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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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This paper documents the macroeconomic effects of changes in downpayment requirements on mortgage loans in a model where investment is undertaken by collateral-constrained agents. I find that a permanent tightening in lending standards substantially lowers aggregate spending in the short run and permanently lowers house prices. These effects are much larger than in earlier findings from a model where unconstrained agents invest. Furthermore, I document that the amplification of macroeconomic shocks is much stronger when steady-state loan-to-value ratios are high. The loan-to-value shock itself is amplified to a greater extent when the loan-to-value ratio starts out at a higher level. In that sense, the effects of loan-to-value ratios on the economy are non-linear.

Keywords: Collateral effect, financial accelerator
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1 Introduction

In the United States, loan-to-value (LTV) ratios on mortgage loans rose sharply during a period of positive growth in real GDP in the mid-2000s, but declined sharply during and after the Great Recession of 2007-2009.[1] A currently unresolved question in the literature is whether such changes in downpayment requirements on mortgage loans have contributed substantially to the boom and bust in US real GDP and in house prices around that time.[2]

Justiniano, Primiceri and Tambalotti (2015) address this question. In a two-agent model with sticky prices, they find that increases in the LTV cause GDP to decrease somewhat. Part of this response reflects the fact that in their model, investment decreases in response to a relaxation in lending standards. This occurs against the background that they abstract from credit constraints on firms and assume that all investment is undertaken by liquidity-unconstrained households.

In the present paper, I gauge the effects of changes in LTVs in a two-agent model with sticky prices in which all investment is undertaken by collateral-constrained firms. I find that conditional on an LTV shock, LTVs, investment and GDP all move in the same direction. The comparison of these results with those of Justiniano, Primiceri and Tambalotti (2015) suggests that liquidity constraints on productive investment are an important component of the transmission mechanism of lending shocks to aggregate real activity.

My finding that conditional on an LTV shock, LTVs and GDP move in the same direc-

[1] Duca, Muellbauer and Murphy (2011) and Bachmann and Rueth (2020) measure the average LTV for the United States. De Jong and De Veirman (2019) do so for the Netherlands.

[2] For instance, Duca, Muellbauer and Murphy (2011) and Gelain, Lansing and Natvik (2018) find that changes in credit conditions were an important factor, while Justiniano, Primiceri and Tambalotti (2015) and Kaplan, Mitman and Violante (2020) find that they were not the primary factor.

tion is in line with the finding by Bachmann and Rueth (2020) that in a Structural Vector Autoregression, aggregate output increases following an increase in the LTV.

On another point, I show how permanent changes in LTVs alter the transmission of macroeconomic shocks. I document that a permanent decline in LTVs substantially weakens the amplification of housing demand and monetary policy shocks, in the sense that the financial accelerator effect is much weaker when the LTV is somewhat lower. In addition, I document that amplification of the lending shock itself is much stronger when the LTV starts off at a high level. In this sense, the effects of permanent reductions in LTVs are non-linear. My results suggest that in the United States, the initial declines in LTVs from about 95 percent in 2005 exerted considerable downward pressure on mortgage lending and the aggregate economy, while any one percentage point decline from LTVs of 80 percent would have minor effects.

To check for the influence of credit-constrained investment as well as for the effect of steady-state changes in LTVs, I incorporate variation in LTVs in the Two-Agent New Keynesian model with collateral-constrained borrowers of Iacoviello (2005). In this model, all investment is undertaken by credit-constrained entrepreneurs. To my knowledge, Justiniano, Primiceri and Tambalotti (2015) and the present paper are the only two papers that allow for time-variation in LTVs in a two-agent model with sticky prices.[3]

To my knowledge, this paper is the first to use a two-agent model to examine whether permanent changes in lending standards have permanent effects. I find that a permanent

[3] Jensen, Hove Ravn and Santoro (2018) examine the effects of changes in LTV shocks in a two-agent real model, while Kiyotaki, Michaelides and Nikolov (2011, 2020), Favilukis, Ludvigson and van Nieuwerburgh (2017) and Kaplan, Mitman and Violante (2020) do so in overlapping generations models. Huo and Rios Rull (2018) examine the joint effects of LTV and interest rate shocks in a heterogeneous agent model. Ferrero (2012) and Boz and Mendoza (2014) examine the effects of changing LTVs in open-economy models.

tightening in lending standards has a permanent downward effect on house prices. Furthermore, I find that such a permanent reduction in LTVs has substantial, albeit transitory, downward effects on aggregate consumption and investment and therefore on Gross Domestic Product (GDP).

To give an overview of the mechanism, I find that after a tightening in LTVs, collateral-constrained borrowers consume less and demand less housing. Since borrowers sell housing, they have less collateral available, which further reduces their access to credit and amplifies the effect of the shock on their spending. The decline in aggregate spending occurs because the reduction in spending of credit-constrained borrowers is much larger than a short-run increase in the consumption of lenders, who freely substitute consumption intertemporally.

An aspect that plays a role in the difference between the effects on GDP in Justiniano, Primiceri and Tambalotti (2015) and those in my analysis is that Justiniano, Primiceri and Tambalotti (2015) find that LTV shocks have a small effect on house prices. They conclude from this that the value of collateral barely increases during a credit expansion, such that the credit shock is barely amplified. In the model I use, I find larger effects of LTVs on house prices than in Justiniano, Primiceri and Tambalotti (2015).[4] Furthermore, I find that substantial changes in house prices are not necessary for amplification through collateral constraints to occur. In particular, I find that conditional on an LTV shock, the collateral effect operates through changes in the quantity of housing held by collateral-constrained borrowers. The reason for this is that when downpayment requirements tighten, these borrowers sell housing in an effort to dampen the decrease in their consumption.

