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Aggregate Lending Standards and Inequality

Vanessa Schmidt* Hannah Seidl†

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Abstract

We study the effects of movements in aggregate lending standards on macroeconomic aggregates and inequality. We show in a New Keynesian model with heterogeneous households and housing that a looser loan-to-value (LTV) ratio stimulates housing demand, nondurable consumption, and output. Our model implies that the LTV shock transmits to macroeconomic aggregates through higher household liquidity and a general-equilibrium increase in house prices and labor income. We also show that a looser LTV ratio redistributes housing wealth from the top 10% of the housing wealth distribution to the bottom 50%, indicating an overall decrease in inequality.

Keywords: Heterogeneous Agents, Incomplete Markets, Housing, Macroprudential Policies

JEL Codes: E12, E21, E44, E52

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1 Introduction

The Great Financial Crisis demonstrated the critical role of the mortgage market for financial stability (see, e.g., Kaplan et al. (2020)). To stabilize the mortgage market, macroprudential policy in the form of adjustments to aggregate lending standards has emerged as a key tool (see, e.g., Rhu et al. (2011)). Empirical evidence shows that lending policies impact macroeconomic aggregates—such as house prices and output (see, e.g., Richter et al. (2019) and Bachmann and Rüth (2020))—as well as inequality dynamics (see, e.g., Georgescu and Martin (2024)). The influence of lending policies on both aggregates and inequality is important, as recent work on New Keynesian models with heterogeneous agents (HANK) finds interactions between inequality and macroeconomic outcomes (see, e.g., Ahn et al. (2018), Kaplan et al. (2018), and Bayer et al. (2024)). While the HANK literature has primarily focused on monetary and fiscal policy, macroprudential policy has received relatively little attention.

In this paper, we study the macroeconomic and distributional effects of changes in aggregate lending standards in a HANK model with housing. Specifically, we model changes in lending standards as shocks to the loan-to-value (LTV) ratio. We find that a looser LTV ratio stimulates housing demand, nondurable consumption, and output. The transmission operates through increased liquidity: in response to a looser LTV ratio, households convert more of their housing wealth into liquid assets and use this additional liquidity for housing and consumption, thereby raising output. These effects are further amplified by general-equilibrium increases in labor income and house prices. In contrast, systematic monetary tightening triggered by LTV-induced inflation dampens the stimulative effects of the LTV shock. Moreover, the fiscal response to monetary tightening further mutes the macroeconomic expansion. In particular, a higher interest rate increases government debt payments, causing fiscal policy to raise labor taxes to maintain a balanced budget. This tax increase reduces labor income and, in turn, aggregate consumption. We also find that a looser LTV ratio reduces housing wealth inequality by redistributing housing wealth from the top 10% of the housing wealth distribution to the bottom 50%. These distributional dynamics interact with macroeconomic aggregates: since the bottom 50% have on average higher marginal propensities to consume (MPCs) out of housing wealth than the top 10%, the reduction in inequality further amplifies the expansionary effects of the LTV shock.

We derive our findings in a HANK model in which households obtain utility from nondurable consumption and housing. We assume that every household owns housing. Households are subject to idiosyncratic productivity shocks to their labor income. Markets are incomplete which limits households' ability to insure against these shocks. This structure gives rise to a mass of constrained households that face a binding LTV constraint. The portfolio of households consists of liquid assets and housing. Housing is illiquid due to fixed adjustment costs, capturing frictions such as transaction fees and moving costs. On the supply side, we incorporate nominal wage stickiness, which gives rise to a New Keynesian Phillips curve. We include wage stickiness rather than price stickiness to avoid countercyclical profits as they have large effects on the model's cyclical properties of macroeconomic aggregates and inequality dynamics (see Werning (2016) and Broer et al. (2020)). The government consists of a monetary and a fiscal authority. In the baseline model, we assume that monetary policy follows a Taylor rule. The fiscal authority issues liquid assets and collects labor taxes proportional to household productivity. Because the government pays interest on its debt, changes in the interest rate affect the government budget constraint and induce a fiscal response. Following McKay and Wieland (2021), we assume that the fiscal authority adjusts the labor taxes to balance the effects on the government budget constraint.

One of our main findings is that a looser LTV constraint increases housing demand, house prices, and output, consistent with empirical evidence (see, e.g., Kim and Mehrotra (2018) and Bachmann and Rüth (2020)). We analyze the transmission mechanism and show that in response to a looser LTV ratio, households convert a larger fraction of their housing wealth into liquid assets. This conversion of illiquid housing wealth into liquid assets stimulates aggregate output because the additional liquidity is spent on consumption and housing. As the output expansion raises labor demand, labor income increases in general equilibrium. We find that higher labor income further stimulates output as our model generates on average high MPCs out of labor income, consistent with empirical evidence (see, e.g., Johnson et al. (2006) and Jappelli and Pistaferri (2010)).[1] We also show that house prices increase in general equilibrium. Since households borrow against the value of their house, higher house prices relax the tightness of the LTV constraint and, thus, further increase the liquidity of households. This amplifies the expansionary effects of the LTV shock.

In our baseline model, the monetary authority sets the nominal interest rate based on a standard Taylor rule. As inflation increases in response to the loosening LTV shock, monetary policy tightens, and the real interest rate increases. To analyze the role of the higher real rate for the stimulative effects of the LTV shock, we compute a counterfactual

[1]The importance of the general equilibrium increase in labor income for macroeconomic stimulation is also emphasized in the HANK literature on conventional monetary policy (see, e.g., Kaplan et al. (2018)).

in which the nominal interest rate is set such that the real rate remains constant. We compare this counterfactual with our baseline model and find that a higher real interest rate dampens the aggregate effects of the LTV shock. This is first because of intertemporal substitution: an increase in the real interest rate incentivizes households to postpone consumption. In addition, we show that a higher real rate mutes the increase of house prices, which reduces the amount of additional liquidity that households obtain. As a consequence, aggregate consumption and, thus, output increase by less.

We also find that a higher real interest rate dampens the aggregate effects of the LTV shock through the fiscal response. Specifically, in the baseline model, a higher real rate increases government debt payments. To balance the budget, labor taxes rise, thereby reducing households' disposable income. Since households have, on average, high MPCs out of disposable income, this reduction in income depresses consumption and output and, thus, mitigates the expansionary effects of the LTV shock. We further explore the importance of the fiscal response in a model variation with a lower steady-state government spending share. This variation confirms the intuition from our baseline results. In particular, a lower spending share requires smaller fiscal adjustments in response to the rising real interest rate, resulting in smaller tax increases and higher disposable income. Consequently, with a weaker fiscal response than in the baseline model, consumption increases more strongly, amplifying the stimulative effects of the LTV shock.

Subsequently, we turn to an analysis of the distributional dynamics of the LTV shock. This analysis is motivated by a recent literature showing that the aggregate effects of macroeconomic shocks depend on their implied distributional dynamics (see, e.g., Auclert (2019), Ahn et al. (2018), and Bayer et al. (2024)). We focus on housing wealth inequality as changes in aggregate lending standards primarily affect the housing market, making housing wealth inequality the most direct inequality measure of the LTV policy. We find that a looser LTV ratio reduces housing wealth inequality as it redistributes housing wealth from the top 10% of the housing wealth distribution toward the bottom 50%. We highlight that this lower wealth inequality stimulates output giving rise to an interaction of distributional dynamics and macroeconomic aggregates. This is because the MPCs out of housing wealth are higher for the bottom 50% of the housing wealth distribution than for the top 10%. Hence, by redistributing housing wealth from the top 10% to the bottom 50%, aggregate consumption increases.

Our theoretical results help explain a range of empirical findings in the literature. First, the empirical literature on aggregate lending standards finds that house prices fall in response to a contractionary LTV shock (see, e.g., Tillmann (2015), Richter et al.

(2019), and Georgescu and Martin (2024)). Kim and Mehrotra (2018) and Bachmann and Rüth (2020) find an increase in output in response to a loosening LTV shock. Consistent with these results, we find that house prices, aggregate consumption, and output increase in response to the loosening LTV shock.

