with x's).

When monetary policy in unconstrained, the unconditional social welfare is maximized for an LTV of about 0.85, which is the benchmark value in our high indebtedness model (to be exact, maximum welfare is obtained for an LTV of 0.84). From the second panel we see that the savers welfare is monotonically increasing in the LTV value, whereas the third panel shows that borrower's welfare is deteriorating when the steady state LTV exceeds 0.77. Hence, the LTV level which maximizes total welfare trades off the utility gains the savers obtain with a higher LTV with the utility costs the borrowers experience for higher LTV values. Higher LTVs have a negative impact on borrowers' welfare as it causes an increase in their consumption volatility. For relatively low values of the LTV, the welfare of the savers dominates but for higher LTVs the increasing rate of deterioration of borrowers' welfare dominates.

When the ZLB is imposed, however, total welfare is maximized for a notably lower LTV value (0.71) in our model. As seen from the second and third panel, the lower optimal LTV value is entirely driven by lower welfare of borrowers for higher LTV values. Hence, a tightening of macroprudential policy from an LTV value of 0.85 to 0.75 can be rationalized on unconditional welfare grounds in an environment where the ZLB is taken into account.

Our results indicate that borrowers are more negatively affected by the ZLB than savers. To shed light on this issue, the lower panels in Figure 12 show the simulated distributions for the output gap (left), non-housing consumption of savers (middle) and borrowers (right) for an LTV fixed at 0.70. As can be seen here, the ZLB introduces a severe left skew for the output gap and non-housing consumption of borrowers, which is very costly in terms of welfare. Savers non-housing consumption, on the other hand, is largely unaffected by the ZLB, presumably because the savers can use their savings to smooth their non-housing consumption and gain from buying cheaper houses from the borrowers when the ZLB binds.

Finally, we note that our analysis implicitly assumes that neither unconventional monetary policy (UMP) nor fiscal policy tools are available to stabilize the economy when the ZLB binds. Given the existence of UMPs, this assumption may bias the results in favor of a too low optimal LTV value. On the other hand, there is a considerable debate on the effectiveness of UMP to deal with deep recessions (see e.g. CGFS Report (2019) and the references therein) and whether fiscal policy can act quickly and forcefully enough to provide meaningful relief in recessions. Moreover, it should be noted that the ZLB does not bind unreasonably often in our simulations: the economy is only at the ZLB in about 300 out of 5,000 simulated periods when LTV equals 0.7 (i.e. with a probability of 0.06). Hence, our finding of a lower optimal LTV ratio when the policy rate is subject to an effective lower bound may hold up well even if we allow for fiscal policy and UMP unless those tools can be designed to put money directly in the hands of constrained borrowers.

8 Conclusions

We documented four factors that together can account for a doubling of household indebtedness between the 1990's and the 2010's in several advanced economies, with the lower real mortgage rate as the main driver.

Our findings show that in the presence of an effective lower bound on policy rates, there is a need to limit household indebtedness from a welfare perspective even if house prices are consistent with fundamental values.[33] Specifically, taking into account the ZLB, our model implies that unconditional welfare is maximized when LTV on new loans is capped around 70 percent – significantly lower than the welfare-maximizing LTV level in a setting where monetary policy is never constrained by the ZLB. The limited ability of the central bank to provide monetary stimulus in a recession is an important reason to restrict household bor-

[33] See Biljanovska et al. (2019) for a model considering optimal macroprudential policy in the presence of asset price bubbles.

rowing as monetary handcuffs imply higher volatility of borrowers' non-housing and housing consumption in settings with high LTV.

But how should household indebtedness be reduced when debt is already above its welfare maximizing level to begin with? To study this issue, we compared both short- and long-term effects of a number of borrower-based macroprudential tools. We find that the long-term output costs of all the macroprudential measures (tightening of LTV, LTI or DSTI ratios or lower mortgage interest deductibility) are moderate. The short-term effects, however, depend critically on which MPP tool that is used. In an environment with elevated debt levels and little scope for the central bank to cut rates, an LTV tightening or reduction in mortgage deductibility may be associated with a significant drop in output and consumption in the near-term as they generate a large housing price decline which triggers an adverse impact on aggregate demand and reinforces a transitory negative feedback effect on borrowing capacity as prices are part of the collateral constraint. Under these initial conditions, LTI or DSTI tightenings are more efficient tools to curb household debt with lower output cost. The reason is that these tools avoid the adverse feedback effects through the collateral constraint, that they induce a smaller fall in the aggregate demand due to a milder fall in house prices and that borrowers can offset the tightened borrowing limit by increasing their labor supply. Hence the economy is less dependent on monetary accommodation. When the initial debt level is lower and monetary policy is unconstrained, the short-term costs will be smaller and any of the four MPP tools studied in this paper can be used to reduce indebtedness at low output cost.

Some important extensions are left for future research. For example, although our theoretical framework is quite rich, it does not allow for heterogeneity between borrowers. It would be interesting to examine the robustness of our policy conclusions in a framework that does allow for such heterogeneity. It is conceivable that a such a framework would imply that a combination of tools, with different tools binding for different borrowers, may entail lower short-term costs or better address long-term financial stability risks. Allowing for borrower heterogeneity may also show that macroprudential deleveraging engineered solely through lower loan-to-income limits may require shutting down access to credit disproportionately for low income borrowers.

All told, our findings stress that when designing macroprudential policies aimed at addressing current household debt imbalances, it is critical to account for their interaction with monetary policy and the current state of the economy. Extending the model to heterogeneous borrowers with different binding borrowing constraints would improve the welfare analysis although it most likely would not change the main results in the paper.

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9 Tables and Figures

Table 1: Calibrated structural parameters.

Description	Symbol	Value
Capital share in the goods production function	μ_c	0.35
Capital share in the housing production function	μ_h	0.10
Land share in the housing production function	μ_l	0.10
Intermediate share in the housing production function	μ_o	0.10
Gross markup in prices and wages	X, X_{wh}, X_{wc}	1.15
Housing depreciation	δ_h	0.005
Capital depreciation, non-housing sector	δ_{kc}	0.025
Capital depreciation, housing sector	δ_{kh}	0.03
Taylor rule coefficient on inflation	r_π	2.00
Taylor rule coefficient on output gap	r_{Δ_y}	0.50
Taylor rule coefficient on output	r_y	0.25
Taylor rule smoothing	ρ_R	0.75
Calvo price rigidity	θ_π	0.9200
Calvo wage rigidity, non-housing sector	θ_{wc}	0.7920
Calvo wage rigidity, housing sector	θ_{wh}	0.9118
Price indexation	ι_π	0.6911
Wage indexation, non-housing sector	$\iota_{wc},$	0.08301
Wage indexation, housing sector	ι_{wh}	0.41186
Share of patient hhs	α	0.67
Consumption habit	$\varepsilon_P, \varepsilon_I$	0.70
Capital utilization cost	ζ	0.70
Investment adjustment costs non-housing sector	S_c''	5.316
Investment adjustment costs, housing sector	S_h''	7.485
Inverse Frisch elasticity, patient hhs	η_P	0.5238
Inverse Frisch elasticity, impatient hhs	η_I	0.5060
Sectorial labor mobility, patient hhs	ξ_P	0.6833
Sectorial labor mobility, impatient hhs	ξ_I	0.9654
Amortization rate on hhs loans	κ	0.0075
Share refinancing	Φ	0.3
Housing preference weight, patient hhs	j_P	0.1235
Housing preference weight, impatient hhs	j_I	0.2316
Housing transaction costs	ϕ_h	10

Table 2: Parameters that drive the change in indebtedness.

Parameter	Moment	Low debt		High debt	
		Value	Target	Value	Target
β_P	Real rate	0.9925	3%	0.99875	0.5%
θ^{LTV}	LTV	0.75	75%	0.85	85%
$\bar{\pi}$	Inflation rate	0.005	2%	0.00375	1.5%
γ	HEW fraction	0.015	-	0.02095	LTI=433%

Table 3: Long-run equilibrium in low debt vs. high debt economy (in percent)

	Low debt			High debt		
	LTV	LTI	DSTI	LTV	LTI	DSTI
LTI borrowers	217	217	217	433	433	433
DSTI (after tax) borrowers	14.2	14.2	14.2	19.1	19.1	19.1
Interest (after tax)/income of borrowers	7.67	7.67	7.66	6.08	6.08	6.07
Non-residential investment /GDP	17.1	17.2	17.2	20.9	20.9	21.0
Residential investment /GDP	3.0	2.6	2.6	5.2	4.4	4.4
House prices (%Δ from 1990's to 2010')				36.5	34.4	34.4

Table 4: Steady state effects of MPP in the two indebtedness regimes (percent change).

	Low debt				High debt			
	LTV		LTI	DSTI	LTV		LTI	DSTI
	LTV	MID	LTI	DSTI	LTV	MID	LTI	DSTI
Aggregate LTI	-10.2	-10.2	-10.2	-10.2	-10.2	-10.2	-10.2	-10.2
Output	-0.23	-0.27	-0.34	-0.34	-0.32	-0.37	-0.56	-0.56
Consumption	-0.11	-0.12	-0.33	-0.34	-0.07	-0.08	-0.56	-0.56
Non-residential investment	-0.17	-0.20	-0.34	-0.34	-0.20	-0.24	-0.56	-0.56
Residential investment	-2.72	-3.48	-0.37	-0.37	-3.05	-3.56	-0.58	-0.58
House prices	-1.06	-1.37	-0.04	-0.05	-1.21	-1.41	-0.07	-0.07
DSTI (after tax) of borrowers	-10.2	6.24	-10.2	-10.2	-10.2	2.09	-10.2	-10.2
Interest/income (after tax) of borrowers	-10.2	20.2	-10.2	-10.2	-10.2	28.32	-10.2	-10.2
Consumption of borrowers	1.07	1.20	0.37	0.38	0.98	1.11	-0.33	-0.33
Housing of borrowers	-7.03	-9.21	0.42	0.42	-7.94	-9.30	-0.27	-0.27
Hours worked of borrowers	-1.05	-1.23	-1.31	-1.31	-1.11	-1.27	-1.79	-1.79
Income of borrowers	-0.26	-0.32	-0.34	–0.34	-0.38	-0.44	-0.56	-0.56

Note: In the high debt environment, mortgage interest deductibility (MID) is completely removed.
In the low debt environment, MID is reduced to 6.35% to obtain the same reduction in LTI.