[4] Justiniano, Primiceri and Tambalotti (2015) find that a ten percentage point decrease in the LTV from 95 percent implies a two percent drop in house prices. In the present paper, I find that a *one* percentage point decrease in the LTV from 95 percent implies a one percent decrease in house prices.

My finding that a permanent tightening in lending standards implies a permanent decline in house prices is consistent with the finding of Kiyotaki, Michaelides and Nikolov (2020), within an overlapping generations model, that a permanent credit tightening implies a permanent decline in house prices. In both cases, this reflects the feature that housing is in fixed supply, which is motivated by the fact that in the data, land accounts for a substantial share of housing wealth.[5]

My results apply to the effects of changes in LTVs irrespective of the extent to which these changes are influenced by macroprudential policy actions such as changes in a regulatory maximum on LTVs.[6] My analysis speaks for changes in explicit macroprudential policy as well as for changes in any government guidelines to agencies that purchase mortgages such as the Government Sponsored Enterprises (GSEs), since guidelines about which mortgages can be bought would influence average LTVs of mortgages originated in the market.

One of the common aims of LTV limits is to enhance financial stability by reducing the risk of non-repayment of mortgage loans and by reducing loan loss given default. The present paper quantifies a way in which reducing LTVs enhances macroeconomic stability: reducing average LTVs permanently substantially reduces the amplification of macroeconomic shocks through borrower balance sheets.[7] This effect is separate from any effect of LTV cuts on loan loss risks for banks.

[5]See Davis and Heathcote (2007).

[6]An increasingly large number of economies have adopted such limits on LTVs. See Shim e.a. (2013), Cerutti e.a. (2017), Akinci and Olmstead-Rumsey (2018) and Alam e.a. (2019) for databases on the use of macroprudential policy tools including LTV limits.

[7]In an open-economy model, Cesa-Bianchi, Ferrero and Rebucci (2018) show that a steady-state increase in the LTV of domestic households increases the amplification of a one-time change in the maximum allowed leverage of a global bank. Lamont and Stein (1999) show empirically that house prices are more sensitive to income shocks in cities where high LTVs are more common. Almeida, Campello and Liu (2006) find that the same relationship is stronger in countries with higher maximum LTVs.

Section 2 describes selected features of the model. Section 3 interprets the model responses to transitory and permanent lending shocks. Section 4 documents reduced amplification of housing demand and monetary policy shocks at low steady-state LTVs. Section 5 concludes.

2 Model

I extend the model of Iacoviello (2005) with loan-to-value shocks. As the model is well-known, this section focuses on making intuitive those parts of the model that are crucial for the interpretation of the impulse responses in ensuing sections. The Appendix states the full log-linearized model that I use.

In Iacoviello (2005), patient households lend to impatient households and entrepreneurs. Each of these classes of agents consume and purchase a share of a fixed housing stock. Both types of borrowers are liquidity-constrained and borrow up to a constant loan-to-value ratio. Borrowers are more impatient than lenders, which ensures that the liquidity constraints are always binding in steady state. Retail firms purchase output from entrepreneurs and re-set prices infrequently as in Calvo (1983), without indexation, which implies a forward-looking Phillips curve. The central bank follows an interest rate rule.

I modify the model by introducing a lending shock that induces time-variation in LTVs around steady state. The lending shock captures changes in lending that are exogenous from the point of view of lenders as well as borrowers. Implicitly, they reflect changes in how much banks lend for any given value of collateral for any reason, including but not limited to cases where these changes are driven by regulatory policy.

2.1 Model Essentials

In the model, impatient households consume and work for the entrepreneurs. Entrepreneurs consume, invest in plant and equipment, hire labor from patient and impatient households, and produce output. The entrepreneur and impatient household each face a repayment constraint on one-period borrowing from patient households. This constraint is specified as a function of their expected housing wealth at the time of repayment. For entrepreneur and impatient household, respectively:

$$R_t b_t = m_t \, E_t \left(q_{t+1} h_t \pi_{t+1} \right) \quad (1)$$

$$R_t b_t^{''} = m_t^{''} \, E_t \left(q_{t+1} h_t^{''} \pi_{t+1} \right) \quad (2)$$

where R_t is the gross nominal interest rate, q_t the real house price and π_{t+1} gross inflation. b_t indicates real borrowing by entrepreneurs, h_t their stock of housing, while m_t is the LTV on loans to entrepreneurs. $b_t^{''}$, $h_t^{''}$ and $m_t^{''}$ are analogously defined for the impatient household. Unlike in Iacoviello (2005), m_t and $m_t^{''}$ are time-varying.

On the left hand side, the constraints indicate the real amount, combining principal and interest, that the borrower has to repay after one period. Keeping the value of collateral constant, an increase in R_t tightens liquidity constraints since borrowers can only achieve the same repayment amount by borrowing less. In either of the above equations, an increase in the LTV relaxes the borrowing constraint as it allows for more borrowing for any given value of collateral. Borrowing constraints are also relaxed if borrowers expect to have more housing wealth available when the loan is due, either through rising house prices or increased holdings of housing. Inflation erodes the real value of debt and therefore relaxes the credit constraint.