There is a large literature that studies housing and macroeconomics (see among many others Iacoviello (2005), Piazzesi and Schneider (2016), Hedlund et al. (2017), and Kaplan et al. (2020)). One strand of this literature analyzes the role of house price dynamics (see, e.g., Justiniano et al. (2015), Berger et al. (2018), Garriga and Hedlund (2020), and Seidl (2025)). Our model accounts for this evidence as higher house prices stimulate aggregate consumption and output.

Our analysis builds on the growing literature on the transmission mechanism of fiscal and monetary policy in HANK models (see among many others Werning (2016), McKay et al. (2016), Kaplan et al. (2018), Auclert (2019), Hagedorn et al. (2019), Auclert et al. (2020), and Seidl and Seyrich (2023)). In line with this literature, we find that macroprudential policy in the form of an LTV shock is mainly transmitted through general equilibrium effects (see, e.g., Kaplan et al. (2018)) and that there is an interaction of macroeconomic aggregates and inequality dynamics (see, e.g., Ahn et al. (2018) and Bayer et al. (2024)).

There are several papers that examine the effects of macroprudential policy on both macroeconomic aggregates and inequality dynamics in more stylized models (Carpantier et al. (2018) and Georgescu and Martin (2024)). Our findings are consistent with their results of negative effects on inequality due to tighter LTV limits.

Closest to our paper are Favilukis et al. (2017), Guerrieri and Lorenzoni (2017), and Larkin (2020), who analyze tighter credit conditions in heterogeneous-agent models. We contribute to this literature as we additionally include an analysis of the interaction of LTV policies with monetary and fiscal policy.

The structure of the paper is as follows. Section 2 contains the model, section 3 presents the data and calibration. Section 4 contains the main results. Section 5 studies the interaction of monetary and LTV policy. Section 6 analyzes the role of the fiscal response. Section 7 concludes.

2 A HANK model with housing

This section outlines the model, which is based on McKay and Wieland (2021). The sticky-wage New Keynesian model includes incomplete markets and lumpy housing adjustment.

Households are heterogeneous in their holdings of liquid assets and illiquid housing. The model features an LTV constraint such that households can borrow up to a fraction of the value of their housing. To study the effects of changes in aggregate lending standards, we add to this model an LTV shock.

2.1 Households

There is a continuum of households indexed by $i \in [0,1]$. The preferences of household i are given by:

$$E_{i0} \int_{t=0}^{\infty} e^{-\rho t} \left[u(c_{it}, h_{it}) - \bar{u}_{c,t} \int_{0}^{1} v(n_{ijt}) dj \right] dt, \tag{1}$$

where n_{ijt} denotes labor supply of household i and of labor type $j \in [0,1]$, and ρ is the discount rate. Due to information frictions, the expectation operator is individual-specific as further explained below. Households consume nondurable consumption, c, and receive utility from housing, h. While McKay and Wieland (2021) study a model focused more generally on nondurables, we focus on housing and therefore need to specify the ownership structure. We here follow Favilukis et al. (2017) and assume that every household owns housing and, thus, abstract from a rental market. This assumption is based on Greenwald and Guren (2021), who show that rental markets are highly frictional, which discourages renting. In an extreme case, renting is so difficult that this situation is comparable to assuming that everyone owns housing. Abstracting from a rental market implies that all households are affected directly by the LTV shock through higher house prices. In a model with a rental market, renting households are affected indirectly by LTV shocks through changes in renting costs, such that the effects of a change in the LTV ratio would arise with more delay.

As further described below, a set of unions determines labor supply by taking into account the preferences of households. Additively separable preferences induce a wealth effect on labor supply: an increase in household wealth leads to higher consumption. Higher consumption lowers the marginal utility of consumption which makes leisure relatively more attractive such that labor supply decreases. For computational reasons, we follow McKay and Wieland (2021) and eliminate the wealth effect on labor supply[2] through introducing a preference shifter into household preferences (equation (1)), given

[2]Removing the wealth effect simplifies the computation (see McKay and Wieland (2019) for details). The reasoning is as follows. A change in the LTV ratio affects the interest rate and, thus, household wealth. In a model with a wealth effect on labor, labor supply is then affected, which, in turn, affects again the interest rate. Removing the wealth effect breaks this feedback loop.

by:

$$\bar{u}_{c,t} = \int_0^1 \frac{\partial u(c_{it}, h_{it})}{\partial c_{it}} di. \tag{2}$$

Hence, the preference shifter captures the marginal utility of consumption. It eliminates the wealth effect on labor supply as the disutility of labor adjusts in proportion to the marginal utility of consumption: when consumption rises, the scaled disutility of labor rises proportionally.

Our model incorporates information frictions as in Carroll et al. (2020) to avoid an implausibly large consumption response to an LTV shock.[3] More specifically, information frictions slow down how quickly agents update their beliefs, so they react with delay. As a result, the economy's adjustment to shocks is more gradual.

The household's felicity function is specified as a constant elasticity of substitution (CES) function:

$$u(c,h) = \frac{\left[(1-\psi)^{\frac{1}{\xi}} c^{\frac{\xi-1}{\xi}} + \psi^{\frac{1}{\xi}} h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-\sigma)}{\xi-1}} - 1}{1-\sigma}, \tag{3}$$

where ψ denotes the consumption share of housing, ξ represents the elasticity of substitution between consumption and housing, and σ is the inverse of the elasticity of intertemporal substitution.

In addition to housing, households hold liquid assets, denoted by a_{it}. Liquid assets pay a real interest rate r_t. When reshuffling the portfolio (a_{it}, h_{it}) to (a'_{it}, h'_{it}), households pay a fixed adjustment cost, f, proportional to the value of the durable stock. We therefore have:

$$a'_{it} + p_t h'_{it} = a_{it} + (1-f) p_t h_{it}, \tag{4}$$

where p_t denotes the relative price of housing in terms of the consumption good. Households can borrow against the value of their house up to an aggregate maximum LTV ratio, denoted by λ_t. The borrowing constraint in the form of an LTV constraint for each household is given by:

$$a_{it} \geq -\lambda_t (1-f) p_t h_{it}. \tag{5}$$

Correspondingly, each household has an endogenous LTV ratio that depends on its housing wealth, resulting in a distribution of individual LTV ratios across households.

To capture changes in lending standards, we introduce a shock to the aggregate maximum LTV ratio. The shock follows an Ornstein-Uhlenbeck process, which is the

[3] A related issue arises in Reiter et al. (2013), who find a counterfactually high investment response in models with fixed adjustment costs.

continuous-time counterpart of the discrete-time AR(1)-process. Specifically, the evolution of λ_t is governed by:

$$d\lambda_t = -\rho_\lambda(\lambda_t - \bar{\lambda})dt + \sigma_\lambda d\mathcal{W}_t^\lambda, \tag{6}$$

where $\bar{\lambda}$ represents the aggregate maximum LTV ratio in steady state. This is the LTV ratio up to which households can borrow in steady state. When the loosening LTV shock hits, the maximum LTV ratio increases, such that households can borrow up to a larger share of the value of their house. The parameter $\rho_\lambda > 0$ determines the speed at which λ_t reverts toward its steady state, $\bar{\lambda}$, and $\mathcal{W}_t^\lambda$ is a Brownian motion. The parameter σ_λ captures the volatility of the LTV ratio shock process, measuring the magnitude of random fluctuations in λ_t driven by the stochastic term $d\mathcal{W}_t^\lambda$. The first term, $-\rho_\lambda(\lambda_t - \bar{\lambda})$, ensures that deviations from $\bar{\lambda}$ diminish over time, reflecting mean-reverting behavior. The second term, $\sigma_\lambda d\mathcal{W}_t^\lambda$, introduces stochastic perturbations, allowing λ_t to vary around its mean.

Housing depreciates at rate δ, so that the stock of housing evolves according to:

$$\dot{h}_{it} = -\delta h_{it}, \tag{7}$$

where a dot over a variable denotes the derivative with respect to time.