Figure 1: International Evidence

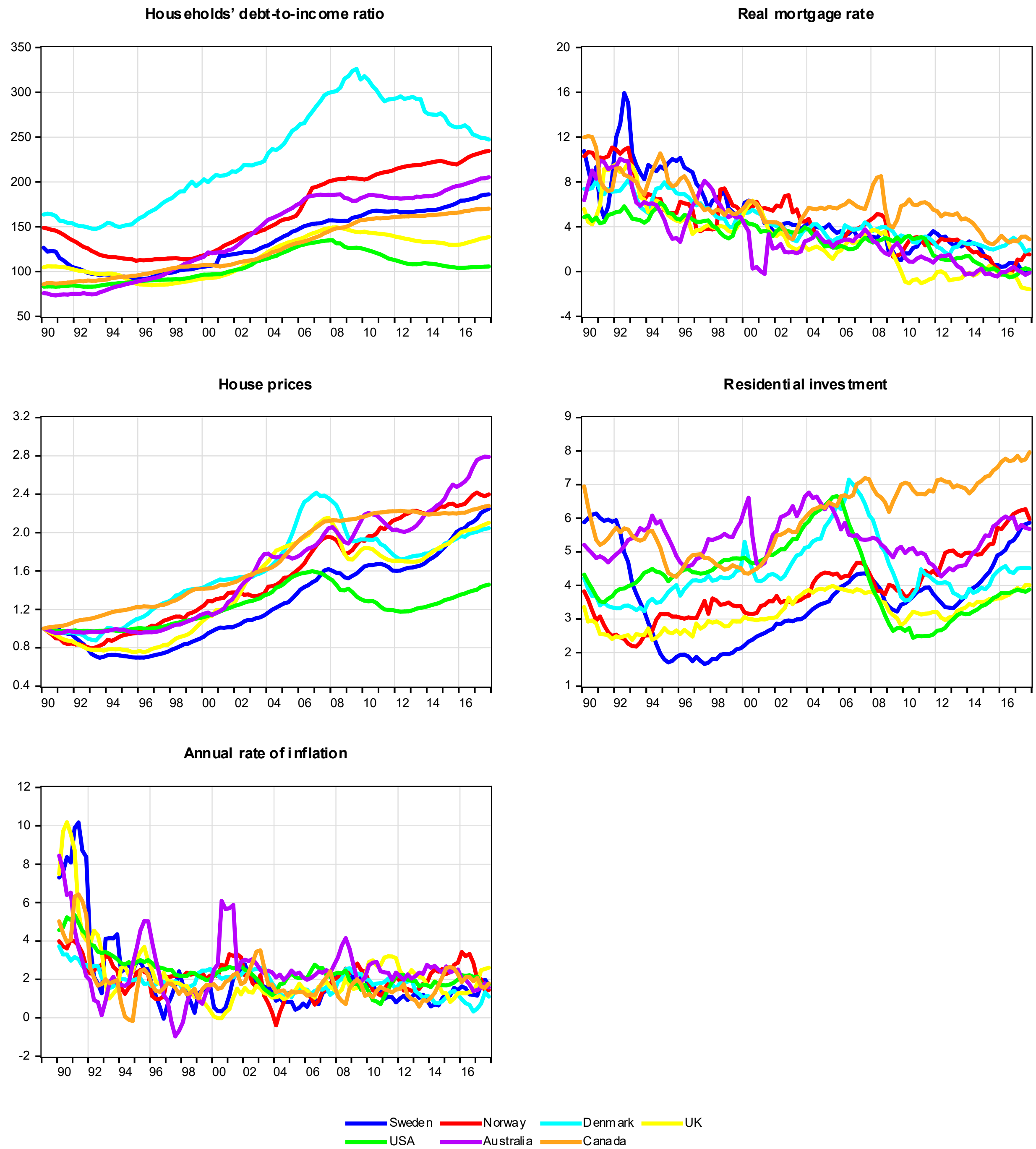


Figure 2: LTV in Sweden

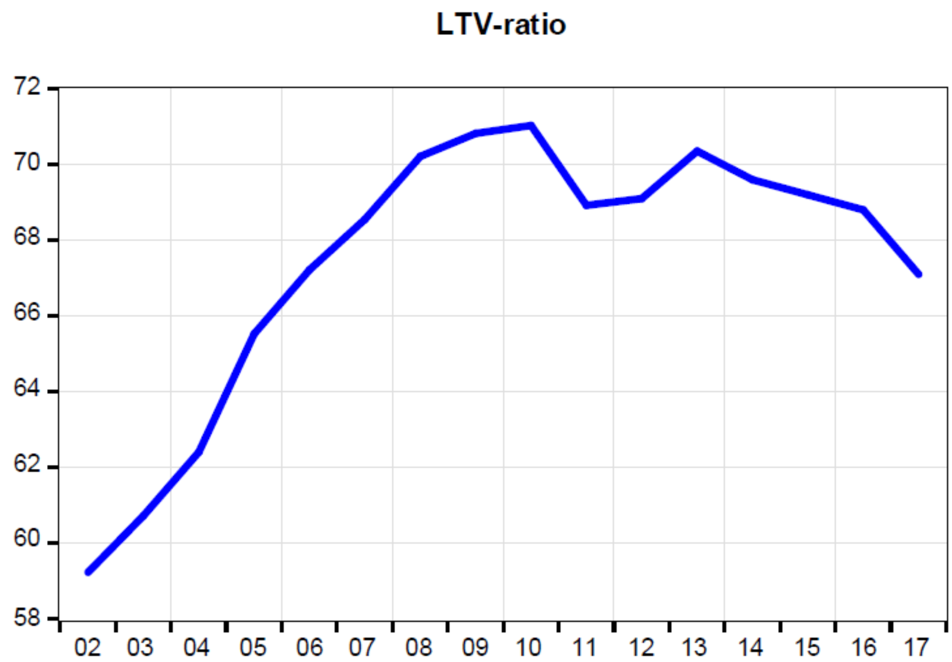


Figure 3: LTI and LTV in Sweden, average 2015-2017. Source: Swedish FSA Mortgage Survey

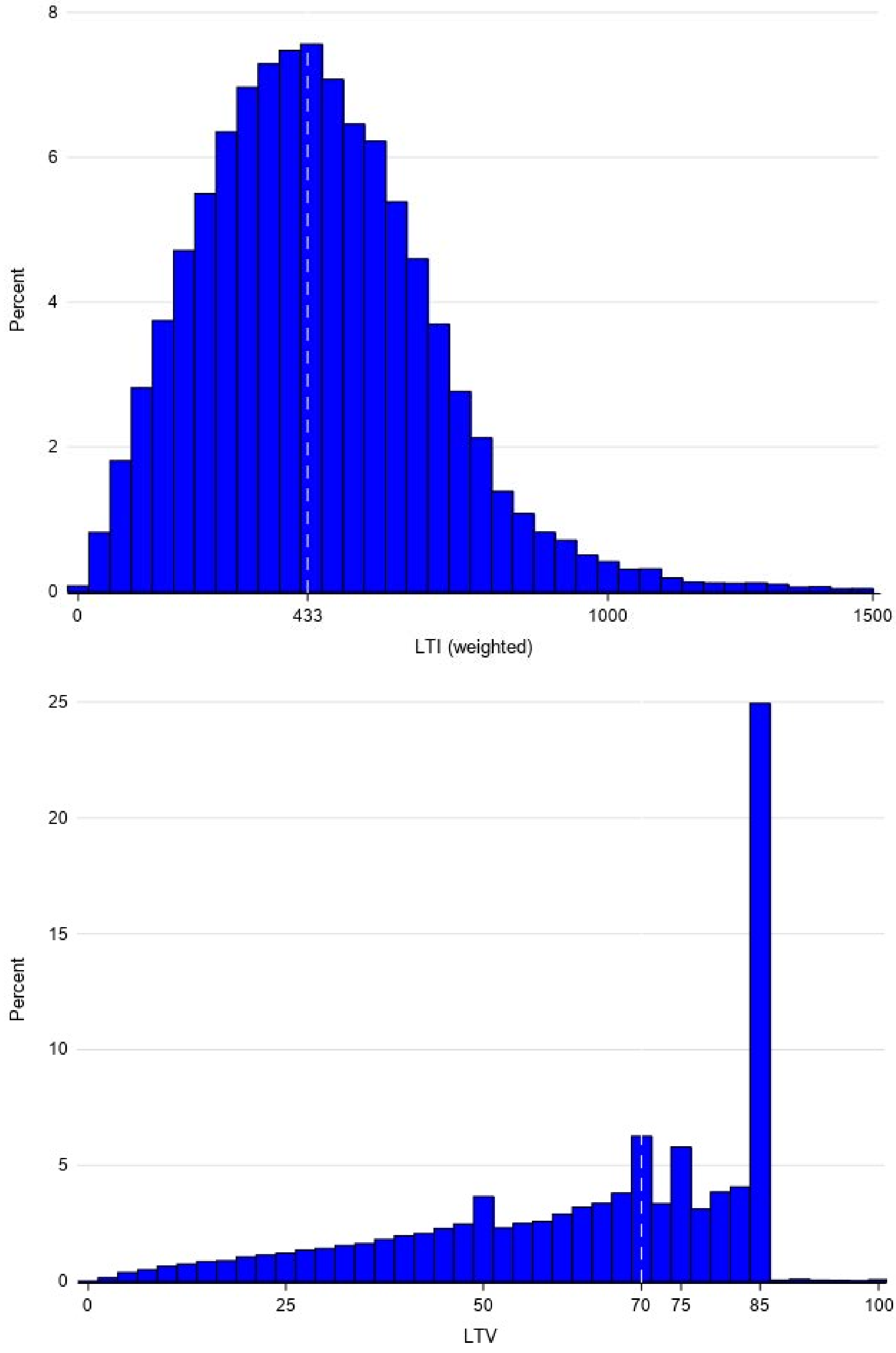


Figure 4: Aggregate effects of LTV tightening under alternative household leverage assumptions.

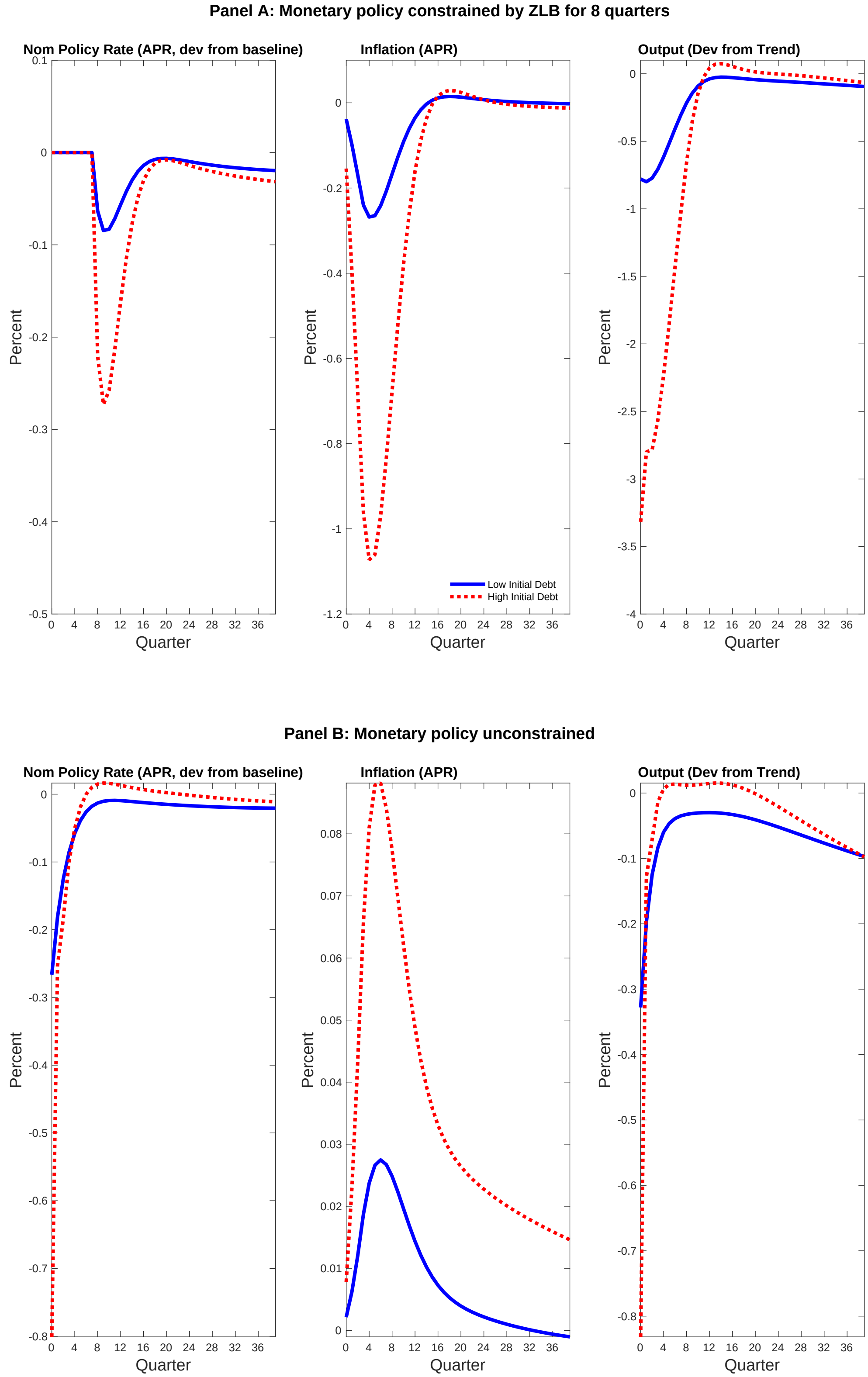


Figure 5: Disaggregate effects of permament LTV tightening in a liquidity trap under alternative household leverage assumptions