I assume the following shock process for the loan-to-value ratios m_t and $m_t^{''}$ of the entrepreneur and impatient household, respectively:

$$m_t = m^{1-\rho_m} \, m_{t-1}^{\rho_m} \, e_{m,t} \quad (3)$$

$$m_t^{''} = m^{''1-\rho_{m''}} \, m_{t-1}^{''\rho_{m''}} \, e_{m'',t} \quad (4)$$

where m and $m^{''}$ are the respective steady-state LTVs, while $e_{m,t}$ and $e_{m'',t}$ are shocks with mean one.

The consumption Euler equations for entrepreneurs, patient households and impatient households, respectively, are:

$$\frac{1}{c_t} = \gamma \, E_t \left(\frac{R_t}{c_{t+1}\pi_{t+1}} \right) + \lambda_t R_t \quad (5)$$

$$\frac{1}{c_t^{'}} = \beta \, E_t \left(\frac{R_t}{c_{t+1}^{'}\pi_{t+1}} \right) \quad (6)$$

$$\frac{1}{c_t^{''}} = \beta^{''} E_t \left(\frac{R_t}{c_{t+1}^{''}\pi_{t+1}} \right) + \lambda_t^{''} R_t \quad (7)$$

where c_t is consumption by entrepreneurs and γ their time discount factor, while λ_t is the Lagrange multiplier on their liquidity constraint. $c_t^{'}$ and β are consumption and the time discount factor for patient households. $c_t^{''}$, $\beta^{''}$ and $\lambda_t^{''}$ are consumption, discount factor and multiplier on the liquidity constraint for impatient households.

The equation for patient households is the standard Euler equation with log-linear utility in consumption except for the influence of expected inflation. Because loans are in nominal terms, an increase in expected inflation reduces the real return on loans, which tends to cause the impatient household to save less.

As for entrepreneurs and impatient households, the degree to which the liquidity constraint is binding affects the timing of their consumption. A tightening in the budget constraint implies an increase in the shadow value of relaxing that constraint. Credit-constrained borrowers therefore cut current consumption and borrowing so as to relax the constraint.

The first-order conditions for housing demand for entrepreneurs, patient households and impatient households, respectively, are:

$$\begin{aligned} & E_t\left\{\frac{\gamma}{c_{t+1}}\left[q_{t+1}\left(1+\frac{\varphi_e}{2}\left(\frac{h_{t+1}^2-h_t^2}{h_t^2}\right)\right)+\frac{1}{X_{t+1}}\nu\frac{Y_{t+1}}{h_t}\right]+\lambda_t\ m_t\ q_{t+1}\pi_{t+1}\right\} \\ = & \frac{q_t}{c_t}\left(1+\varphi_e\left(\frac{h_t-h_{t-1}}{h_{t-1}}\right)\right) \end{aligned} \tag{8}$$

$$\frac{j_t}{h_t^{'}}+\beta\ E_t\left\{\frac{q_{t+1}}{c_{t+1}^{'}}\left[1+\frac{\varphi_h}{2}\left(\frac{\left(h_{t+1}^{'}\right)^2-\left(h_t^{'}\right)^2}{\left(h_t^{'}\right)^2}\right)\right]\right\}=\frac{q_t}{c_t^{'}}\left[1+\varphi_h\left(\frac{h_t^{'}-h_{t-1}^{'}}{h_{t-1}^{'}}\right)\right] \tag{9}$$

$$\begin{aligned} & \frac{j_t}{h_t^{''}}+\lambda_t^{''}m_t^{''}E_t(q_{t+1}\pi_{t+1})+\beta^{''}E_t\left\{\frac{q_{t+1}}{c_{t+1}^{''}}\left[1+\frac{\varphi_h}{2}\left(\frac{\left(h_{t+1}^{''}\right)^2-\left(h_t^{''}\right)^2}{\left(h_t^{''}\right)^2}\right)\right]\right\} \\ = & \frac{q_t}{c_t^{''}}\left[1+\varphi_h\left(\frac{h_t^{''}-h_{t-1}^{''}}{h_{t-1}^{''}}\right)\right] \end{aligned} \tag{10}$$

where φ_e governs the level of housing adjustment costs for the entrepreneur, $1/X_t$ is the relative price of entrepreneurial output purchased by price-setting retailers (and therefore real marginal cost) and $\nu Y_t/h_{t-1}$ is the marginal product of housing in terms of aggregate output Y_t. $h_t^{'}$ is the housing stock of the patient household. For both types of households, j_t

governs the utility from housing services and φ_h governs housing adjustment costs.

Each agent optimizes such that the marginal utility loss from giving up consumption to buy a unit of housing at the relative price q_t equals the expected marginal utility gain. Each agent uses housing as a store of wealth for future consumption, such that the expected marginal utility gain from purchasing houses at t depends positively on expected house prices in $t+1$.

For entrepreneurs and impatient households, the marginal utility of housing depends on the degree to which an extra unit of housing allows for more borrowing as well as on the shadow value of relaxing the borrowing constraint. For entrepreneurs, housing is an input into production, such that the marginal utility of housing depends on the marginal revenue product of housing. For both types of households, the marginal utility of housing directly depends on the marginal utility of housing services.