Households receive labor income, y_{it}, given by:

$$y_{it} = (Y_t - \bar{\tau}_t)z_{it},$$

where Y_t is aggregate income. The government collects labor taxes, $\bar{\tau}_t$, in proportion to households' idiosyncratic labor productivity, z_{it}. We assume that z_{it} follows an Ornstein-Uhlenbeck process, given by:

$$\mathrm{d}\ln z_{it} = -\rho_z(\ln z_{it} - \ln \bar{z})\,\mathrm{d}t + \sigma_z\,\mathrm{d}\mathcal{W}_{it}^z,$$

where $\mathrm{d}\mathcal{W}_{it}$ represents a Brownian motion, ρ_z governs the degree of mean reversion of the income process, σ_z determines the variance of the income process, and $\bar{z}$ is a constant ensuring that $\int z_{it}\,di = 1$.

When a household does not adjust its housing position, the evolution of liquid assets is given by:

$$\dot{a}_{it} = r_t a_{it} + r_t^b a_{it} I_{a_{it}<0} - c_{it} + y_{it} - \delta p_t h_{it}, \tag{8}$$

where r_t is the real interest rate, r_t^b denotes a borrowing spread and I is an indicator function which equals 1 when savings are negative, that is, $a_{it} < 0$. Hence, households have either interest income, $r_t a_{it}$, or borrowing costs, $(r_t + r_t^b)a_{it}$. They have expenditures for nondurable consumption, c_{it}, the depreciation of housing, $\delta p_t h_{it}$, and they receive labor income, y_{it}.

2.2 Final goods producers

A representative firm produces the final good, Y_t, using aggregate labor, L_t. The production function is given by:

$$Y_t = L_t. \tag{9}$$

Aggregate labor and aggregate wage are given by the following indices:

$$L_t = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}}, \tag{10}$$

$$W_t = \left(\int_0^1 W_{jt}^{1-\phi} dj \right)^{\frac{1}{1-\phi}}, \tag{11}$$

where ϕ denotes the elasticity of substitution between different types of labor, W_{jt} is the wage rate for labor type j, l_{jt}. The price of the final good, P_t, is flexible and equal to marginal costs, so $P_t = W_t$. As shown in Appendix A, the demand curve for labor is given by:

$$l_{jt} = L_t \left(\frac{W_{jt}}{W_t} \right)^{-\phi}. \tag{12}$$

2.3 Labor unions

A set of unions determines households' labor supply and households take labor supply and labor income as given.

Unions collect differentiated productivity-weighted labor, $z_{it} n_{ijt}$, and aggregate it to labor type j, l_{jt}, according to:

$$l_{jt} = \int_0^1 z_{it} n_{ijt} di. \tag{13}$$

They sell this labor to final goods producers at the nominal wage rate W_{jt}. Nominal wages are sticky, and the Rotemberg-style wage adjustment costs are given by:

$$\frac{\Psi}{2} \bar{u}_{c,t} L_t (\mu_{jt})^2, \tag{14}$$

where Ψ is the strength of nominal rigidities. Including the preference shifter, $\bar{u}_{c,t}$ (as defined in equation (2)), in the Rotemberg adjustment costs functions ensures that wage adjustment costs are higher when the marginal utility of consumption is high, meaning that in periods of low consumption, the economy exhibits greater wage rigidity.

The growth rate of the wage for variety j, μ_{jt}, is given by:

$$dlnW_{jt} = \mu_{jt}dt. \tag{15}$$

The union chooses a wage growth rate for labor type j, μ_{jt}, that is optimal for households. Note that individual labor supply of type j, n_{ijt}, is equally distributed across all households. The objective function of the union is given by the following equation:

$$\max_{\mu_{jt}} \int_{t=0}^{\infty} e^{-\rho t} \int_0^1 \left[u_c(c_{it}, h_{it}) \frac{W_{jt}}{P_t} l_{jt} - \bar{u}_{c,t} v(l_{jt}) - \frac{\Psi}{2} \bar{u}_{c,t} L_t (\mu_{jt})^2 \right] didt. \tag{16}$$

The first term of the maximization problem represents the utility gain for households, which is real labor earnings for labor type j, $W_{jt}l_{jt}/P_t$, in terms of utility, that is, multiplied by the marginal utility of consumption of household i, $u_c(c_{it}, h_{it})$. The second term is the disutility of supplying labor of type j. As explained in section 2.1, the disutility of supplying labor is scaled by the preference shifter $\bar{u}_{c,t}$ to eliminate the wealth effects on labor supply. The last term captures the quadratic adjustment costs that arise when the wage changes. These costs depend on the size of the change, $L_t(\mu_{jt})^2$, the adjustment cost parameter, Ψ, and the preference shifter, $\bar{u}_{c,t}$ as explained above.

A union maximizes the objective function (equation (16)), with respect to labor demand (equation (12)) and the growth rate of wages (equation (15)). The union optimizes with respect to the growth rate of wages, rather than wage levels, because Rotemberg adjustment costs penalize large wage changes. This leads to gradual wage adjustments and prevents unrealistic jumps, in line with observed wage-setting behavior. The resulting optimality condition yields the following Phillips curve log-linearized around the zero inflation steady state:

$$\dot{\pi}_t = \rho \pi_t - \kappa \left(\frac{Y_t - \bar{Y}_t}{\bar{Y}_t} \right), \tag{17}$$

where $\bar{Y}_t$ is natural output, inflation, π_t, is defined as $\pi_t \equiv \frac{dlnP_t}{dt}$ and $\kappa \equiv \frac{(\phi-1)\eta}{\psi}$ is the slope of the Phillips curve, where $1/\eta$ denotes the Frisch elasticity. For details of the derivation of the Phillips curve see Appendix B.

2.4 Housing supply

A representative firm produces housing, X_t, using a nondurable good, M_t, as an input, and using a constant flow of land, $\bar{D}$. The government makes land available and sells it. The production function is given by:

$$X_t = \omega M_t^{1-\zeta} \bar{D}^{\zeta}, \tag{18}$$

where ω is a constant, and ζ is the share of land in housing production.

Profit maximization yields the following relative price of housing

$$p_t = (1-\zeta)^{-1} \omega^{-\frac{1}{1-\zeta}} \left(\frac{X_t}{\bar{D}} \right)^{\frac{\zeta}{1-\zeta}}. \tag{19}$$

The supply elasticity of housing is thus given by $\frac{1-\zeta}{\zeta}$. For details of the derivation see Appendix C.

2.5 Government

The government consists of the monetary and the fiscal authority. In the baseline model, the monetary authority sets the nominal interest rate, i_t, according to a Taylor rule as in Kaplan et al. (2018), given by:

$$i_t = \bar{r} + \phi_\pi \pi_t, \tag{20}$$

where ϕ_π denotes by how much monetary policy reacts to deviations in inflation, π_t, and $\bar{r}$ denotes the steady state real interest rate.

The nominal and the real interest rate are linked via the Fisher equation:

$$r_t = i_t - \pi_t.$$

The fiscal authority issues liquid assets and follows a constant-debt policy:

$$A_t = \int_0^1 a_{it} dt = \bar{A}. \tag{21}$$

The period-by-period government budget constraint is given by:

$$\bar{\tau}_t = r_t \bar{A} + G_t, \tag{22}$$

where G_t is government consumption. Since the government has positive debt, a change in the real interest rate affects the government budget constraint. Labor taxes are the instrument that the fiscal authority adjusts to balance the effects on the government budget. Since this affects the disposable income of households, the fiscal response matters for the aggregate effects of the LTV shock.

2.6 Market clearing conditions

The non-durable goods market clearing condition is given by:

$$Y_t = \int_0^1 c_{it}\ \mathrm{d}i + M_t + G_t + r_t^b \int_0^1 a_{it} I_{(a_{it}<0)} \mathrm{d}i.$$

The housing market clearing condition is given by:

$$X_t = \int_0^1 \left(\frac{\mathrm{d}h_{it}}{\mathrm{d}t} - \delta h_{it} \right) \mathrm{d}i + f \int_0^1 I_{h'_{it} \neq h_{it}} h_{it}\ \mathrm{d}i.$$

The bond market clearing condition is given by:

$$A_t = \int_0^1 a_{it}\ \mathrm{d}i.$$

By Walras' law, aggregate labor demand equals aggregate labor supply.