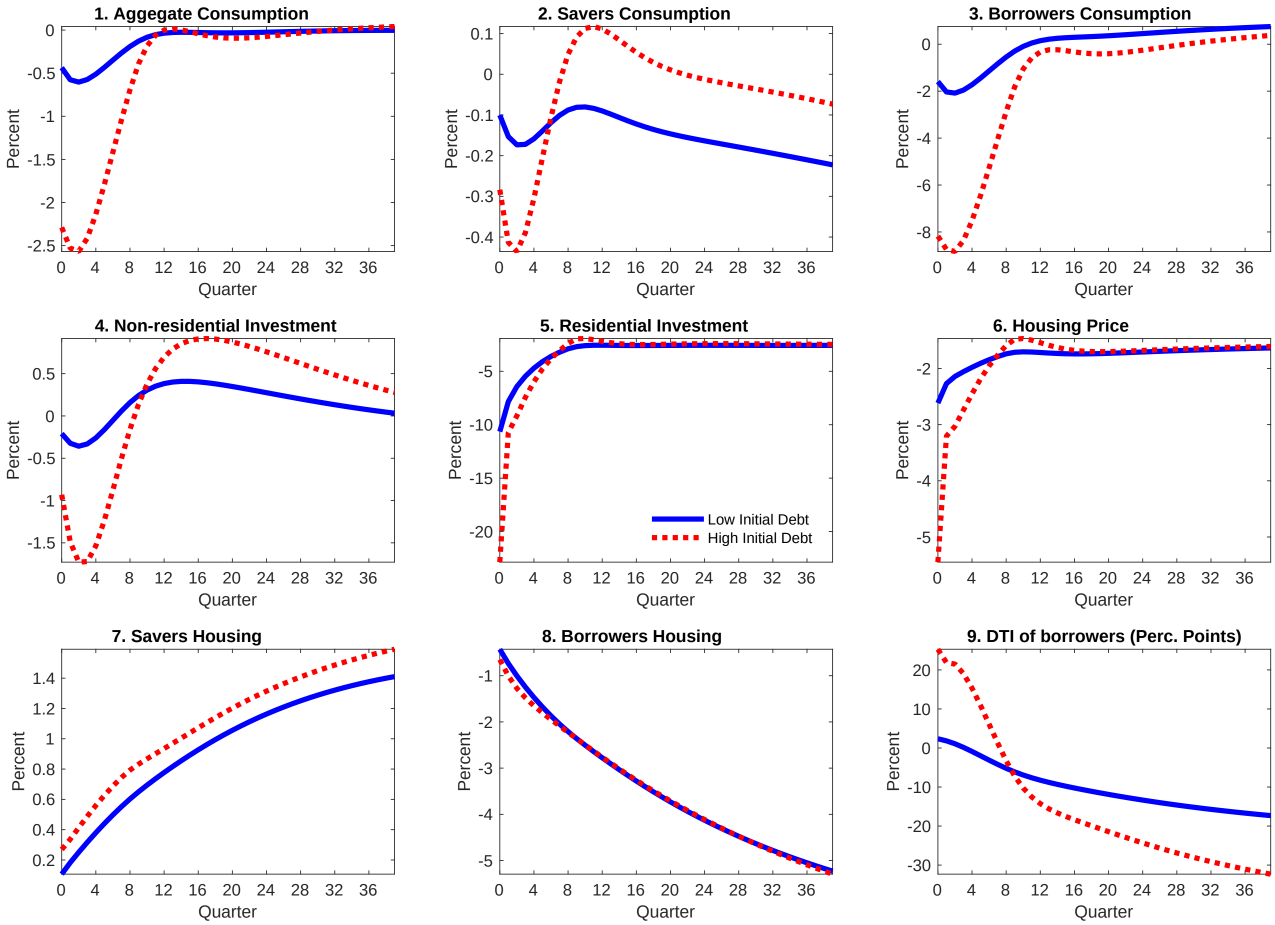


Figure 6: Effects of a contractionary monetary policy shock under alternative household leverage assumptions in the LTV model

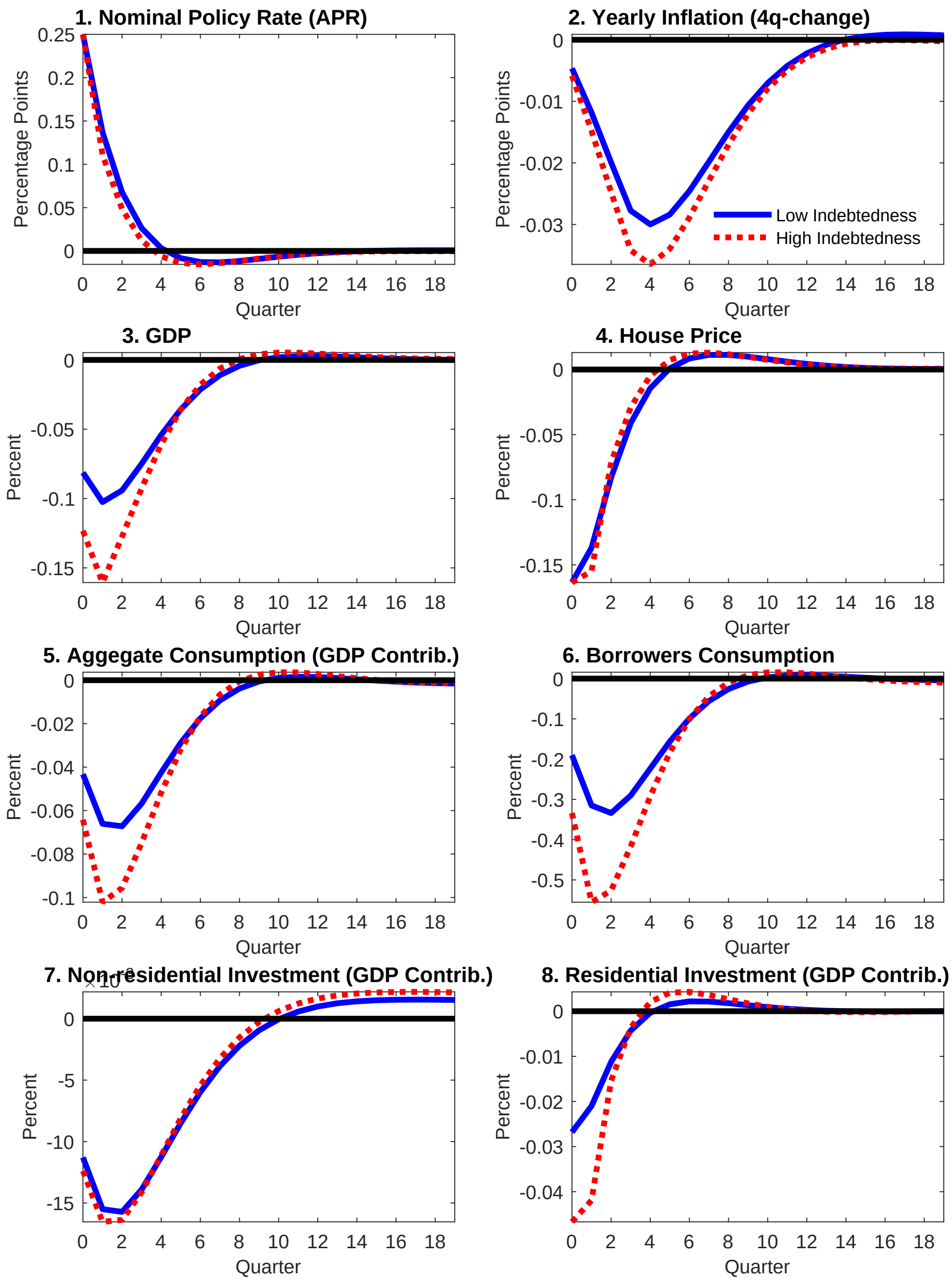


Figure 7: Aggregate Effects of LTV, LTI, DSTI and MID tightening in a liquidity trap under high indebtedness

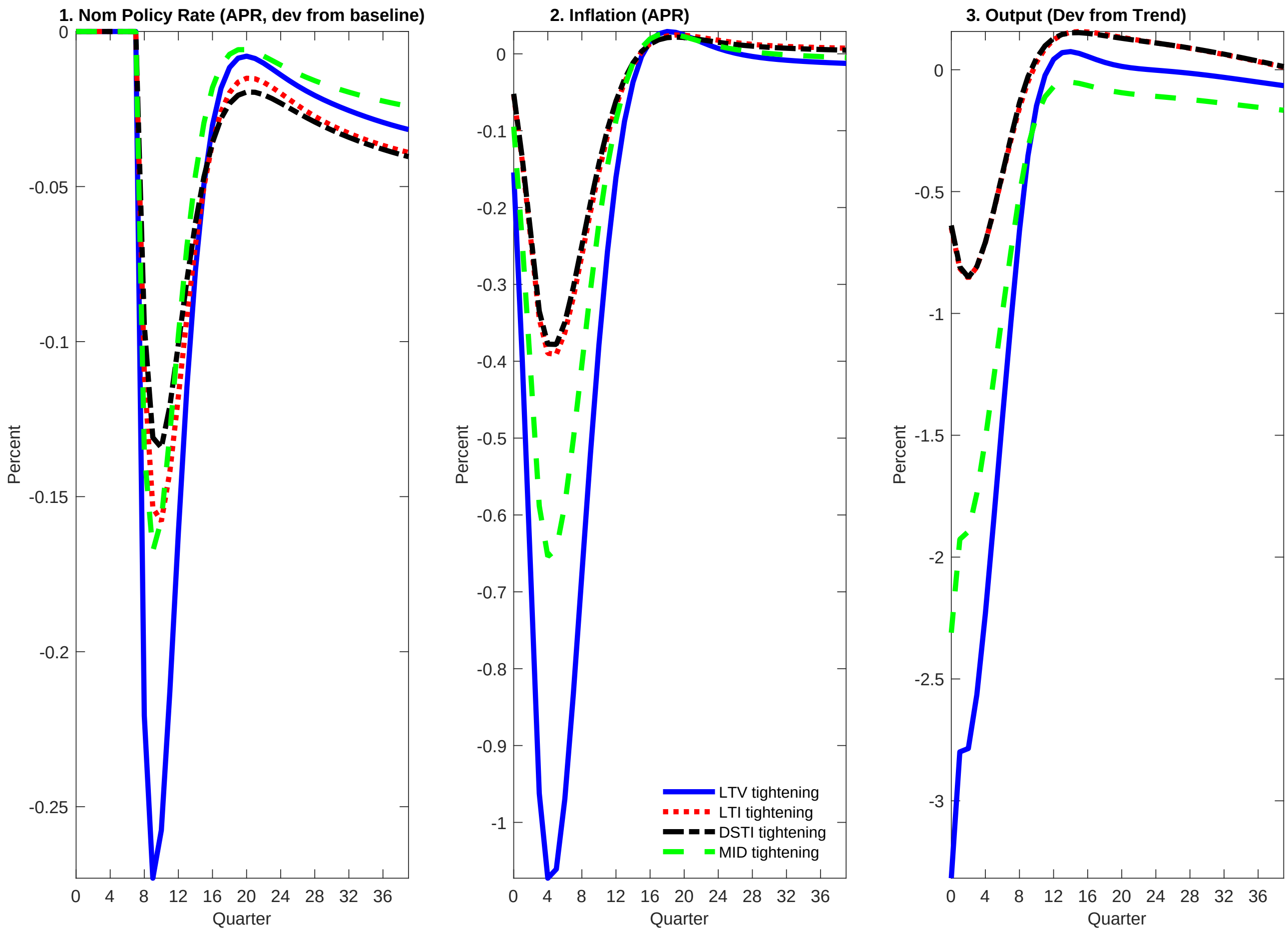


Figure 8: Disaggregate effects of LTV, LTI, DSTI and MID tightening in a liquidity trap under high indebtedness