2.2 Log-Linearized Equations

In this subsection, I state the log-linearized borrowing constraints and housing demand conditions for the entrepreneur and impatient household as well as the log-linearized shock processes for LTVs. Other equations are analogous to Iacoviello (2005) and are in the Appendix.

The log-linearized entrepreneurial credit constraint is:[8]

$$\widehat{b}_t = \widehat{m}_t + E_t\widehat{q}_{t+1} + \widehat{h}_t - \widehat{rr}_t \tag{11}$$

[8]To arrive at this equation, take logarithms of the entepreneurial credit constraint (1), compute the first-order Taylor expansion $\log(E_t\left(q_{t+1}h_t\pi_{t+1}\right)) \simeq \log(qh\pi) + [(E_tq_{t+1} - q)/q] + [(h_t - h)/h] + [(E_t\pi_{t+1} - \pi)/\pi]$ and subtract the steady state.

where hats denote percentage deviations from steady state and where $\widehat{rr}_t \equiv \widehat{R}_t - E_t\widehat{\pi}_{t+1}$.

Analogously, the log-linearized impatient household credit constraint is:

$$\widehat{b}''_t = \widehat{m}''_t + \ E_t\widehat{q}_{t+1} + \widehat{h}''_t - \widehat{rr}_t \tag{12}$$

Combining the optimality condition for entrepreneurs' housing demand with their consumption Euler equation by substituting out λ_t yields, after log-linearizing:

$$\begin{aligned} \widehat{q}_t \ &= \ [(1-m)\gamma + m\beta] \ E_t\widehat{q}_{t+1} + (m\beta - 1)(E_t\widehat{c}_{t+1} - \widehat{c}_t) + \gamma\varphi_e(E_t\widehat{h}_{t+1} - \widehat{h}_t) - \beta m \ \widehat{rr}_t \\ &\quad +[m(\beta-\gamma)]\widehat{m}_t - [1-(1-m)\gamma - m\beta][E_t\widehat{X}_{t+1} - E_t\widehat{Y}_{t+1} + \widehat{h}_t] - \varphi_e(\widehat{h}_t - \widehat{h}_{t-1}) \end{aligned} \tag{13}$$

Analogously, the combined housing/consumption condition for impatient households is:

$$\begin{aligned} \widehat{q}_t \ &= \ [\beta'' + (\beta - \beta'')m''] \ E_t\widehat{q}_{t+1} + (1-\beta m'')\left[\widehat{c}''_t + \frac{\beta''(m''-1)}{1-\beta m''}E_t\widehat{c}''_{t+1}\right] + \beta''\varphi_h(E_t\widehat{h}''_{t+1} - \widehat{h}''_t) \\ &\quad -\beta m'' \ \widehat{rr}_t + [m''(\beta-\beta'')]\widehat{m}''_t - \varphi_h(\widehat{h}''_t - \widehat{h}''_{t-1}) + [1-(\beta-\beta'')m'' - \beta''](\widehat{j}_t - \widehat{h}''_t) \end{aligned} \tag{14}$$

Finally, the log-linearized process for the entrepreneur's LTV is:

$$\widehat{m}_t = \rho_m\widehat{m}_{t-1} + \widehat{e}_{m,t} \tag{15}$$

while the analogous process for the impatient household is:

$$\widehat{m}''_t = \rho_{m''}\widehat{m}''_{t-1} + \widehat{e}_{m'',t} \tag{16}$$

3 Lending Shocks

This section documents the effect of lending shocks on the economy under alternative values for steady-state loan-to-value ratios. I consider transitory lending shocks before considering permanent lending shocks.

For all shocks in this paper, I document the degree of amplification depending on the level of the (initial) steady-state LTV while keeping all other parameter values fixed. I set these parameters at the values estimated or calibrated by Iacoviello (2005).[9] So as to focus on a manageable number of cases, I always set the LTV of the entrepreneur equal to that of the impatient household.

3.1 Transitory Lending Shocks

I consider transitory lending shocks implying that entrepreneurial and impatient household LTVs drop one percentage point below steady state on impact, after which they return to steady state at a rate governed by $\rho_m = \rho_{m''} = 0.90$.

Figure 1 plots the responses for consumption, mortgage lending and the housing stock for the patient household, impatient household and entrepreneur. Figure 2 plots the responses for the aggregate economy. These and all other impulse responses below plot percentage

[9] I set the discount factor of the patient household $\beta = 0.99$, that of the entrepreneur $\gamma = 0.98$ and that of the impatient household $\beta^{''} = 0.95$. The parameter governing patient and impatient households' steady-state utility from housing is $j = 0.1$, while $\eta = 1.01$ such that the elasticity of labor supply is high, in particular $1/(\eta - 1) = 100$. In the production function, I set the elasticity of output to housing $\nu = 0.03$, the elasticity of output to capital $\mu = 0.3$, and the parameter associated with patient household labor $\alpha = 0.64$. I set the capital depreciation rate $\delta = 0.03$, the parameter governing the level of capital adjustment costs $\psi = 2$, and set housing adjustment costs for the entrepreneur and for both types of households to zero such that $\varphi_e = 0$ and $\varphi_h = 0$. As for price setting by retailers, the steady-state markup $X = 1.05$ and the probability of the retailer not adjusting its price $\theta = 0.75$. In the monetary policy rule, the response of the nominal interest rate to the lagged output gap $r_Y = 0.13$, the response of the nominal interest rate to lagged inflation $1 + r_\pi = 1.27$, and the degree of interest smoothing $r_R = 0.73$.

deviations from steady state with respect to quarters since the shock.