2.7 Model solution

As McKay and Wieland (2021), we solve the model building on the continuous-time methods developed by Achdou et al. (2022) for the steady state and on the Sequence-Space-Jacobian method by Auclert et al. (2021) for the aggregate dynamics. The full details for the computation are provided in Appendix A of McKay and Wieland (2021).

Steady State. We solve for the steady-state equilibrium based on the continuous-time methods developed by Achdou et al. (2022). They show that heterogeneous-agent models boil down to a Hamilton-Jacobi-Bellman (HJB) equation for the optimal choices of a household taking the distribution of households over the three state variables (income, assets, and housing) and prices as given, and a Kolmogorov Forward (KF) equation, which describes the evolution of this distribution based on households' optimal choices. Since the model includes housing subject to fixed costs, individuals solve stopping time problems (Stokey (2008)). Due to the stopping time problem, the value function solves a

HJB Variational Inequality (HJBVI, Øksendal (1995)) rather than a HJB equation. The HJBVI characterizes household's optimal consumption and saving behavior by comparing the value function with and without adjustment. We define a grid over the state variables and use the finite difference method to solve for the HJBVI. More specifically, this method approximates derivatives by computing differences between function values at discrete points. The approximation is conducted with a larger point of the value function—the forward difference—or a smaller point— the backward difference. Based on the upwind scheme, we choose whether the forward or the backward difference is used. Specifically, the forward difference is used whenever the drift of the state variable is positive, and, vice versa, the backward difference is used whenever the drift of the state variable is negative. To give an example, if a household is accumulating savings (that is, the drift is positive), the forward difference is used. We then iterate to obtain the value function at each grid point. This solution gives the optimal policies, which are then used to compute the distribution of households over the three state variables—the KF equation.

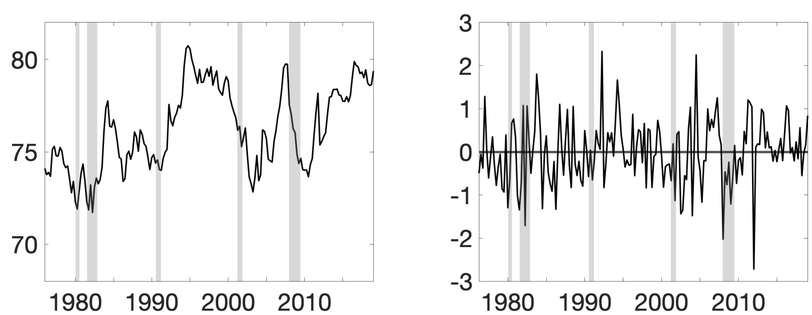
Aggregate dynamics. We solve for the aggregate dynamics using the Sequence-Space-Jacobian approach by Auclert et al. (2021). This is a perfect-foresight solution with respect to aggregate shocks which implies that the model does not feature aggregate but only idiosyncratic uncertainty arising from shocks to households' labor income. As shown by Boppart et al. (2018), due to certainty equivalence, the dynamics of the perfect-foresight solution are equivalent to those obtained from the solution of the linearized rational expectations model, as in Reiter (2009) and Ahn et al. (2018).

The Sequence-Space-Jacobian method derives the first-order approximation of equilibrium responses to anticipated shocks by reformulating the equilibrium as a system of linear equations within the space of perfect-foresight sequences. The key feature of this method is the use of Sequence-Space Jacobians, which link changes in aggregate variables to variations in prices and aggregate shocks. The first step in the computation is to calculate the partial equilibrium Jacobians which capture how changes in aggregates are related to changes in prices or shocks. Specifically, we solve for the HJBVI marching backward in time and assume that the shock has vanished at the starting point of the calculation, which is the point in time that is furthest away, $t = T$. We then solve for the KF equation marching forward in time. This process is repeated for all periods, from $t = 0$ to $t = T$, to construct the entire Jacobian matrix. Accordingly, each entry of the Jacobian represents the change in an aggregate variable in response to a change in prices. The rows of the matrix capture how the aggregate variable evolves over time in response to a price change in a given period, while the columns show how the aggregate variable in a specific period responds to price changes over time. Specifically, the first entry of the row shows how the aggregate variable responds to a price change in period one, the second row shows how the aggregate variable responds to a price change in period two, and so on. The general equilibrium Jacobians are solved for by incorporating the endogenous price and income changes that satisfy the market clearing conditions.

3 Data and calibration

The model is calibrated to US data at the quarterly frequency. Figure 1a shows the average LTV ratio in the US since 1976 of single-family mortgages of newly built and previously occupied homes. It reflects that the average LTV ratio over time in the data is 76%, and the highest average LTV ratios in this time period were in 1994/1995 at around 80%. Correspondingly, we choose a maximum LTV ratio of 0.8 which corresponds to a down-payment of 20%.[4]

Figure 1: The LTV ratio in the US



(a) LTV ratio in %

(b) LTV shock series

Notes: (i) Data source: Monthly Interest Rate Survey of the Federal Housing Finance Agency, table 17, (ii) time span: January 1976 to March 2019 (the survey is discontinued as of May 2019 due to dwindling participation), (iii) frequency: the quarterly mean of the monthly data, (iv) data is seasonally adjusted.

To calibrate the persistence of the LTV shock, we estimate an AR(1) process of the seasonally adjusted LTV ratio in discrete time,

$$\lambda_t = \rho_{AR1}\lambda_{t-1} + \varepsilon_t, \tag{23}$$

[4]Note that there is no maximum LTV ratio in the US that is binding for all households, which is why we use the average time series as a proxy. Our calibrated LTV ratio corresponds to McKay and Wieland (2021).

where ρ_{AR1} is the persistence parameter, and ε_t is an independent and identically distributed (i.i.d.) shock. We follow Bachmann and Rüth (2020) here, who use the seasonally adjusted quarterly LTV ratio in a vector autoregressive model. Our estimate results in a persistence of 0.94. Figure 1b shows the innovation series ε_t from this AR(1) process.

Table 1: Calibration

Parameter	**Description**	**Value**
ρ	Discount rate	0.085
σ	Inverse elasticity of intertemporal substitution	4
ψ	Housing consumption share	0.327
ξ	Elasticity of substitution between consumption and housing	0.5
δ	Depreciation rate	0.023
f	Fixed costs	0.038
ρ_z	Income persistence	0.09
σ_z	Income standard deviation	0.216
Ξ	Rate of information updating	2/3
ρ_λ	Persistence of LTV ratio	0.94
$\bar{\lambda}$	Maximum LTV ratio	0.8
ζ	Land share in the production of housing	0.14
G/Y	Government spending share	0.2
ϕ_π	Response to inflation	1.25
κ	Slope of the Phillips curve	0.03

Table 1 summarizes the calibration of our model. We follow McKay and Wieland (2021) for the calibration of the elasticity of intertemporal substitution, the elasticity of substitution between housing and consumption goods, the discount rate, the share of housing in the consumption aggregation, and the depreciation rate. The inverse elasticity of intertemporal substitution, σ, is set to 4, and the elasticity of substitution between housing and consumption goods, ξ, to 0.5. The discount rate, ρ, and the share of housing in the consumption aggregation, ψ, are calibrated to match the ratio of net assets to GDP equal to 0.92 and housing to consumption equal to 1.92, respectively. The depreciation of housing is set to 2.3% which matches the quarterly value for housing depreciation divided by the total housing stock as in the Bureau of Economic Analysis Fixed Asset tables.