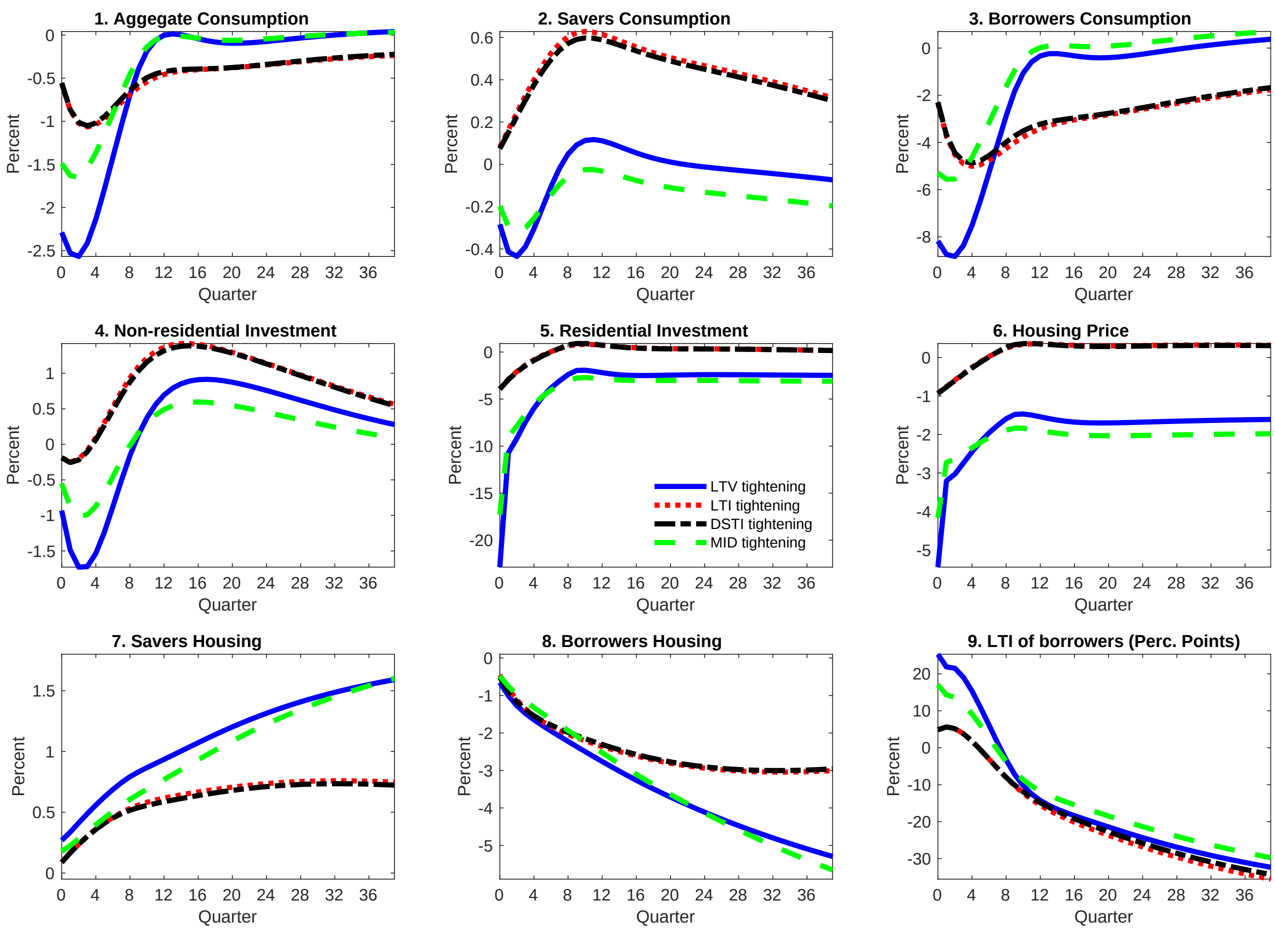


Figure 9: Decomposing the contractionary effects of an LTV tightening

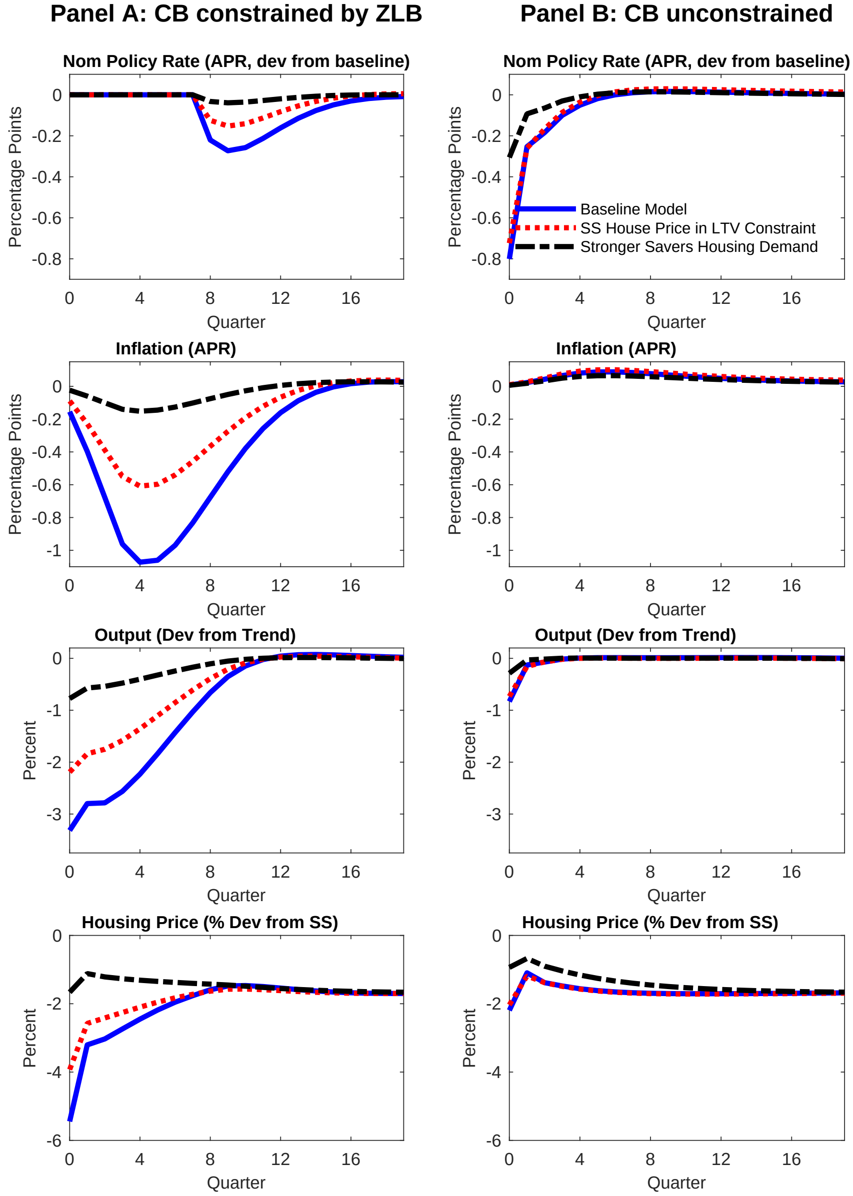


Figure 10: Aggregate effects of an LTI tightening in a liquidity trap in the one constraint and multiconstrant models

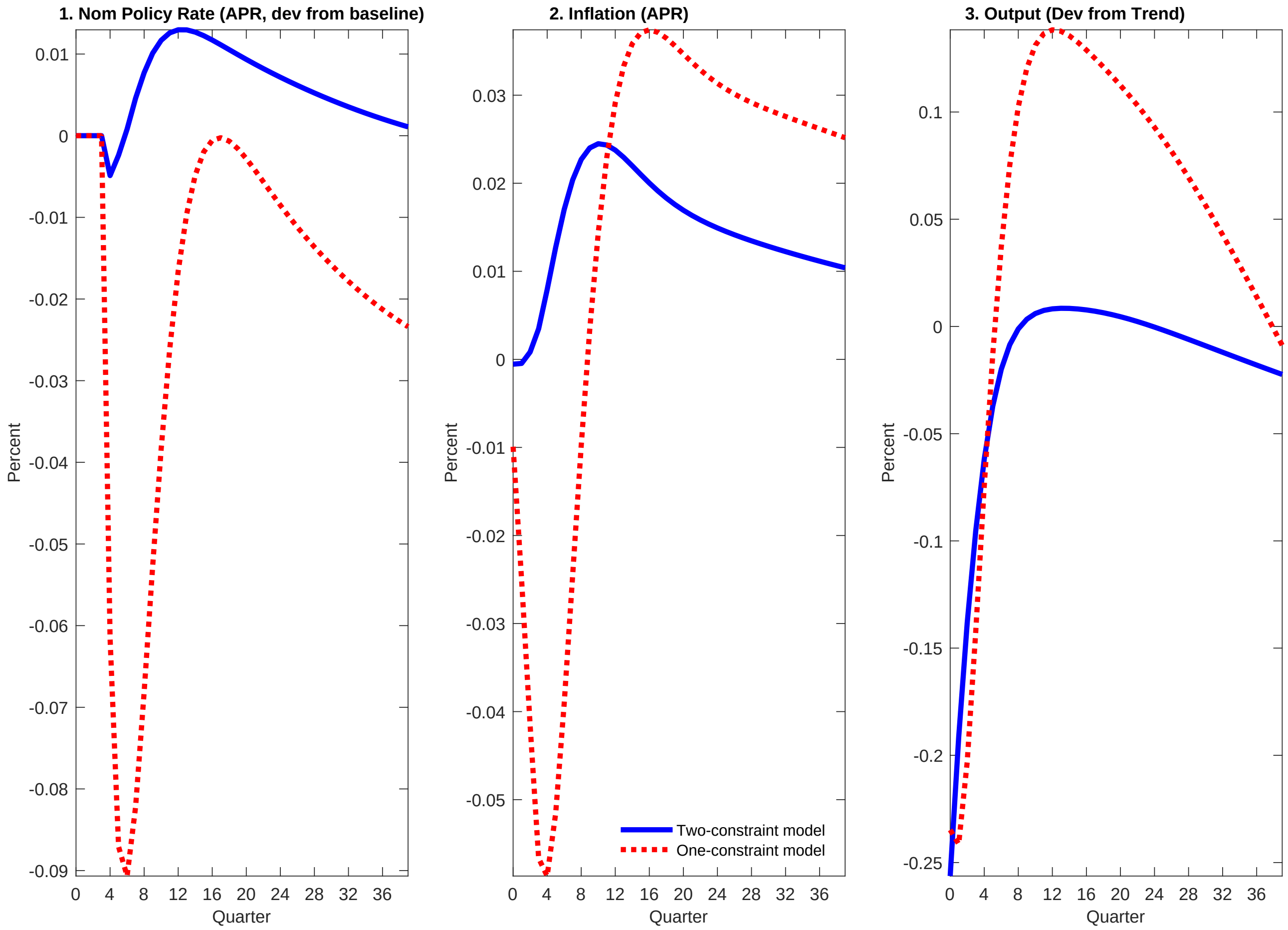


Figure 11: Disaggregate effects of an LTI tightening in a liquidity trap in the one constraint and multiconstraint models