First consider the blue lines. These pertain to the case where steady-state LTVs for the entrepreneur and the impatient household, i.e. m and m'', are both at 0.95. At these high LTVs, even a relatively modest tightening in collateral requirements has substantial real effects. On impact, a one percentage point reduction in LTVs causes aggregate output to fall 3.06 percent below steady state.

The aggregate response mostly reflects the spending responses by borrowers since fluctuations in patient household consumption are comparatively small. This plausibly reflects the fact that the patient household is not liquidity-constrained such that it can freely reallocate consumption across time through changes in its saving and in so doing resembles a Permanent Income Hypothesis consumer. The patient household response reflects the intertemporal substitution effect: it consumes more at times when expected returns on saving from that point on are low, following its consumption Euler equation.[10] Patient household consumption reaches its trough six quarters after the shock, from which point onwards expected returns on saving are comparatively high as the real interest rate rises somewhat above steady state and as house prices reach their trough.[11]

The responses of impatient households and entrepreneurs consist of two aspects. First,

[10] The behavior of patient household consumption is as in De Veirman and Dunstan (2011), who show that in a model with a single type of consumer and without collateral constraints, intertemporal substitution can explain why consumption cycles coincide with cycles in asset returns.

[11] House price changes are only one component of returns on housing. Using the entrepreneur as an illustration, I combine the housing and consumption conditions for the entrepreneur by eliminating current marginal utility so as to arrive at the following expression for the expected excess real return on housing for the entrepreneur: $E_t(rr^q_{t+1}) - E_t(R_t/\pi_{t+1}) = \left\{\gamma\left[cov_t(1/c_{t+1}, R_t/\pi_{t+1}) - cov_t(1/c_{t+1}, rr^q_{t+1})\right] + \lambda_t[R_t - m_t E_t(q_{t+1}\pi_{t+1}/q_t(1+\varphi_e(\Delta h_t/h_{t-1})))]\right\}/\gamma E_t(1/c_{t+1})$, where I define the gross real return on housing as: $rr^q_{t+1} \equiv \left\{q_{t+1}\left[1+(\varphi_e/2)\left((h^2_{t+1}-h^2_t)/h^2_t\right)\right] + (1/X_{t+1})(\nu Y_{t+1}/h_t)\right\} / \quad \{q_t\left[1+\varphi_e\left(\Delta h_t/h_{t-1}\right)\right]\}$. This demonstrates that housing returns for the entrepreneur reflect housing adjustment costs and the marginal value product of housing as well as changes in the relative price of housing.

the reduction in LTVs tightens borrowing constraints. This tends to increase the Lagrange multipliers λ_t and λ_t'' on the credit constraints. This causes credit-constrained borrowers to cut current consumption relative to the future as they follow their consumption Euler equations. This, in turn, increases their marginal benefit of consuming today relative to tomorrow. Following their housing demand conditions, this increases the utility value of selling housing today so as to free up resources for consumption at a time when the marginal utility of consumption is high. Borrowers therefore engage in fire sales of housing in an effort to reduce the fall in consumption.

Second, there is another reason why entrepreneurs and impatient households sell housing: the reduction in LTVs in itself reduces the marginal benefit from a unit of housing since a unit of housing now does not increase borrowing capacity by as much as it used to.

As a result of these combined effects on housing demand, a transitory one percentage point decline in LTVs implies that on impact, borrower housing stocks fall about 15 percent below steady state. Both the decline in LTVs and the decline in borrower housing stocks imply that entrepreneurs and impatient households have to cut down borrowing drastically. This reduction in borrowing implies pronounced changes in impatient household consumption and in entrepreneurial consumption and investment.

Note that the LTV shock has only small effects on house prices, but has substantial effects on borrower housing stocks. It is the decline in borrower housing stocks that triggers the collateral effect and amplifies the shock.[12]

[12]The plotted response of the housing stock is conditional on assuming zero adjustment costs to housing. Iacoviello (2005) estimates housing adjustment costs to be zero. Positive levels of housing adjustment costs dampen changes in housing transactions but imply enormous reductions in consumption since borrowers are not able to dampen the consumption response through housing sales.

Finally, patient households buy the housing which borrowers sell since housing is in fixed supply. The reduction in mortgage lending by patient households mirrors the decline in borrowing by impatient households and entrepreneurs. Therefore, patient households transfer more wealth to the future through housing wealth, and less through claims on borrowers, than they do in steady state.

The red lines in the same two figures mark the case with steady-state LTVs at 0.80. In this case, aggregate output only falls by 0.43 percent on impact.

This occurs because at lower LTVs, any reduction in the housing stock has a smaller downward effect on borrowing and on current consumption, such that the incentive to sell housing to dampen the fall in consumption is weaker. Therefore, the collateral effect is weaker, and so is the amplification of the LTV shock. My results suggest that the difference in amplification of credit shocks is very large: the impact response is seven times larger when LTVs are 0.95 than when they are 0.80.

Table 1 summarizes the cumulative impulse responses of aggregate output, house prices and mortgage lending to a transitory tightening in lending standards for a wider range of steady-state LTVs. It tabulates these impulse responses on impact, 40 quarters after the shock and in the long run, all in percent deviations from steady state. The table documents the generality of the finding that the impact effect of credit shocks on output and mortgage lending is considerably larger when steady-state LTVs are higher. This finding extends to cumulative output losses after 40 quarters and in the long run. Mortgage lending tends to react more strongly at high steady-state LTVs.