The fixed costs are expressed as a percentage of the value of households' housing stocks. These costs are incurred when a household adjusts its housing stock. To match the empirical estimate from Bachmann and Cooper (2014), who find that 15% of households move to a new house each year, we calibrate the model such that the quarterly fixed costs amount to 3.75% of the value of the housing stock. This ensures that the frequency of housing adjustments in the model aligns with observed data. The calibration of the income process follows Floden and Lindé (2001). The rate of information updating is two third according to Coibion and Gorodnichenko (2012) which implies that the expected time between information updates is 6 quarters. We calibrate the share of land in the production of housing, ζ, to 14% as in McKay and Wieland (2021).

We set the parameter governing the monetary policy reaction to inflation, ϕ_π, to 1.25 as in Kaplan et al. (2018). The steady-state ratio of government spending to output, G/Y, is set to 0.2 which is a standard value in the literature. As the specification of fiscal policy matters for the transmission of the LTV shock, we discuss a variation of this parameter in section 6. The slope of the Phillips curve, κ, expressed in terms of annualized inflation per unit of the quarterly output gap, is set to 0.03 which falls within the range of empirical estimates (Mavroeidis et al. (2014)).

4 The aggregate and distributional effects of LTV shocks

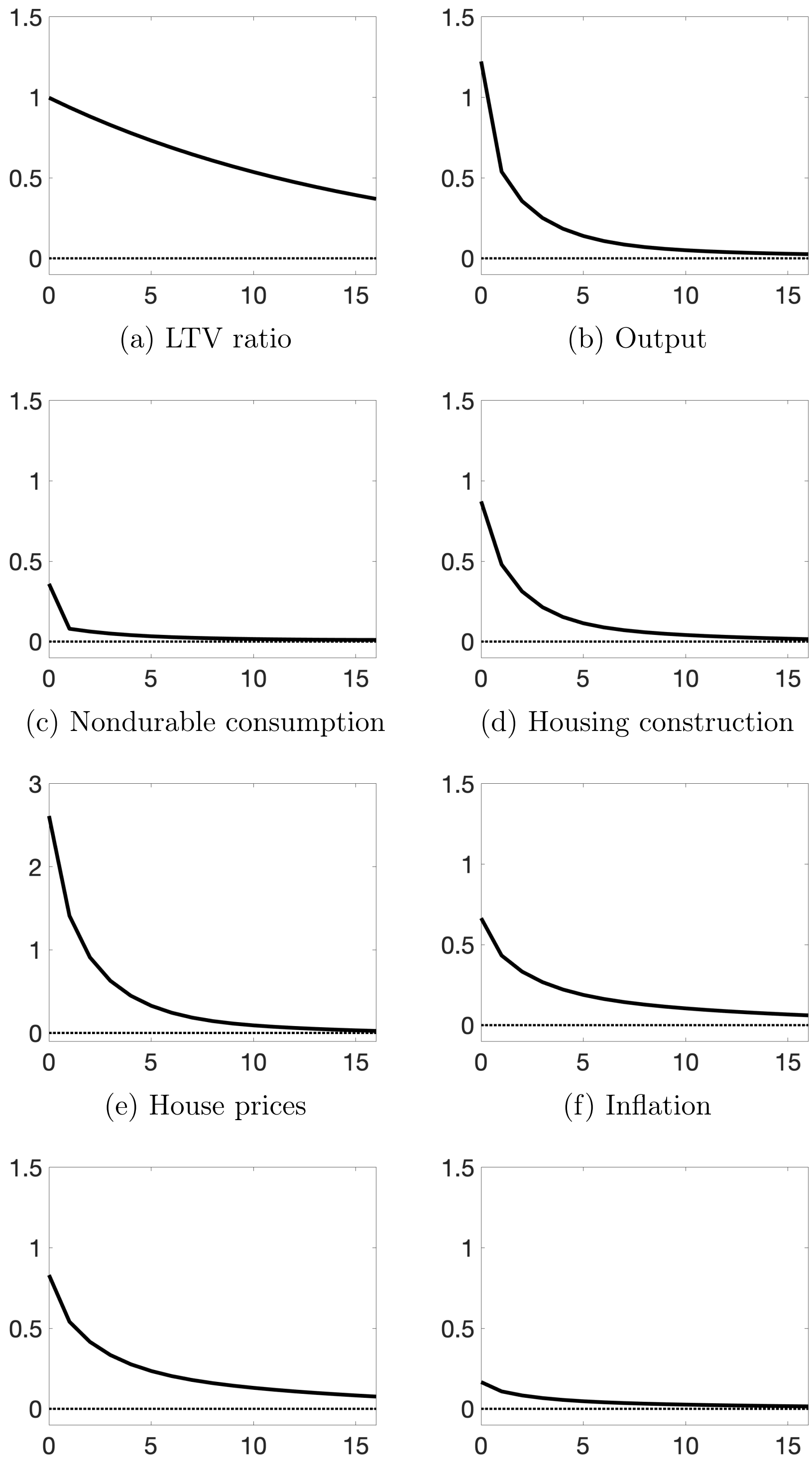
This section presents our main results.

4.1 Aggregate effects

Figure 2 shows the impulse response functions to a loosening in the LTV ratio by 1 percentage point (panel 2a) which increases output (panel 2b) and consumption (panel 2c).

We now analyze the transmission mechanism of a looser LTV ratio to macroeconomic aggregates. Our first finding is that, by increasing the borrowing capacity, a looser LTV ratio provides additional liquidity to households. The reason is that a looser LTV ratio allows households to convert a larger part of their housing wealth into liquid assets. Figure 3 shows that households make use of this additional borrowing capacity. More specifically, panel 3a shows the change in the amount of borrowing households in the economy. It illustrates that the number of borrowing households is above its steady-state level for almost as long as the shock to the LTV ratio lasts. The peak response is one year after the shock, with 0.2 percentage points (pp) more borrowing households. Panel 3b further shows that, in addition to increasing the number of borrowing households, the looser LTV ratio also leads to a persistent decline in liquid asset holdings of borrowers—indicating that they take on more debt. As households spend the additional liquidity on consumption and housing, aggregate output increases.

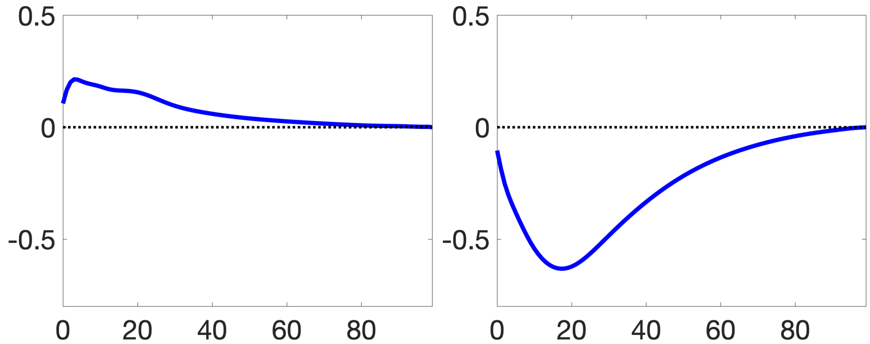
Figure 2: Impulse response functions to a loosening LTV shock



(a) LTV ratio
(b) Output
(c) Nondurable consumption
(d) Housing construction
(e) House prices
(f) Inflation
(g) Nominal rate
(h) Real rate

Notes: (i) positive 1 percentage point shock to the LTV ratio under perfect foresight, (ii) the LTV ratio, interest rates, and inflation are in percentage point deviations, all other variables are in % deviations from steady state, inflation and interest rates are expressed in annualized terms, (iii) horizontal axes denote quarters.

Figure 3: Debt dynamics in response to the looser LTV ratio



(a) Share of borrowing households (b) Liquid assets of borrowers

Notes: (i) positive 1 percentage point shock to the LTV ratio under perfect foresight, (ii) the change in the share of borrowing households is in percentage point deviation from steady state, and the change in liquid assets of borrowers is in percent deviation from steady state, (iii) horizontal axes denote quarters.

At the same time, this higher spending on housing increases housing demand, which, in turn, increases through general equilibrium housing construction by 0.9% (panel 2d) and house prices by 2.6% (panel 2e). The rise in house prices further amplifies the expansion in output, as the LTV constraint is defined relative to the value of the house (see equation (5)). Hence, higher house prices relax the LTV constraint even more, allowing households to access additional liquidity.