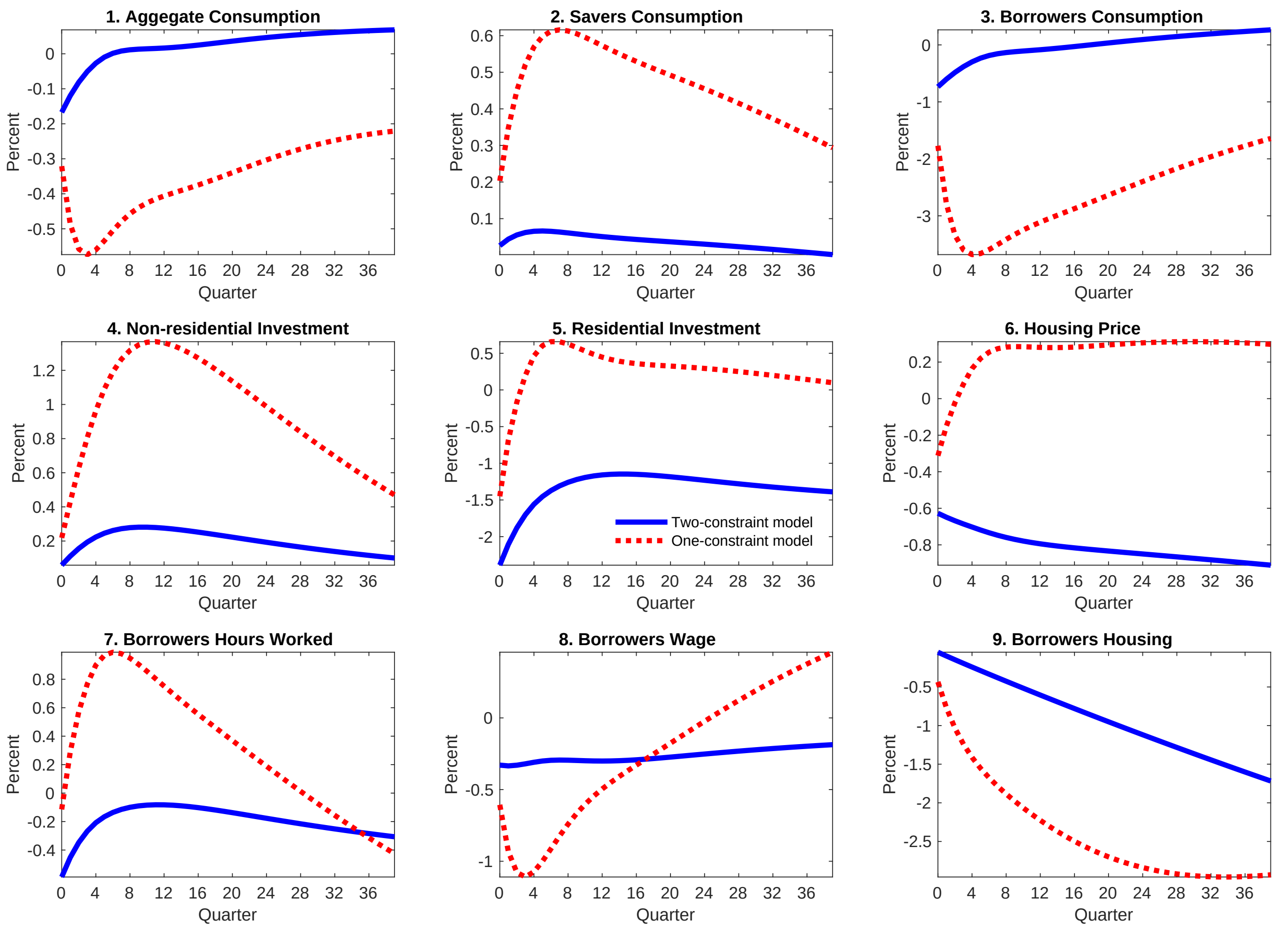
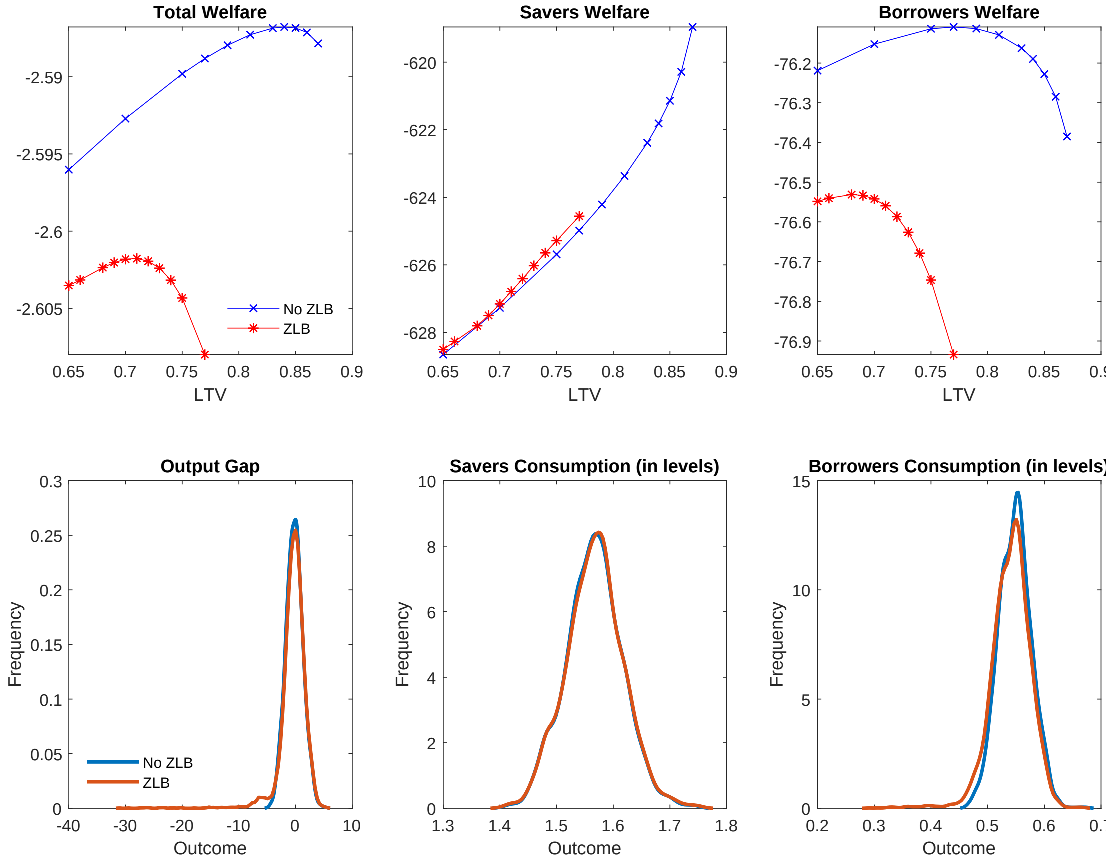


Figure 12: Unconditional welfare and simulated distributions of variables



The upper panels show unconditional welfare. Welfare is computed using second order approximation of the model and using the method of Hebden, Lindé and Svensson (2010) to handle the ZLB. Total welfare refers to the following expression, $W_S = (1 - \beta_P)\, W_p + (1 - \beta_I)\, W_I$, following Lambertini et al. (2013). The lower panels show the distribution of the outcome of variables for an LTV of 0.7.

A Technical appendix

In this appendix, we first provide a complete description of the simple two-period model and macroprudential tightening in that model. We then present additional details of the quantitative model, including all the first order conditions.

A.1 Two-period economy

Agents solve the following problem

$$\begin{aligned}
&Max \sum_{t=1}^{2} \beta^{t-1} \left(c_t + \log(h_t) - \frac{n_t^2}{2} \right) \\
&st : c_t + q_t (h_t - h_{t-1}) = n_t - R b_{t-1} + b_t \\
&b_1 \leq \bar{B}_1 \\
&b_0 = 0, h_0 = \bar{H}, \ b_2 = \theta
\end{aligned}$$

where we consider two set-ups with different specifications for the borrowing limit, $\bar{B}_t$:

$$LTV : \bar{B}_1 = \theta q_1 h_1$$

$$or$$

$$LTI : \bar{B}_1 = \theta n_1$$

The problem can be rewritten in a more compact form:

$$\begin{aligned}
&Max \sum_{t=1}^{2} \beta^{t-1} \left(n_t - R b_{t-1} + b_t - q_t (h_t - h_{t-1}) + \log(h_t) - \frac{n_t^2}{2} \right) \\
&s.t. : LTV : b_1 \leq \theta q_1 h_1 \ or \ LTI : b_1 \leq \theta n_1
\end{aligned}$$

with the following first order conditions:

$$b_t : 1 = \beta R + \mu$$

LTV constraint

$$\begin{aligned}
&h_1 : q_1 = \frac{1}{h_1} + \beta q_2 + \mu \theta q_1 \\
&h_2 : q_2 = \frac{1}{h_2} \\
&n_t : n_t = 1, \ t = 1, 2
\end{aligned}$$

LTI constraint

$$
\begin{aligned}
h_1 &: q_1 = \frac{1}{h_1} + \beta q_2 \\
h_2 &: q_2 = \frac{1}{h_2} \\
n_t &: n_1 = 1 + \mu\theta
\end{aligned}
$$

A.1.1 Equilibrium

Market clearing condition

$$h_t = \bar{H}, \ t = 1, 2$$

LTV limit. The behavior of house prices and debt in equilibrium is described by:

$$
\begin{aligned}
q_1 &= \frac{1}{H} + \beta q_2 + (1 - \beta R)\,\theta q_1 \\
&= \frac{(1+\beta)}{1 - (1-\beta R)\,\theta} \frac{1}{\bar{H}} \\
q_2 &= \frac{1}{\bar{H}} \\
q_1 - q_2 &= \frac{1}{\bar{H}} \left(\frac{\beta + (1-\beta R)\,\theta}{1 - (1-\beta R)\,\theta} \right) > 0
\end{aligned}
$$

$$
\begin{aligned}
b_2 &= \theta \\
b_1 &= \theta q_1 \bar{H} = \frac{\theta\,(1+\beta)}{1 - (1-\beta R)\,\theta} \\
b_1 - b_2 &= \theta \left(\frac{\beta + (1-\beta R)\,\theta}{1 - (1-\beta R)\,\theta} \right) > 0
\end{aligned}
$$

Consumption is determined by the following budget constraints:

$$
\begin{aligned}
c_2 &= 1 - Rb_1 + b_2 = 1 - R\frac{\theta\,(1+\beta)}{1 - (1-\beta R)\,\theta} + \theta \\
&= 1 - R\frac{\theta\,(1+\beta)}{1 - \mu\theta} + \theta \\
&= \frac{(1-\mu\theta)\,(1+\theta) - R\theta\,(1+\beta)}{1 - \mu\theta} \\
&= \frac{1 - \theta^2\mu - R\theta}{1 - \mu\theta}, \\
c_1 &= 1 + b_1 = 1 + \frac{\theta\,(1+\beta)}{1 - (1-\beta R)\,\theta}.
\end{aligned}
$$

To make sure that consumption in the second period is non-negative, the following condition needs to be satisfied:

$$\frac{1-\theta^2\mu-R\theta}{1-\mu\theta}>0.$$

Given our assumption $\theta<\beta<1$, the denominator of the expression above is always positive and so is the numerator:

$$\begin{aligned}1-\theta^2\mu-R\theta &=\\ 1-\theta^2\left(1-R\beta\right)-R\theta &>\\ 1-\theta^2\left(1-R\beta\right)-R\beta &>\\ \left(1-R\beta\right)\left(1-\theta^2\right) &>0\end{aligned}$$

LTI limit. In the LTI economy, the behavior of house prices in equilibrium is simply described by:

$$\begin{aligned}q_1 &= \frac{1}{\bar{H}}+\beta q_2\\ q_2 &= \frac{1}{\bar{H}}\end{aligned}$$

Differently from before, labor supply is higher in the first period:

$$\begin{aligned}n_1 &= 1+\theta\left(1-\beta R\right)\\ n_2 &= 1\end{aligned}$$

Debt

$$\begin{aligned}b_1 &= \theta\left(1+\theta\left(1-\beta R\right)\right)\\ b_2 &= \theta\end{aligned}$$

As before, consumption can determined by the intraperiod budget constraints:

$$\begin{aligned}c_2 &= n_2-Rb_1+b_2=1-R\theta\left(1+\theta\left(1-\beta R\right)\right)+\theta\\ &= 1+\theta-R\theta\left(1+\theta\mu\right)\\ &= \theta\left(1-R\theta\mu\right)+\left(1-R\theta\right)\\ c_1 &= n_1+b_1=\left(1+\theta\right)\left(1+\theta\left(1-\beta R\right)\right)\end{aligned}$$

Note that also in this case our assumption $\theta<\beta$ is sufficient to ensure a positive consumption level in the second period since $\theta<\beta<\frac{1}{R}<\frac{1}{R\mu}$.

A.1.2 Macroprudential experiment

We start from a situation where debt in period 2 in the two economies is equal:

$$b_{2,LTI} = b_{2,LTV} = \theta$$

and we want to cut b_2 in both economies by a fraction $x < 1$

$$\theta' = x\theta$$

The cut is permanent and it affects also b_1.

LTV contraction The behavior of house prices in equilibrium is described by:

$$q_1' = \frac{(1+\beta)}{1-(1-\beta R)\,\theta x}\frac{1}{\bar{H}}$$
$$q_2' = \frac{1}{\bar{H}}$$

$$b_1' = \theta x q_1' \bar{H} = \frac{x\theta\,(1+\beta)}{(1-(1-\beta R)\,\theta x)}$$

Consumption

$$c_2' = 1 - Rb_1' + b_2' = 1 - R\frac{x\theta\,(1+\beta)}{(1-(1-\beta R)\,\theta x)} + x\theta$$
$$c_1' = 1 + b_1' = 1 + \frac{x\theta\,(1+\beta)}{(1-(1-\beta R)\,x\theta)}$$

LTI Contraction

$$q_1' = \frac{1}{\bar{H}} + \beta q_2'$$
$$q_2' = \frac{1}{\bar{H}}$$

Labor supply

$$n_1' = 1 + x\theta\,(1-\beta R)$$

$$n_2' = 1$$

Debt

$$b_1' = \theta x \left(1 + x\theta \left(1 - \beta R\right)\right)$$
$$b_2' = x\theta$$

Consumption

$$c_2' = 1 - Rb_1' + b_2 = 1 - R\theta x \left(1 + x\theta \left(1 - \beta R\right)\right) + x\theta$$
$$c_1' = \left(1 + \theta x \left(1 - \beta R\right)\right)\left(1 + \theta x\right)$$

A.1.3 Comparison between the two economies

In the LTV economy

$$\begin{aligned}
\Delta b_{1,LTV} &= b'_{1,LTV} - b_{1,LTV} \\
&= \theta\left(1+\beta\right)\left[\frac{x}{\left(1-\left(1-\beta R\right)x\theta\right)} - \frac{1}{\left(1-\left(1-\beta R\right)\theta\right)}\right] \\
&= \theta\left(1+\beta\right)\left[\frac{x}{\left(1-\left(1-\beta R\right)x\theta\right)} - \frac{1}{\left(1-\left(1-\beta R\right)\theta\right)}\right] \\
&= \theta\left(1+\beta\right)\left[\frac{\left(1-\left(1-\beta R\right)\theta\right)x - \left(1-\left(1-\beta R\right)x\theta\right)}{\left(1-\left(1-\beta R\right)x\theta\right)\left(1-\left(1-\beta R\right)\theta\right)}\right] \\
&= -\frac{\theta\left(1+\beta\right)\left(1-x\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}
\end{aligned}$$

where we used $\mu = \left(1 - \beta R\right)$. In the LTI economy:

$$\begin{aligned}
\Delta b_{1,LTI} &= b'_{1,LTI} - b_{1,LTI} = \theta x\left(1+\theta x\left(1-\beta R\right)\right) - \theta\left(1+\theta\left(1-\beta R\right)\right) \\
&= \theta x\left(1+\theta x\mu\right) - \theta\left(1+\theta\mu\right) \\
&= -\theta\left(1-x\right)\left(\theta\mu\left(1+x\right)+1\right)
\end{aligned}$$

$$\Delta n_{1,LTI} = -\left(1-x\right)\theta\mu$$

$$\Delta b_{1,LTI} + \Delta n_{1,LTI} = -\theta\left(1-x\right)\left(\mu\left(\theta\left(1+x\right)+1\right)+1\right)$$