High steady-state LTVs also imply that a credit tightening causes house prices to fall by more, albeit only after some time. On impact and at high steady-state LTVs, a credit tightening implies that house prices increase somewhat. At lower steady-state LTVs, house prices decrease a little on impact. This difference plausibly arises because with low steady-state LTVs, output falls by less, such that real interest rates decline by less. In general equilibrium, this corresponds to a less pronounced decline in housing returns. Therefore, with low steady-state LTVs, expected housing returns are higher than with high LTVs, which is achieved through lower house price levels on impact.

3.2 Permanent Lending Shocks

Figures 3 and 4 report the effects of a quasi-permanent[13] decline by one percentage point in the LTV, using the same calibration as above for the initial steady state. Blue lines pertain to a decline in the LTV from 0.95 to 0.94 while red lines pertain to a decline from 0.80 to 0.79.

First consider the case when LTVs are 0.95 in the initial steady state. On impact, aggregate output falls by 4.29 percent. This impact response is somewhat larger than in the case of the transitory lending shock, but not of an entirely different magnitude. The same applies to the initial effects on housing stocks, borrowing and consumption of credit-constrained borrowers.

The mechanism is the same as for the transitory shock. The LTV decreases, which implies a decline in current borrower consumption. Both the decrease in the LTV and the decline in current consumption tend to reduce borrower housing demand. The decline in the LTV as

[13] In this case, I set the persistence parameter $\rho_m = \rho_{m''} = 1 - 10^{-10}$.

well as the reduction in borrowers' housing stocks reduce borrowing capacity and negatively affect current consumption through the collateral effect.

To understand the difference between the short- and long-run responses of borrowers' housing demand conditional on a permanent credit shock, consider each factor affecting housing demand. First, the upward consumption path in the first two years after the shock means that the marginal utility of consumption today is comparatively high, giving credit-constrained households a disincentive to save and therefore an incentive to reduce housing wealth. The consumption path becomes fairly flat about two years after the shock, which nearly eliminates this particular motive for not holding houses. Second, the real house price is initially on a downward path which also constitutes a disincentive to hold houses, but eventually stabilizes such that this disincentive also vanishes in the long run. Third, the LTV declines permanently, which reduces the benefit of holding houses for the purpose of borrowing in the short run as well as in the long run. This effect accounts for a permanent decline in housing demand by credit-constrained borrowers.

As a result of the permanent reduction in housing demand, and since the aggregate housing stock is fixed, house prices decline permanently.

While impatient household and entrepreneurial consumption declines on impact, in the long run it somewhat exceeds the initial steady state. Plausibly, this is because borrowers' interest expenditure permanently declines because they permanently borrow less. This decline in interest expenditure amounts to an increase in their lifetime resources which relaxes their intertemporal budget constraint. This constitutes a wealth effect in the strict sense, as opposed to the collateral effect which operates through the liquidity constraint.

The mirror image of this is that in the long run, patient households consume less. This plausibly reflects a decline in their permanent income as they permanently lend less and therefore permanently earn less interest revenue.

The only noteworthy permanent effects of a permanent reduction in LTVs are reductions in the steady-state values of real house prices, mortgage lending, housing held by credit-constrained borrowers, and an increase in the share of borrowers' consumption in aggregate consumption. Therefore, apart from the reallocation of consumption between borrowers and lenders, there are only substantial long-run effects on variables which enter into steady-state collateral constraints.

A plausible reason why effects on aggregate real activity are largely transitory is that the reduction in mortgage lending redistributes wealth from lenders to borrowers through the reduction in interest expenditure, but does not amount to a change in aggregate wealth. A long-run effect on aggregate consumption can still occur because credit-constrained borrowers have higher marginal propensities to consume, but this effect turns out to be small in this setting.

The red lines in Figures 3 and 4 document that the short-run effects of a permanent tightening in credit standards are much smaller with initial steady-state LTVs at 0.80. The initial decline in aggregate output is only 0.68 percent. Therefore, the impact effect on output of a permanent decline in LTVs is about six times larger when the initial LTV is 0.95 than when it is 0.80.

With initial LTVs at 0.80, the long-run effects on house prices are somewhat smaller than with LTVs at 0.95. The long-run effects on housing stocks, mortgage lending and consumption are similar.

Table 2 shows the effects of a permanent one percentage point decline in LTVs for a wider range of initial steady-state LTVs. In this case, I show the non-accumulated effects. The results confirm that a permanent decline in LTVs has much larger impact effects on output and mortgage lending at high initial LTVs than when LTVs are already low. The impact effect on house prices is always small and not strongly related to the initial LTV.

The initial level of LTVs has fairly limited effects on the long-run responses reported in the table. Steady-state house prices and mortgage lending decline somewhat less at lower initial LTVs. Steady-state output increases marginally in all reported cases, plausibly due to the above-mentioned redistribution of lifetime wealth to borrowers as they spend less in terms of interest expenditure.

4 Collateral Requirements and the Amplification of Shocks

In this section, I quantify how the effects of shocks other than those to loan-to-value ratios depend on the steady-state loan-to-value ratio. I discus supply and housing demand shocks before I discuss monetary policy shocks.