We now analyze how the looser LTV ratio is transmitted through a general-equilibrium increase in labor income, driven by higher output and the associated rise in labor demand. We find that our model generates on average high MPCs out of labor income. Specifically, in the first period following the shock, households consume 5.7% of the increase in labor income, on average.[5] Note that this average MPC is four times higher than in standard representative-agent New Keynesian models in which the MPC of the representative agent is roughly the same size as the interest rate (Kaplan and Violante (2022)). The elevated MPCs reflect that households facing a binding LTV constraint cannot increase their borrowing in liquid assets. The on average high MPC aligns the model-implied consumption behavior with empirical evidence (see, e.g., Johnson et al. (2006) and Jappelli and Pistaferri (2010)).

The looser LTV ratio increases (annualized) inflation by 0.7 pp as reflected in panel 2f. We assume that monetary policy follows a Taylor rule and increases the nominal interest rate in response to this higher inflation. This results in an increase of the (annualized)

[5]For computational details see Appendix D.

nominal interest rate by 0.8 pp as reflected in panel 2g.[6] As a result, the real interest rate increases by 0.2 pp (panel 2h). In section 5, we show that this systematic monetary tightening attenuates the stimulative effects of the LTV ratio.

We also find that the fiscal reaction to the monetary tightening shapes the overall size of the output response. To be precise, a higher interest rate increases the interest rate payments of the government on its debt. To balance the effects on the government budget constraint, the fiscal authority increases labor taxes which mutes the increase in labor income of households. We find that the 0.2 pp rise in the real interest rate reduces labor income by 0.2% on impact.[7]

4.2 Distributional Effects

In this section, we study the distributional consequences of the LTV shock in our HANK model with housing. This analysis is motivated by a growing body of literature showing that macroeconomic shocks can have different aggregate effects depending on how they redistribute resources across households (see, e.g., Ahn et al. (2018), Auclert (2019), and Bayer et al. (2024)). We focus on housing wealth inequality because housing is both a key asset in household portfolios and a direct target of policy through the LTV ratio.

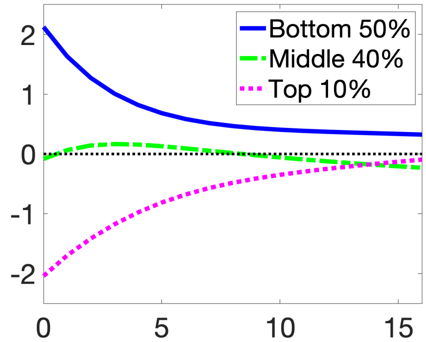
Consistent with empirical evidence by Georgescu and Martin (2024), we find that a looser LTV ratio decreases housing wealth inequality. Figure 4 shows the distributional effects of the LTV shock along the housing wealth distribution. Specifically, the pink dotted line depicts the change in housing wealth held by the top 10% of the housing wealth distribution relative to the rest of the distribution. The green dash-dotted line represents the response for the middle 40%, and the blue solid line shows the response for the bottom 50%, each relative to the remainder of the housing wealth distribution. While the housing wealth of the bottom 50% increases by approximately 2.1 pp relative to the rest of the distribution, the top 10% see a nearly proportional decline. Housing wealth for the middle 40% is largely unchanged. This shift demonstrates a redistribution of housing wealth toward the lower end of the distribution.

These relative changes arise for two reasons. First, the overall housing stock of the bottom 50% is relatively large. The increase in house prices, thus, yields a large increase in their housing wealth. Second, the relaxation of the LTV constraint is especially relevant for lower-wealth households. With improved access to credit, these households expand

[6]Note that this systematic tightening of monetary policy in response to the stimulative effects of looser LTV ratios matches the empirical results by Bachmann and Rüth (2020).

[7]For computational details see Appendix D.

Figure 4: Distributional efects of the LTV shock across the housing wealth distribution



Notes: (i) positive 1 percentage point shock to the LTV ratio under perfect foresight, (ii) responses are percentage point deviations from steady state, (iii) horizontal axis denotes quarters.

their housing positions, unlike higher-wealth households, whose borrowing is already unconstrained and therefore largely unaffected by the policy.

We find that the distributional effects amplify the stimulative effects of the LTV shock by computing the MPCs out of housing wealth along the distribution. We find that in response to a 1 pp increase in housing wealth, the bottom 50% increases their consumption by 5.6 pp more than the rest of the distribution.[8] Hence, a reallocation of housing wealth toward the bottom 50% stimulates aggregate demand.

5 The interaction of monetary and LTV policy

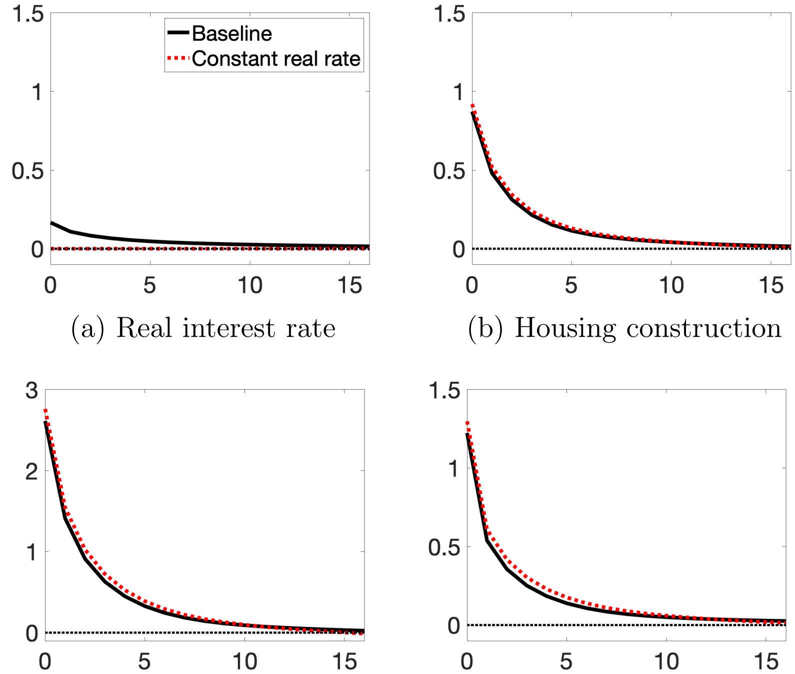
Our baseline model accounts for the empirically observed systematic tightening of monetary policy in response to the LTV shock (Bachmann and Rüth (2020)). In particular, the central bank increases the nominal interest rate in response to the higher inflation according to a Taylor rule. This results in a higher real interest rate.

In this section, we analyze the effects of this monetary tightening for the output response. To this end, we conduct a counterfactual experiment where the central bank does not follow a Taylor rule but sets the nominal interest rate in a way that the real interest rate stays constant. In figure 5, we compare this counterfactual (red dotted lines) with our baseline model (black lines). As reflected in panel 5a, the monetary policy response induces an increase in the real interest rate in the baseline model while in the counterfactual, the real interest rate remains constant.

We find that the monetary tightening attenuates the expansionary effects of the looser

[8]For computational details see Appendix D.

Figure 5: Impulse response functions in a model with a constant real interest rate



(a) Real interest rate

(b) Housing construction

(c) House prices

(d) Output

Notes: (i) positive 1 percentage point shock to the LTV ratio under perfect foresight, (ii) the real interest rate is annualized and in percentage point deviations from steady state, all other variables are in % deviations from steady state, (iii) horizontal axes denote quarters.

LTV ratio. More specifically, panel 5d shows that output increases by more in the scenario with a constant real interest rate (1.3%) than in the baseline model where monetary policy follows a standard Taylor rule (1.2%). This is a sizeable impact on output given that the real interest rate increases by only 0.2 pp in the baseline model.