Now, let us compare the reduction in debt in both economies

$$\begin{aligned}
\Delta b_{LTV} - \Delta b_{LTI} &= -\left[\frac{\theta\left(1+\beta\right)\left(1-x\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)} - \theta\left(1-x\right)\left(\mu\theta\left(1+x\right)+1\right)\right] \\
&= -\left[\frac{\theta\left(1+\beta\right)\left(1-x\right) - \theta\left(1-x\right)\left(\theta\mu\left(1+x\right)+1\right)\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] \\
&= -\left(1-x\right)\theta\left[\frac{\beta+1-\left(\theta\mu\left(1+x\right)+1\right)\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] \\
&= -\left(1-x\right)\theta\left[\frac{\theta^2\mu^2\left(\left(1-\theta\mu\right)x\left(1+x\right)+1\right)+\beta}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] < 0
\end{aligned}$$

This implies that debt decreases more in the LTV economy, i.e. that house prices respond more than labor supply to the policy change. In terms of consumption, in period 2:

$$\Delta c_{2,LTV} = -R\Delta b_{1,LTV} + \Delta b_{2,LTV}$$

$$\Delta c_{2,LTI} = -R\Delta b_{1,LTI} + \Delta b_{2,LTI}$$

$$\Delta c_{2,LTV} - \Delta c_{2,LTI} = R\left(\Delta b_{1,LTI} - \Delta b_{1,LTV}\right) > 0$$

In period 1

$$\Delta c_{1,LTV} = \Delta b_{1,LTV}$$

$$\Delta c_{1,LTI} = \Delta n_{1,LTI} + \Delta b_{1,LTI} = -\theta\left(1-x\right)\left(\theta\mu\left(1+x\right)+1+\mu\right)$$

We can now compute the difference between the drop in consumption in the two models:

$$\begin{aligned}
\Delta c_{1,LTV} - \Delta c_{1,LTI} &= \Delta b_{LTV} - \Delta b_{LTI} - \Delta n_{1,LTI} \\
&= -\left[\frac{\theta\left(1+\beta\right)\left(1-x\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)} - \theta\left(1-x\right)\left(\mu\left(\theta\left(1+x\right)+1\right)+1\right)\right] \\
&= -\left[\frac{\theta\left(1+\beta\right)\left(1-x\right) - \theta\left(1-x\right)\left(\mu\left(\theta\left(1+x\right)+1\right)+1\right)\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] \\
&= -\left(1-x\right)\theta\left[\frac{\beta+1-\left(\mu\left(\theta\left(1+x\right)+1\right)+1\right)\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] \\
&= -\left(1-x\right)\theta\left[\frac{\theta^2\mu^2\left(\left(1-\theta\mu\right)x\left(1+x+\frac{1}{\theta}\right)+1\right)+\beta-\mu\left(1-\theta\mu\right)}{\left(1-\mu x\theta\right)\left(1-\mu\theta\right)}\right] < 0
\end{aligned}$$

where the last inequality follows from

$$\beta > \frac{1}{1+R}$$
$$\beta + R\beta > 1$$
$$\beta > \mu$$

That is, the drop in consumption is higher in the LTV case, Q.E.D.

A.2 DSGE model

This section reports all first-order conditions of the quantitative DSGE model. The superscript prime refers to impatient households.

$$\begin{aligned} & c_t + \frac{i_{ct}}{a_{k,t}} + \imath_{ht} + q_t h_t + l_t \\ & = w_{ct} n_{ct} + w_{ht} n_{ht} + R_{ct} z_{ct} k_{ct-1} + R_{ht} z_{ht} k_{h,t-1} \\ & + \left(r^M_{t-1} + \kappa\right) \frac{d_{t-1}}{\pi_t} + \mu_l q_t I H_t \\ & + q_t \left(1 - \delta_h\right) h_{t-1} - \frac{\phi_h}{2} \left(\frac{h_t}{h_{t-1}} - 1\right)^2 q_t h_{t-1} \\ & + \left(1 - \frac{1}{X_t}\right) Y_t - a\left(z_{ct}\right) p^{kc}_t \frac{k_{c,t-1}}{a_{k,t}} - a\left(z_{ht}\right) p^{kh}_t k_{ht-1} - T_t \end{aligned} \tag{17}$$

$$Div_t = \left(1 - \frac{1}{X_t}\right) Y_t$$

$$\begin{aligned} & u_{c,t} q_t \left[1 + \Phi^h \left(\frac{h_t}{h_{t-1}} - 1\right)\right] \\ & = a_{z,t} a_{j,t} \frac{j_t}{h_t} \\ & + u_{c,t+1} \beta q_{t+1} (1 - \delta) \\ & + \left[\frac{\Phi^h}{2} u_{c,t+1} \beta q_{t+1} \left((\frac{h_{t+1}}{h_t})^2 - 1\right)\right] \end{aligned} \tag{18}$$

$$u_{h,t} = \varsigma_t \frac{j_t}{h_t}$$

$$u_{ct} = \beta u_{ct+1} R_t / \pi_{t+1} \tag{19}$$

$$\lambda_t{}^{dP} + r_t^M \lambda_t{}^{rP} = \frac{\beta}{\pi_{t+1}} \Big[u_{ct+1}(r_t^M + \kappa) + (1-\kappa) \Big(\lambda_{t+1}^{dP} + \lambda_{t+1}^{rP} [(1-\Phi) r_t^M + \Phi r_{t+1}^F] \Big) \Big] \tag{20}$$

$$p_t^{kc} u_{ct} = \beta u_{ct+1} \left[R_{ct+1} z_{ct+1} + p_{t+1}^{kc} \left(1 - \delta_{kc} - \frac{a\,(z_{ct+1})}{a_{k,t+1}} \right) \right] \tag{21}$$

$$u_{c,t} = \frac{\beta u_{c,t+1} \left(R_{ht+1} z_{ht+1} + p_{t+1}^{kh} \left\{ 1 - \delta_{kh} - a(z_{ht+1}) \right\} \right)}{p_t^{kh}} \tag{22}$$

$$1 = p_t^{kc} a_{k,t} \left[1 - S_{c,t} - S'_{c,t} \frac{\Gamma_{AK} i_{ct}}{i_{ct-1}} \right] + \beta \frac{u_{c,t+1}}{u_{c,t}} p_{t+1}^{kc} a_{k,t} S'_{c,t} \left(\frac{i_{ct+1}}{i_{ct}} \right)^2 \tag{23}$$

$$1 = p_t^{kh} \left[1 - S_{h,t} - S'_{h,t} \frac{i_{ht}}{i_{ht-1}} \right] + \beta \frac{u_{c,t+1}}{u_{c,t}} p_{t+1}^{kh} S'_{h,t} \left(\frac{i_{ht+1}}{i_{ht}} \right)^2 \tag{24}$$

$$a_t a_{z,t} (n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi})^{\frac{\eta-\xi}{1+\xi}} n_{c,t}^{\xi} = u_{ct} \frac{w_{ct}}{X_{wct}} \tag{25}$$

$$a_t a_{z,t} (n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi})^{\frac{\eta-\xi}{1+\xi}} n_{h,t}^{\xi} = u_{ct} \frac{w_{ht}}{X_{wht}} \tag{26}$$

$$d_t = \frac{(1-\kappa)}{\pi_t} d_{t-1} + l_t \tag{27}$$

$$r_t^M d_t = (1-\Phi)(1-\kappa) d_{t-1} \frac{r_{t-1}^M}{\pi_t} + \left[l_t + \Phi(1-\kappa) \frac{d_{t-1}}{\pi_t} \right] r_t^F \tag{28}$$

$$u_{ct} = \lambda_t^{dP} + \lambda_t^{rP} r_t^F \tag{29}$$

$$\lambda_t^{rP} = \frac{\beta}{\pi_{t+1}}\left(u_{ct+1} + (1-\Phi)(1-\kappa)\lambda_{t+1}^{rP}\right) \tag{30}$$

$$transfer_t' = T_t' = \frac{r_{t-1}^M \tau_{t-1} d_{t-1}}{\pi_t} \tag{31}$$

$$T_t = 0 \tag{32}$$

$$S_{ct}' = \frac{1}{2}\sqrt{S_c''}\left\{\exp\left[\sqrt{S_c''}\left(\frac{i_{ct}}{i_{ct-1}} - 1\right)\right] - \exp\left[-\sqrt{S_c''}\left(\frac{i_{ct}}{i_{ct-1}} - 1\right)\right]\right\}$$

$$S_{ht}' = \frac{1}{2}\sqrt{S_h''}\left\{\exp\left[\sqrt{S_h''}\left(\frac{i_{ht}}{i_{ht-1}} - 1\right)\right] - \exp\left[-\sqrt{S_h''}\left(\frac{i_{ht}}{i_{ht-1}} - 1\right)\right]\right\}$$

$$\begin{aligned} &c_t' + q_t h_t' + [r_{t-1}^M + \kappa]\frac{d_{t-1}}{1\pi_t} + \left[\frac{\Phi^{h'}}{2}\left(\frac{h_t'}{h_{t-1}'} - 1\right)^2 q_t h_{t-1}'\right] \\ &= w_{c,t}' n_{c,t}' + w_{h,t}' n_{h,t}' + q_t(1-\delta_h)\frac{h_{t-1}'}{1} + l_t + \tau_t r_{t-1}^M \frac{d_{t-1}}{1\pi_t} - T_t' \end{aligned} \tag{33}$$

$$\begin{aligned} u_{c,t}' q_t\left[1 + \Phi^{h'}\left(\frac{h_t'}{h_{t-1}'} - 1\right)\right] &= a_{z,t} a_{j,t}' \frac{j_t'}{h_t'} \\ &+ u_{c,t+1}' \beta' q_{t+1} 1(1-\delta) \\ &+ \left[\frac{\Phi^{h'}}{2} u_{c,t+1}' \beta' q_{t+1}\left((\frac{h_{t+1}'}{h_t'})^2 - 1\right)\right] \\ &+ \lambda_t^{ltv} m_t^{ltv} q_t - \lambda_{t+1}^{ltv} \beta' q_{t+1}(1-\delta_h)(m_{t+1}^{ltv} - \gamma) \end{aligned} \tag{34}$$

$$l_t = \theta_t^{ltv} q_t[h_t' - (1-\delta_h)h_{t-1}'] + \gamma[q_t(1-\delta_h)h_{t-1}' - (1-\kappa)\frac{d_{t-1}}{\pi_t}] \tag{35}$$

$$\begin{aligned} &\lambda_t'^{dp} + \lambda_t'^{rP} r_t^M = \frac{\beta'}{\pi_{t+1}}\Bigg\{u_{c,t+1}'(r_t^M(1-\tau_{t+1}) + \kappa) + \lambda_{t+1}^{ltv}\gamma(1-\kappa) + (1-\kappa)\Bigg[\lambda_{t+1}'^{dp} \\ &+ \lambda_{t+1}'^{rP}\left((1-\Phi)r_t^M + \Phi r_{t+1}^F\right)\Bigg]\Bigg\} \end{aligned} \tag{36}$$

$$a_t a_{z,t}(n_{c,t}^{'1+\xi'} + n_{h,t}^{'1+\xi'})^{\frac{\eta-\xi'}{1+\xi'}} n_{c,t}^{'\xi'} = u'_{c,t} \frac{w'_{ct}}{X'_{wct}} \tag{37}$$

$$a_t a_{z,t}(n_{c,t}^{'1+\xi'} + n_{h,t}^{'1+\xi'})^{\frac{\eta-\xi'}{1+\xi'}} n_{h,t}^{'\xi'} = u'_{c,t} \frac{w'_{ht}}{X'_{wht}} \tag{38}$$

$$u'_{c,t} - \lambda_t^{ltv} - \lambda_t^{'dP} - \lambda_t^{'rP} r_t^F = 0 \tag{39}$$