4.1 Supply Shocks and Housing Demand Shocks

First, I briefly discuss the case of generic supply shocks, i.e. inflationary shocks that enter the Phillips curve. In this case, impulse responses (not plotted here) are similar for steady-state LTVs of 0.95 and 0.80. Borrowing by impatient households and entrepreneurs responds only moderately to such supply shocks. This may be the net effect of two mechanisms. First, an increase in inflation relaxes borrowing constraints as it erodes the real value of debt. Second, in this model, a supply shock that causes inflation to rise also causes the real rate to rise due to the monetary policy reaction to the shock. This increase in the real rate tends to tighten borrowing constraints. The fact that borrowing responds only moderately to inflationary shocks may explain why the steady-state LTV hardly influences the responses to supply shocks.

Next, Figures 5 and 6 plot the impulse responses to a transitory one-standard deviation decrease in the parameter j which governs utility from housing services for patient and impatient households.[14] As before, blue lines indicate steady-state LTVs of 0.95 and red lines indicate LTVs of 0.80.

The impulse responses are similar to those for the transitory lending shock reported above. Still, there are a few noteworthy differences. First, the decline in utility from housing implies a non-trivial decline in house prices on impact.

Second, while impatient household's housing, borrowing and consumption responses are similar to those for the transitory lending shock, entrepreneurial housing and borrowing follow a different path for the housing demand shock. To see why, note that while the credit shock directly affects impatient households and entrepreneurs, the housing preference shock originates from both types of households but only indirectly affects the responses of entrepreneurs because they do not derive utility from housing services.

Entrepreneurial housing and borrowing decline on impact but then overshoot. Entrepreneur's housing demand is influenced by various factors. On the one hand, the reduced level of house

[14] I calibrate the shock process as in Iacoviello (2005).

prices means that any unit in housing demand now yields less borrowing capacity, which tends to decrease their housing demand. On the other hand, the convergence of house prices to equilibrium implies a high return from housing which tends to increase their housing demand.

All agents' spending responses are similar to those for the credit shock. In particular, entrepreneurial consumption and investment decline persistently and overshoot only somewhat.

As Figures 5 and 6 show, housing shocks are amplified to a substantially greater extent when steady-state LTVs are at 0.95 than when they are at 0.80. In terms of percent deviations, the impact effect on aggregate output is 4.65 times larger in the former case than in the latter case.

4.2 Monetary Policy Shocks

The blue lines in Figures 7 and 8 show the effects of a one-standard deviation monetary policy tightening when steady-state LTVs are at 0.95 while the red lines pertain to the case where they are at 0.80.[15]

Turning first to the case with comparatively high LTVs, the monetary policy tightening implies sharp contractions in consumption and investment, with aggregate output falling 2.69 percent below steady state on impact.

Similar to my findings above for lending shocks, there are modest fluctuations in patient household consumption as the patient household intertemporally substitutes consumption

[15] As in Iacoviello (2005), the one-standard deviation monetary policy shock implies that the gross nominal interest rate rises 0.29 percent above steady state on impact.

such that in log deviations, its expected consumption growth equals the real interest rate. In response to the monetary policy shock, its consumption peaks one quarter after the shock as the expected returns on saving (through loans as well as through housing) peak at about that time.

For impatient households and entrepreneurs, the tightening in monetary policy tightens the liquidity constraint as borrowers now need to borrow less in order to achieve the same debt repayment amount. This tends to increase the Lagrange multipliers λ_t and λ_t'' on the credit constraints, and tends to cause borrowers to borrow less so as to relax the constraint. Through the consumption Euler equations of constrained borrowers, this tends to reduce current consumption relative to the future, which tends to increase the marginal utility of consuming today relative to the future.

As in the case of lending shocks, this increases the utility value of selling housing today so as to free up resources for consumption at a time when the marginal utility of consumption is high. Borrowers therefore engage in fire sales of housing in an effort to reduce the fall in consumption. The reduction in the housing stock almost entirely explains the pronounced fall in mortgage borrowing, which itself drives the large and persistent falls in borrower consumption that occur in equilibrium.

While the above mechanism is similar to that for lending shocks, a difference with lending shocks is that in that case LTVs decrease which has an additional downward effect on housing demand as it reduces the extra borrowing capacity associated with the purchase of a unit of housing.

The monetary policy impulse is short-lived: the real interest rate is below steady state from one quarter after the shock onwards as monetary policy endogenously reacts to the sharp downturn that it engendered. Nevertheless, the falls in borrowing and consumption are persistent, which suggests that it is the tightening in the borrowing constraint resulting from the drop in borrowers' housing stocks that drives the consumption path.

As the red lines in Figures 7 and 8 reveal, the same monetary policy tightening is amplified to a much smaller extent with steady-state LTVs at 0.80. On impact, aggregate output falls 1.06 percent below steady state. Therefore, aggregate output responds 2.54 times more strongly in the case with steady-state LTVs at 0.95 than in the present case.

Table 3 documents the cumulative effects of the same one-standard deviation monetary policy tightening on aggregage output, real house prices and total mortgage lending for a wider range of steady-state values. The impact and cumulative effects on aggregate output and mortgage lending decline monotonically when one considers lower steady-state LTVs. These results confirm the pattern from Figures 7 and 8 that the effects on mortgage borrowing and aggregate output are amplified to a substantially greater extent when steady-state LTVs are higher.