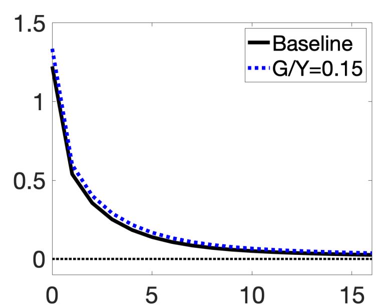
The higher real rate mitigates the stimulative effects of the looser LTV ratio as follows. A higher real interest rate incentivizes households through a standard intertemporal substitution channel to postpone consumption. In addition, we find that the dampening of a higher real rate works through house prices and the fiscal response. More specifically, housing construction (panel 5b) and house prices (panel 5c) increase by more with a constant real rate than in our baseline model. The reason is that with a constant real rate, borrowing is less expensive, such that households increase their demand for housing. In general equilibrium, housing construction and house prices increase by more. The magnitude of the house price response determines the extent to which the LTV constraint relaxes and, consequently, how much additional liquidity households can access. The reason is that, consistent with the intuition from our baseline model, higher house prices enhance household liquidity and, in turn, lead to a larger increase in aggregate consumption.

In addition, a higher interest rate transmits to aggregate consumption through the fiscal response. In particular, in our baseline model, a higher real rate increases government debt payments. To balance the effects on the government budget constraint, labor taxes increase. In a model with a constant real rate, the interest rate payments of the government do not increase in response to the LTV shock. Hence, labor taxes remain constant. This difference in labor taxes implies that the labor income of households increases by less in our baseline model (7.4%) than in the counterfactual with a real interest rate (7.6%). As households have on average high MPCs out of labor income, aggregate consumption and, thus, output are lower in the baseline model than in the model with the constant real rate.

6 The role of the fiscal response

In this section, we further study the importance of the fiscal response to monetary tightening in shaping the aggregate impact of the LTV shock. Specifically, in figure 6, we analyze the output response to the same LTV shock in an experiment with a variation of the steady-state share of government over output. The black solid line shows the out-

Figure 6: Output response with a variation in the government spending share



Notes: (i) positive 1 percentage point shock to the LTV ratio under perfect foresight, (ii) % deviation from steady state, (iii) horizontal axis denotes quarters.

put response in the baseline model, where the government spending share, G/Y, is set to 20%. The blue dash-dotted line represents a variation of the model in which G/Y is set to 15%. It becomes evident that a lower government spending share amplifies the stimulative effects of the looser LTV ratio: while output increases by 1.2% in the baseline model, it rises by 1.3% when the government spending share is lower.

The reason for this stronger output response is that a lower government spending share requires a smaller fiscal adjustment. Specifically, the government needs less tax revenue than in the baseline model to cover its spending and interest payments. As a result, taxes increase less than in the baseline model, allowing households to retain more of their income. More specifically, labor income increases by 7.4% in the baseline model and by 7.9% in the model with a lower government spending share. Given that households have high MPCs, consumption increases by more in the model with a lower government spending share. Consequently, a lower government spending share amplifies the overall effect of the LTV shock on aggregate output.

7 Conclusion

In this paper, we study the effects of changes in aggregate lending standards on macroeconomic aggregates and the corresponding distributional dynamics in a New Keynesian model with heterogeneous households and housing. We show that a looser LTV ratio stimulates aggregate nondurable consumption and output. We study the transmission mechanism and show that the LTV shock transmits to macroeconomic aggregates through higher household liquidity and general-equilibrium increases in house prices and labor income. We also study the effects of the LTV policy on housing wealth inequality and find that a looser LTV ratio redistributes housing wealth from the top 10% of the housing wealth distribution to the bottom 50%, indicating a decrease in inequality. We highlight that there is an interaction of macroeconomic aggregates and distributional dynamics: as the bottom 50% have higher MPCs out of housing wealth than the top 10%, the lower inequality amplifies the stimulative effects of the LTV shock.

A recent literature studies state-dependent effects of monetary policy (see, e.g., Berger et al. (2021) and Eichenbaum et al. (2022)). In future work, we aim to study state-dependent effects of changes in the LTV ratio. Our conjecture is that the stimulative effects of the LTV shock depend on the level of the LTV ratio. The reason is that the LTV ratio determines which households of the housing wealth distribution are affected by the LTV shock. This matters since the level of wealth governs the amount of additional liquidity households obtain in response to the LTV shock. Since this additional liquidity is spent on housing and consumption, the size of this additional liquidity determines the overall macroeconomic effects of the LTV shock. We leave a formal analysis for future work.

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Appendix A Derivation of the labor demand curve

The demand curve for labor of final goods producers is derived in the following. The labor aggregation index is given by:

$$L_t = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}},$$

and the wage index is given by:

$$W_t = \left(\int_0^1 W_{jt}^{1-\phi} dj \right)^{\frac{1}{1-\phi}}.$$

Optimizing behavior of the final goods producer implies the following maximization problem:

$$\max_{L_{jt}} L_t = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}} \quad \text{subject to:} \quad \int_0^1 W_{jt} L_{jt} dj = Z_t,$$

where Z_t is any given level of labor costs. The corresponding Lagrangian is then given by:

$$\mathcal{L} = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}} - \lambda_t \left(\int_0^1 W_{jt} l_{jt} dj - Z_t \right).$$

The first-order condition with respect to a particular labor unit k is then given by:

$$\frac{\phi}{\phi-1} \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}-1} \frac{\phi-1}{\phi} l_{kt}^{\frac{\phi-1}{\phi}-1} - \lambda_t W_{kt} = 0,$$

and with respect to a particular labor unit i:

$$\frac{\phi}{\phi-1} \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}-1} \frac{\phi-1}{\phi} l_{it}^{\frac{\phi-1}{\phi}-1} - \lambda_t W_{it} = 0.$$

Dividing the two first-order conditions by each other yields:

$$\left(\frac{l_{kt}}{l_{it}} \right)^{\frac{\phi-1}{\phi}-1} = \frac{W_{kt}}{W_{it}}$$

$$\leftrightarrow l_{kt} = W_{kt}^{-\phi} W_{it}^{\phi} l_{it}$$

$$\leftrightarrow l_{jt} = W_{jt}^{-\phi} W_{it}^{\phi} l_{it}$$

When plugging the optimality condition into the constraint one obtains:

$$Z_t = \int_0^1 W_{jt} W_{jt}^{-\phi} W_{it}^{\phi} l_{it} dj = W_{it}^{\phi} l_{it} \int_0^1 W_{jt}^{1-\phi} dj = W_{it}^{\phi} l_{it} W_t^{1-\phi}$$

$$\leftrightarrow l_{it} = \left(\frac{W_{it}}{W_t}\right)^{-\phi} \frac{Z_t}{W_t} \leftrightarrow l_{jt} = \left(\frac{W_{jt}}{W_t}\right)^{-\phi} \frac{Z_t}{W_t}$$

In a last step, we show that $\int_0^1 W_{jt} l_{jt} dj = W_t L_t$, and therefore, $\frac{Z_t}{W_t} = L_t$.

$$L_t = \left(\int_0^1 \left(\left(\frac{W_{jt}}{W_t}\right)^{-\phi} \frac{Z_t}{W_t} \right)^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}}$$

$$= \frac{Z_t}{W_t} W_t^{\phi} \left(\int_0^1 (W_{jt}^{1-\phi}) dj \right)^{\frac{\phi}{\phi-1}} = \frac{Z_t}{W_t} W_t^{\phi} W_t^{-\phi} = \frac{Z_t}{W_t}$$

Thus, since $\frac{Z_t}{W_t} = L_t$, the demand curve for labor is given by:

$$l_{jt} = L_t \left(\frac{W_{jt}}{W_t}\right)^{-\phi}. \tag{A.1}$$

Appendix B Derivation of the Phillips Curve

The optimization problem of the unions gives rise to the Phillips curve as in McKay and Wieland (2021).