$$\lambda_t^{'rP} = \frac{\beta'}{\pi_{t+1}} \left(u'_{c,t+1}(1-\tau_{t+1}) + (1-\Phi)(1-\kappa)\lambda_{t+1}^{'rP} \right) \tag{40}$$

$$Y_t = a_{c,t}^{1-\mu_c} \left(n_{c,t}^{\alpha} n_{c,t}^{'1-\alpha} \right)^{1-\mu_c} \left(z_{c,t} k_{c,t-1} \right)^{\mu_c} \tag{41}$$

$$IH_t = \left(a_{h,t}(n_{h,t}^{\alpha} n_{h,t}^{'1-\alpha}) \right)^{1-\mu_h-\mu_b-\mu_l} (z_{h,t} k_{h,t-1})^{\mu_h} (\mu_b q_t IH_t)^{\mu_b} \tag{42}$$

$$(1-\mu_c)\alpha \frac{Y_t}{X_t n_{ct}} = w_{ct} \tag{43}$$

$$(1-\mu_c)(1-\alpha) \frac{Y_t}{X_t n'_{ct}} = w'_{ct} \tag{44}$$

$$(1-\mu_h-\mu_b-\mu_l)\alpha \frac{q_t IH_t}{n_{h,t}} = w_{ht} \tag{45}$$

$$(1-\mu_h-\mu_b-\mu_l)(1-\alpha) \frac{q_t IH_t}{n'_{h,t}} = w'_{ht} \tag{46}$$

$$\frac{\mu_c}{X_t} \frac{Y_t}{k_{ct-1}} = R_{ct} z_{ct} \tag{47}$$

$$\mu_h \frac{q_t IH_t}{k_{ht-1}} = R_{ht} z_{ht} \tag{48}$$

$$
\begin{aligned}
log(\pi_t - \pi^*) - \iota_\pi log(\pi_{t-1} - \pi^*) = \beta\Bigg(& log(\pi_{t+1} - \pi^*) - \iota_\pi log(\pi_t - \pi^*)\Bigg) \\
&- \frac{(1-\theta_\pi)(1-\beta\theta_\pi)}{\theta_\pi} log\Bigg(\frac{X_t}{X^{ss}}\Bigg) + log(\epsilon_{p,t})
\end{aligned} \tag{49}
$$

$$
\begin{aligned}
R_t = R_{t-1}^{r_R}(\pi_t/\pi^{ss})^{(1-r_R)r_\pi}\left(\frac{Y_t}{Y_t^{flex}}/\frac{Y_{t-1}}{Y_{t-1}^{flex}}\right)^{(1-r_R)r_Y} \\
\left(log(\frac{1}{\beta}) + \pi^{ss}\right)^{1-r_R}\frac{\epsilon_{mp,t}}{a_s}
\end{aligned} \tag{50}
$$

$$
h_t + h'_t = (1-\delta)(h_{t-1}/1) + (1-\delta)(h'_{t-1}/1) + IH_t \tag{51}
$$

$$
u_{ct} = a_{z,t}\frac{1-\epsilon}{1(1-\beta\epsilon)}\left(\frac{1}{c_t - \epsilon c_{t-1}} - \frac{\beta\epsilon}{c_{t+1} - \epsilon c_t}\right) \tag{52}
$$

$$
u'_{ct} = a_{z,t}\frac{1-\epsilon'}{1(1-\beta'\epsilon')}\left(\frac{1}{c'_t - \epsilon' c'_{t-1}} - \frac{\beta\epsilon'}{c'_{t+1} - \epsilon' c'_t}\right) \tag{53}
$$

$$
\begin{aligned}
ln(w_{ct}) = & \frac{1}{1+\beta 1} ln(w_{c,t-1}) + (\frac{1}{1+\beta 1})(ln(w_{c,t-1}) + ln\pi_{t+1} - ln\pi^{ss}) \\
& - \frac{(1+\beta 1\iota_{wc})}{1+\beta 1}(\pi_t - \pi^{ss}) + \frac{\iota_{wc}}{1+\beta 1}(ln\pi_{t-1} - ln\pi^{ss}) \\
& - \frac{\frac{(1-\theta_{wc})(1-\beta 1\theta_{wc})}{\theta_{wc}}}{(1+\beta 1)} ln\frac{X_{wc,t}}{X_w^{ss}}
\end{aligned} \tag{54}
$$

$$
\begin{aligned}
ln(w'_{ct}) = & \frac{1}{1+\beta'} ln(w'_{c,t-1}) + (\frac{1}{1+\beta'})(ln(w'_{c,t-1}) + ln\pi_{t+1} - ln\pi^{ss}) \\
& - \frac{(1+\beta'\iota_{wc})}{1+\beta'}(\pi_t - \pi^{ss}) + \frac{\iota_{wc}}{1+\beta'}(ln\pi_{t-1} - ln\pi^{ss}) \\
& - \frac{\frac{(1-\theta_{wc})(1-\beta' 1\theta_{wc})}{\theta_{wc}}}{(1+\beta')} ln\frac{X'_{wc,t}}{X_w^{ss}}
\end{aligned} \tag{55}
$$

$$ln(w_{ht}) = \frac{1}{1+\beta} ln(w_{h,t-1}) + (\frac{1}{1+\beta})(ln(w_{h,t-1}) + ln\pi_{t+1} - ln\pi^{ss})$$
$$- \frac{(1+\beta\iota_{wh})}{1+\beta}(\pi_t - \pi^{ss}) + \frac{\iota_{wh}}{1+\beta 1}(ln\pi_{t-1} - ln\pi^{ss})$$
$$- \frac{\frac{(1-\theta_{wh})(1-\beta\theta_{wh})}{\theta_{wh}}}{(1+\beta)} ln\frac{X_{wh,t}}{X_w^{ss}} \tag{56}$$

$$ln(w'_{ht}) = \frac{1}{1+\beta'} ln(w'_{h,t-1}) + (\frac{1}{1+\beta'})(ln(w'_{h,t-1}) + ln\pi_{t+1} - ln\pi^{ss})$$
$$- \frac{(1+\beta'\iota_{wh})}{1+\beta'}(\pi_t - \pi^{ss}) + \frac{\iota_{wh}}{1+\beta'}(ln\pi_{t-1} - ln\pi^{ss})$$
$$- \frac{\frac{(1-\theta_{wh})(1-\beta'\theta_{wh})}{\theta_{wh}}}{(1+\beta' 1)} ln\frac{X'_{wh,t}}{X_w^{ss}} \tag{57}$$

$$\frac{\frac{R_{ct}}{p_t^{kc}}}{(1/\beta) - (1-\delta_{kc})} = \frac{\zeta_{kc}}{1-\zeta_{kc}} z_{kc,t} + (1 - \frac{\zeta_{kc}}{1-\zeta_{kc}}) \tag{58}$$

$$\frac{\frac{R_{ht}}{p_t^{kh}}}{(1/\beta) - (1-\delta_{kh})} = \frac{\zeta_{kc}}{1-\zeta_{kc}} z_{kh,t} + (1 - \frac{\zeta_{kc}}{1-\zeta_{kc}}) \tag{59}$$

$$k_{ct} = (1-\delta_{kc})\, k_{ct-1} + (1 - S_{c,t})\, i_{ct} \tag{60}$$

$$k_{ht} = (1-\delta_{kh})\, k_{ht-1} + (1 - S_{h,t})\, i_{ht} \tag{61}$$

$$data - Y_t = c_t + c'_t + k_{ct} - (1-\delta_{kc})k_{c,t-1} + k_{h,t} - (1-\delta_{kh})\left(k_{h,t-1} + q_t IH_t\right)$$

$$a(z_{ct+1}) = \left(\frac{1}{\beta} - (1-\delta_{kc})\right)$$
$$- \left(0.5\frac{\zeta_{kc}}{1-\zeta_{kc}} z_{ct}^2 + (1 - \frac{\zeta_{kc}}{1-\zeta_{kc}}) z_{ct} + (0.5\frac{\zeta_{kc}}{1-\zeta_{kc}} - 1)\right) \tag{62}$$

$$a(z_{ht+1}) = \left(\frac{1}{\beta} - (1-\delta_{kh})\right) \\ - \left(0.5\frac{\zeta_{kc}}{1-\zeta_{kc}} z_{kht}^2 + (1-\frac{\zeta_{kc}}{1-\zeta_{kc}}) z_{kht} + (0.5\frac{\zeta_{kc}}{1-\zeta_{kc}} - 1)\right) \tag{63}$$

$$S_{ct} \\ = \frac{1}{2}\left\{ \begin{array}{c} \exp\left[\sqrt{S_c''}\left(\frac{i_{ct}}{i_{ct-1}} - 1\right)\right] \\ +\exp\left[-\sqrt{S_c''}\left(\frac{\Gamma_{AK} i_{ct}}{i_{ct-1}} - 1\right)\right] - 2 \end{array} \right\} \tag{64}$$

$$S_{ht} \\ = \frac{1}{2}\left\{ \begin{array}{c} \exp\left[\sqrt{S_h{}''}\left(\frac{1 i_{ht}}{i_{ht-1}} - 1\right)\right] \\ +\exp\left[-\sqrt{S_h{}''}\left(\frac{1 i_{ht}}{i_{ht-1}} - 1\right)\right] - 2 \end{array} \right\} \tag{65}$$

The following first order conditions are modified with a LTI $\left(\lambda_t^{LTI} > 0\right)$ or a DSTI $\left(\lambda_t^{DSTI} > 0\right)$ constraint:

LTI

$$\left(\theta_t^{LTI}\left(w'_{c,t}n'_{c,t} + w'_{h,t}n'_{h,t}\right) + \gamma\left[q_t(1-\delta_h)h'_{t-1}(i) - (1-\kappa)\frac{d_{t-1}}{\pi_t}\right] - \frac{L_t}{P_t}\right)\lambda_t^{LTI} \geq 0 \tag{66}$$

DSTI

$$\left(\theta_t^{DSTI}\frac{\left(w'_{c,t}n'_{c,t} + w'_{h,t}n'_{h,t}\right)}{((1-\tau_t)r_t^F + \kappa)} + \gamma\left[q_t(1-\delta_h)h'_{t-1}(i) - (1-\kappa)\frac{d_{t-1}}{\pi_t}\right] - \frac{L_t}{P_t}\right)\lambda_t^{DSTI} \geq 0 \tag{67}$$

$$u_{c't} = \lambda_t'^B \tag{68}$$

$$0 = u'_{h,t} + \lambda_{t+1}'^B \beta q_{t+1}(1-\delta) - \lambda_t'^B q_t \tag{69}$$
$$- \left[\lambda_t'^B \Phi^h(\frac{h_t}{h_{t-1}} - 1)q_t - \frac{\Phi^h}{2}\lambda_{t+1}'^B \beta q_{t+1}\left((\frac{h_{t+1}}{h_t})^2 - 1\right)\right]$$
$$+ \lambda_{t+1}^{LTI}\beta\gamma q_{t+1}(1-\delta)$$

$$\lambda_t^{\prime B} - \lambda_t^{LTI} - \lambda_t^{DSTI} - \lambda_t^{\prime dp} - \lambda_t^{\prime rp} r_t^F = 0 \tag{70}$$

$$\begin{aligned} &\lambda_t^{\prime dp} + \lambda_t^{\prime rp} r_t^M = \\ &\frac{\beta}{\pi_{t+1}}\Bigg\{\gamma(1-\kappa)\Big[\lambda_{t+1}^{LTI} + \lambda_{t+1}^{DSTI}\Big] \\ &+ \lambda_{t+1}^{\prime B}(r_t^M(1-\tau_{t+1}) + \kappa) + (1-\kappa)\lambda_{t+1}^{\prime dp} \\ &+ (1-\kappa)\lambda_{t+1}^{\prime rp}\Big((1-\Phi)r_t^M + \Phi r_{t+1}^F\Big)\Bigg\} \end{aligned} \tag{71}$$

$$-\left(u'_{nc,t} + \lambda_t^{LTI}\theta_t^{LTI} w'_{c,t} + \frac{\lambda_t^{DSTI}\theta_t^{DSTI} w'_{h,t}}{(1-\tau_t)r_t^F + \kappa}\right) = u'_{c,t}\frac{w'_{c,t}}{X'_{wc,t}} \tag{72}$$

$$-\left(u'_{nh,t} + \lambda_t^{LTI}\theta_t^{LTI} + \frac{\lambda_t^{DSTI}\theta_t^{DSTI} w'_{h,t}}{(1-\tau_t)r_t^F + \kappa}\right) = u'_{h,t}\frac{w'_{h,t}}{X'_{wh,t}} \tag{73}$$

A.2.1 Shocks

The stochastic process for the exogenous shocks in the model are described below. All innovations are denoted by the letter ε, with a subscript specifying the type. The standard deviations of these innovations are denoted by σ with the corresponding subscript. The preference shocks are AR(1) processes:

$$\begin{aligned} \log z_t &= \rho_z \log z_{t-1} + \varepsilon_{z,t} \\ \log j_{c,t} &= \rho_j \log j_{c,t} + (1-\rho_j)\log j_c + \varepsilon_{j,c,t} \quad , c = \{P, I\} \\ \log v_t &= \rho_v \log v_{t-1} + \varepsilon_{v,t} \end{aligned}$$

Shocks to the LTV, LTI and DSTI requirements, θ, are very persistent AR(1) processes as described in the main text. Interest rate deductibility (τ) follows an AR(2) process also described in the main text. As mentioned above, the cost-push shock, $\varepsilon_{\pi,t}$, and the monetary policy shock, $\varepsilon_{r,t}$, are i.i.d. Technology shocks are described in more detailed in the subsection below.