The union's objective function is composed of the equally-weighted utility of households less adjustment costs, given by:

$$\max_{\mu_{it}} \int_{t=0}^{\infty} e^{-\rho t} \int_0^1 \left[u_c(c_{it}, h_{it}) \frac{W_{jt}}{P_t} l_{jt} - \bar{u}_{c,t} v(l_{jt}) - \frac{\Psi}{2} \bar{u}_{c,t} L_t (\mu_{jt})^2 \right] \, \mathrm{d}i \, \mathrm{d}t, \tag{A.2}$$

subject to labor demand (equation A.1) and to the growth rate of wages given by:

$$d \ln W_{jt} = \mu_{jt} \, \mathrm{d}t.$$

The first-order conditions are given by:

$$\lambda_{jt} = \Psi \mu_{jt} \bar{u}_{c,t} L_t$$

and:

$$\mathrm{d}\lambda_{jt} - \rho \lambda_{jt} \, \mathrm{d}t = -(1-\phi) \bar{u}_{c,t} \left(\frac{W_{jt}}{P_t}\right)^{1-\phi} \left(\frac{W_t}{P_t}\right)^{\phi} L_t \, \mathrm{d}t - \phi L_t \left(\frac{W_{jt}}{W_t}\right)^{-\phi} \bar{u}_{c,t} v_L \left(l_{jt}\right) \mathrm{d}t.$$

Imposing symmetry and market clearing yields:

$$\begin{aligned}
\Psi\mu_t\bar{u}_{c,t}Y_t &= \lambda_t\\
\mathrm{d}\lambda_t - \rho\lambda_t\ \mathrm{d}t &= -(1-\phi)\bar{u}_{c,t}Y_t\ \mathrm{d}t - \phi\bar{u}_{c,t}Y_t v_L Y_t \mathrm{d}t\\
\pi_t &= \mu_t.
\end{aligned}$$

The non-linear Phillips curve is then given by:

$$\mathrm{d}\pi_t = \left[\rho - \frac{\mathrm{d}\bar{u}_{c,t}}{\bar{u}_{c,t}} - \frac{\mathrm{d}Y_t}{Y_t}\right]\pi_t\ \mathrm{d}t - \frac{\phi-1}{\Psi}\left[\frac{\phi}{\phi-1}v_L Y_t - 1\right]\mathrm{d}t.$$

Log-linearizing around the zero-inflation steady state gives:

$$\mathrm{d}\pi_t = \rho\pi_t\ \mathrm{d}t - \frac{\phi}{\Psi}\eta\left(\frac{Y_t - \bar{Y}}{\bar{Y}}\right)\mathrm{d}t,$$

where $\frac{1}{\eta}$ is the Frisch elasticity. Letting $\kappa = \frac{\phi\eta}{\Psi}$ yields equation (17).

Appendix C Derivation of the relative price of housing

Firms that supply housing maximize profits:

$$\Pi_t = P_t^H X_t - P_t M_t - P_t^D \bar{D},$$

where P_t^H is the price of housing, P_t is the price of the final good, and P_t^D is the price of land. The housing production function is given by:

$$X_t = \omega M_t^{1-\zeta}\bar{D}^{\zeta},$$

where $\omega > 0$ is a constant, $\zeta \in (0,1)$ is the elasticity of housing output with respect to land, M_t is the input of intermediate goods, and $\bar{D}$ represents the fixed amount of land.

The firm's maximization problem can be expressed as:

$$\max_{M_t}\Pi_t = P_t^H\omega M_t^{1-\zeta}\bar{D}^{\zeta} - P_t M_t - P_t^D\bar{D}.$$

The firm does not choose $\bar{D}$, as land supply is fixed by the government. Taking the derivative of Π_t with respect to M_t, the first-order condition is:

$$P_t^H\omega(1-\zeta)M_t^{-\zeta}\bar{D}^{\zeta} = P_t.$$

Dividing through by P_t, we define the relative price of housing $p_t = \frac{P_t^H}{P_t}$ and rewrite the first-order condition as:

$$p_t\omega(1-\zeta)M_t^{-\zeta}\bar{D}^{\zeta} = 1.$$

Rearranging, the relative price of housing is expressed as:

$$p_t = \frac{1}{\omega(1-\zeta)M_t^{-\zeta}\bar{D}^{\zeta}}.$$

To eliminate M_t, we substitute the housing production function:

$$X_t = \omega M_t^{1-\zeta}\bar{D}^{\zeta}.$$

Solving for M_t, we obtain:

$$M_t = \left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{\frac{1}{1-\zeta}}.$$

Substituting this expression into the equation for p_t, we get:

$$p_t = \frac{1}{\omega(1-\zeta)\left[\left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{\frac{1}{1-\zeta}}\right]^{-\zeta}\bar{D}^{\zeta}}.$$

Simplify the exponent term gives:

$$\left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{\left(\frac{1}{1-\zeta}\right)^{-\zeta}} = \left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{-\frac{\zeta}{1-\zeta}}.$$

Thus, the relative price of housing becomes:

$$p_t = \frac{1}{\omega(1-\zeta)\bar{D}^{\zeta}}\left(\frac{\omega\bar{D}^{\zeta}}{X_t}\right)^{\frac{\zeta}{1-\zeta}}.$$

Combining terms yields:

$$p_t = (1-\zeta)^{-1}\omega^{-1}\bar{D}^{-\zeta}\omega^{\frac{\zeta}{1-\zeta}}\bar{D}^{\frac{\zeta^2}{1-\zeta}}X_t^{-\frac{\zeta}{1-\zeta}}.$$

Finally, collecting powers of ω and $\bar{D}$, the optimality condition for the relative price of housing is given by:

$$p_t = (1-\zeta)^{-1}\omega^{-\frac{1}{1-\zeta}}\left(\frac{X_t}{\bar{D}}\right)^{\frac{\zeta}{1-\zeta}}.$$

Appendix D Results from Sequence-Space Jacobians

Let x_t and y_t denote two variables, and let $\mathcal{J}$ denote the sequence space Jacobian that captures the responses of y at different horizons to news about x at different horizons,

$$\mathcal{J} = \begin{pmatrix} \frac{dy_0}{dx_0} & \frac{dy_0}{dx_1} & \cdots \\ \frac{dy_1}{dx_0} & \frac{dy_1}{dx_1} & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix}.$$

To give an example, the $(2,1)$ element of $\mathcal{J}$, $\frac{dy_1}{dx_0}$, gives the response of y at time $t = 1$ to a surprise in x at time $t = 0$.

Using the sequence space Jacobians, we calculuate the marginal propensity to consume (MPC) out of labor, the response of taxes to a change in the real interest rate, and the marginal consumption response to housing wealth as follows:

- The MPC out of labor income is given by the $(1,1)$-element of the corresponding Jacobian, $\frac{dC}{dY}$, where C is aggregate consumption and Y denotes aggregate labor income.

- The change in labor income in response to a change in the real interest rate by one unit is given by the $(1,1)$-element of the corresponding Jacobian, $\frac{dY}{dr}$. In section 4.1, the value must be scaled by 0.2 as the interest rate only increases by 20 basis points rather than 100 basis points.

- To obtain the marginal propensity to consume out of housing wealth—defined as the price of the house times the housing stock—, $\frac{dC^g}{dH^g}$, we use the Jacobian of the change in consumption in response to house prices multiplied by the housing stock:

  $$\frac{dC^g}{dH^g} = \frac{1}{H^g} \cdot \frac{dc^g}{dp},$$

  where c^g denotes the nondurable consumption of group $g \in \{\text{B50}, \text{M40}, \text{T10}\}$, where B50 refers to the bottom 50% of the housing wealth distribution, M40 refers to the middle 40% and T10 to the to 10%. Let H^g denote the steady-state housing wealth of group g.

  To compute the difference in marginal consumption responses to housing wealth between the bottom 50% and the rest of the distribution, we compute:

  $$\Delta\text{MPCs} = \frac{1}{H^{\text{B50}}} \cdot \frac{dc^{\text{B50}}}{dp} - \frac{1}{H^{\text{M40}} + H^{\text{T10}}} \cdot \left(\frac{\partial c^{\text{M40}}}{dp} + \frac{\partial c^{\text{T10}}}{dp} \right).$$