Technology shocks We allow for three productivity processes: consumption goods, housing, and non-housing investment-specific productivity. The three processes are:

$$\log a_{ct} = \rho_{AC} \log a_{ct-1} + \varepsilon_{ct}$$
$$\log a_{ht} = \rho_{AH} \log a_{ht-1} + \varepsilon_{ht}$$
$$\log a_{kt} = \rho_{AK} \log a_{kt-1} + \varepsilon_{kt}$$

A.2.2 Definition of investment adjustment cost function and utilization cost

The investment adjustment costs can be expressed as:

$$F\left(i_t, i_{t-1}\right) = \left(1 - \tilde{S}\left(\frac{i_t}{i_{t-1}}\right)\right) i_t \quad s = \{K, H\}$$

where

$$\tilde{S}\left(x\right) = \frac{1}{2}\left\{\exp\left[\sqrt{S_s''}\left(x - \Gamma_s\right)\right] + \exp\left[-\sqrt{S_s''}\left(x - \Gamma_s\right)\right] - 2\right\} \quad s = \{SK, SH\}$$

The capital utilization cost function is (with the same parameter ζ for both sectors)

$$a(z_{st}) = R_s\left(\frac{1}{2}\frac{\zeta}{1-\zeta}z_{st}^2 + (1 - \frac{\zeta}{1-\zeta})z_{st} + (\frac{1}{2}\frac{\zeta}{1-\zeta} - 1)\right) \quad s = \{c, h\}$$

A.2.3 Wage equations

The wage equations for each sector-household pair is:

$$\omega_{c,P,t} - \iota_{wc} \log \pi_{t-1} = \beta_P(E_t\omega_{c,P,t+1} - \iota_{wc} \log \pi_t) - \varepsilon_{w,P,c} \log\left(\frac{X_{wct}}{X_{wc}}\right)$$
$$\omega_{c,I,t} - \iota_{wc} \log \pi_{t-1} = \beta_I(E_t\omega_{c,I,t+1} - \iota_{wc} \log \pi_t) - \varepsilon_{w,I,c} \log\left(\frac{X_{wct}}{X_{wc}}\right)$$
$$\omega_{h,P,t} - \iota_{wh} \log \pi_{t-1} = \beta_P(E_t\omega_{h,P,t+1} - \iota_{wh} \log \pi_t) - \varepsilon_{w,P,c} \log\left(\frac{X_{wht}}{X_{wh}}\right)$$

$$\omega_{h,I,t} - \iota_{wh} \log \pi_{t-1} = \beta_I(E_t\omega_{h,I,t+1} - \iota_{wh} \log \pi_t) - \varepsilon_{w,I,c} \log\left(\frac{X_{wht}}{X_{wh}}\right)$$

where ω_{it} denotes log nominal wage inflation, i.e. $\omega_{it} = w_{it} - w_{it-1} + \pi_t$. $\varepsilon_{wc}, \varepsilon_{wh}$ are defined below.

A.2.4 Definitions of various parameters

$$\varepsilon_{\pi} = (1 - \theta_{\pi})(1 - \beta_P \theta_{\pi}) / \theta_{\pi}$$

$$\varepsilon_{wPc} = (1 - \theta_{wc})(1 - \beta_P \theta_{wc}) / \theta_{wc}$$

$$\varepsilon_{wIc} = (1 - \theta_{wc})(1 - \beta_I \theta_{wc}) / \theta_{wc}$$

$$\varepsilon_{wPh} = (1 - \theta_{wh})(1 - \beta_P \theta_{wh}) / \theta_{wh}$$

$$\varepsilon_{wIh} = (1 - \theta_{wh})(1 - \beta_I \theta_{wh}) / \theta_{wh}$$

A.3 Appendix Figures

Figure A.1: Effects of a contractionary monetary policy shock in models with different borrowing constraints

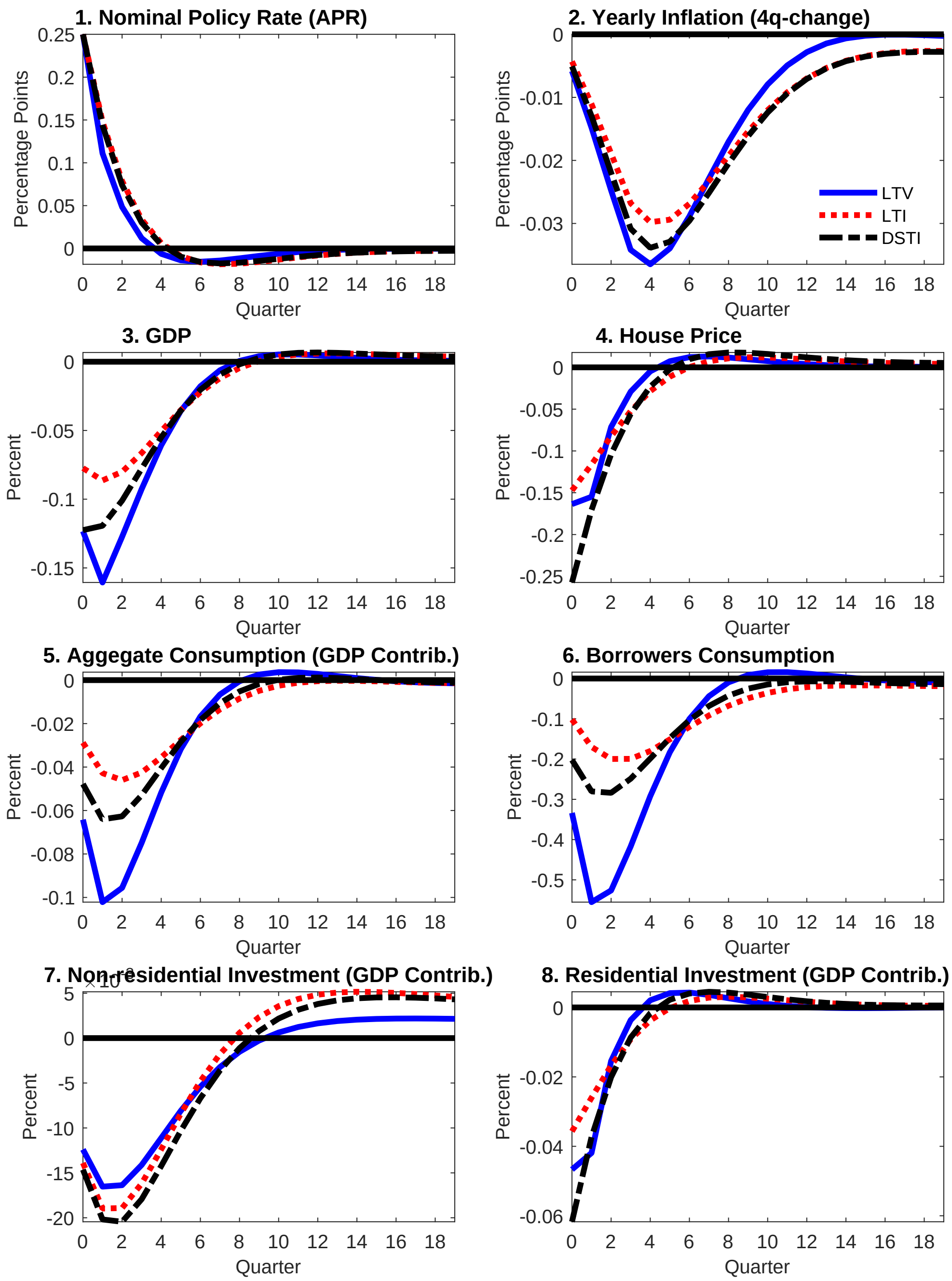
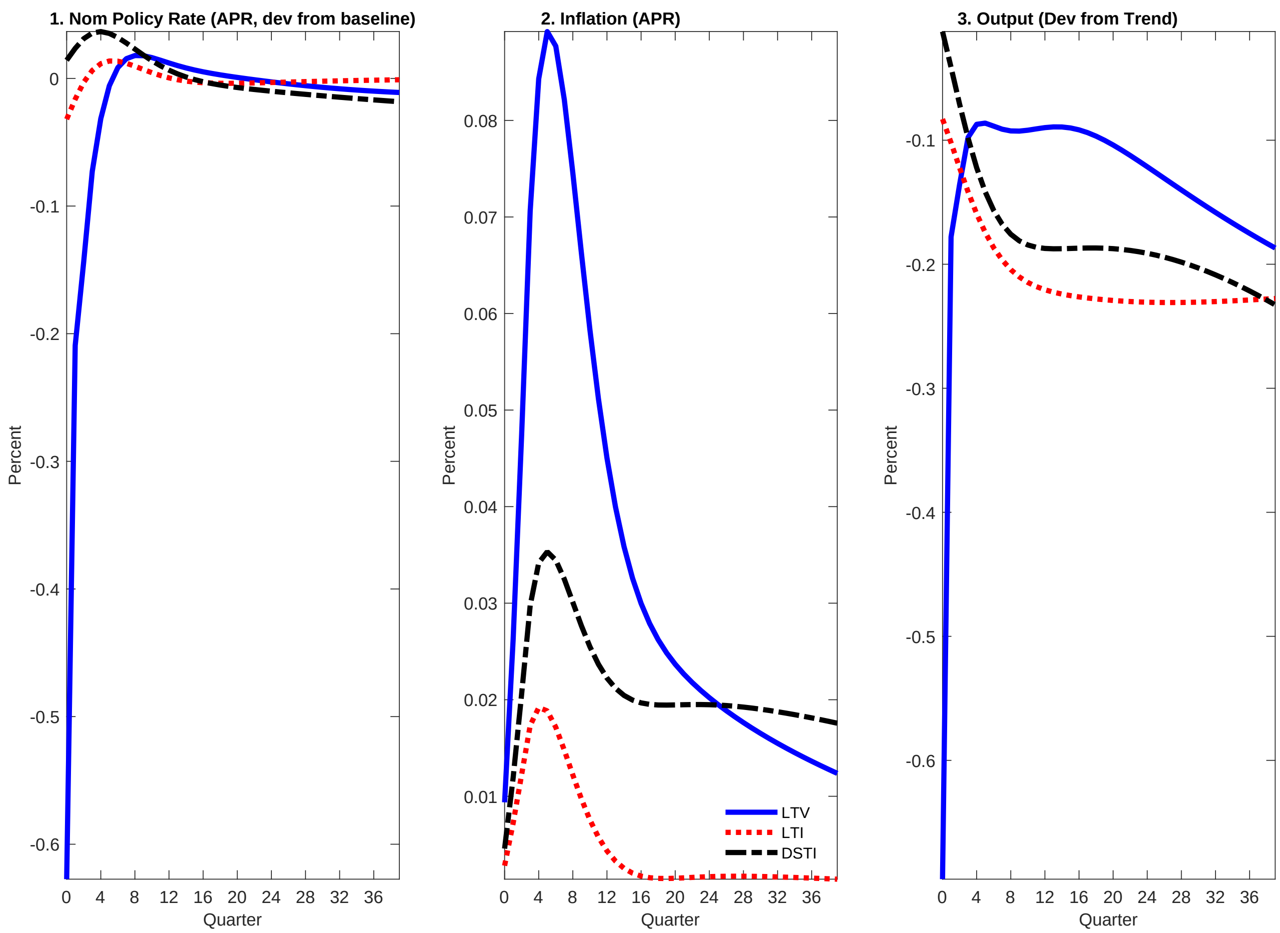


Figure A.2: Aggregate effects of MID removal across different borrowing constraints with unconstrained monetary policy and high indebtedness



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