5 Conclusion

In this paper, I find that changes in loan-to-value ratios can have substantial effects on house prices and aggregate spending in a model where investment is undertaken by credit-constrained entrepreneurs. In the model I use, the finding that a tightening in credit causes credit-constrained borrowers to sell housing plays an important role in the amplification of the shock as it reduces their collateral holdings.

Furthermore, I document that a permanent decline in LTVs implies that some macroeconomic shocks are amplified to a much lesser extent through household balance sheets. I illustrate this conditional on housing demand shocks and monetary policy shocks. On the other hand, I find that LTVs do not matter much for the amplification of supply shocks.

Furthermore, I find that the LTV shock itself is amplified to a much larger extent when LTVs are higher at the outset. To the extent that agents prefer smooth changes in their consumption, this may mean that a macroprudential policymaker who is about to lower LTVs by imposing or lowering an LTV limit would best do so in a gradual and back-loaded fashion, in the sense that the largest cuts occur when LTVs are already low.

Figures and Tables

Table 1: Cumulative Effects of Transitory Tightening in Lending Standards

	$\sum_{s=0}^{\tau} E_t(\widehat{Y}_{t+s})$			$\sum_{s=0}^{\tau} E_t(\widehat{q}_{t+s})$			$\sum_{s=0}^{\tau} E_t(\widehat{lend'}_{t+s})$		
m, m''	$\tau = 0$	$\tau = 40$	$\tau = \infty$	$\tau = 0$	$\tau = 40$	$\tau = \infty$	$\tau = 0$	$\tau = 40$	$\tau = \infty$
0.99	-15.49	-6.64	-7.05	0.78	-8.56	-9.18	-49.28	-53.02	-53.70
0.95	-3.06	-2.63	-2.39	0.15	-5.27	-5.17	-18.01	-46.12	-46.11
0.90	-1.24	-1.33	-0.96	0.00	-3.66	-3.40	-10.78	-40.00	-39.81
0.85	-0.68	-0.81	-0.42	-0.05	-2.78	-2.50	-7.89	-36.10	-35.81
0.80	-0.43	-0.56	-0.17	-0.06	-2.23	-1.96	-6.37	-33.61	-33.23
0.75	-0.30	-0.42	-0.05	-0.06	-1.86	-1.60	-5.46	-32.06	-31.60
0.70	-0.22	-0.33	0.02	-0.06	-1.58	-1.35	-4.88	-31.19	-30.64
0.65	-0.17	-0.28	0.06	-0.06	-1.38	-1.16	-4.50	-30.84	-30.22
0.60	-0.13	-0.25	0.08	-0.06	-1.22	-1.02	-4.26	-30.94	-30.27
0.55	-0.11	-0.22	0.09	-0.05	-1.09	-0.91	-4.13	-31.47	-30.77

Note: this table reports cumulated responses, in percent deviations from steady state, to simultaneous and transitory one-percentage point declines in the LTVs for the entrepreneur and the impatient household, with the persistence of the LTV impulse governed by $\rho_m = \rho_{m''} = 0.90$. I report the responses for aggregate output Y_t, real house prices q_t and aggregate mortgage lending $lend'_t$ on impact, cumulated through 40 quarters after the shock and cumulated through $10,000$ quarters after the shock. Each row pertains to a different value of m and m'', which are the steady-state LTVs for the entrepreneur and impatient household, respectively. For these simulations, I always set the LTV for the impatient household equal to that of the entrepreneur.

Table 2: Effects of Permanent Tightening in Lending Standards

	$E_t(\widehat{Y}_{t+\tau})$			$E_t(\widehat{q}_{t+\tau})$			$E_t(\widehat{lend'}_{t+\tau})$		
m, m''	$\tau = 0$	$\tau = 40$	$\tau = \infty$	$\tau = 0$	$\tau = 40$	$\tau = \infty$	$\tau = 0$	$\tau = 40$	$\tau = \infty$
0.99	-19.98	-0.05	0.03	0.81	-1.19	-1.10	-61.65	-3.09	-3.01
0.95	-4.29	-0.03	0.03	-0.06	-1.00	-0.94	-22.89	-2.86	-2.81
0.90	-1.83	-0.02	0.03	-0.29	-0.84	-0.79	-13.56	-2.69	-2.65
0.85	-1.04	-0.01	0.03	-0.35	-0.72	-0.68	-9.75	-2.58	-2.55
0.80	-0.68	-0.01	0.03	-0.36	-0.63	-0.59	-7.71	-2.53	-2.50
0.75	-0.47	-0.01	0.02	-0.35	-0.56	-0.53	-6.48	-2.52	-2.48
0.70	-0.35	-0.01	0.02	-0.34	-0.51	-0.48	-5.68	-2.54	-2.50
0.65	-0.27	-0.01	0.02	-0.32	-0.46	-0.43	-5.15	-2.60	-2.54
0.60	-0.21	-0.01	0.02	-0.30	-0.42	-0.40	-4.80	-2.68	-2.61
0.55	-0.17	-0.01	0.02	-0.28	-0.39	-0.37	-4.59	-2.79	-2.72

Note: this table reports responses, in percent deviations from steady state, to simultaneous and quasi-permanent one-percentage point declines in the LTVs for the entrepreneur and the impatient household, with the persistence of the LTV impulse governed by $\rho_m = \rho_{m''} = 1 - 10^{-10}$. I report the responses for aggregate output Y_t, real house prices q_t and aggregate mortgage lending $lend'_t$ on impact, at 40 quarters after the shock and at $10,000$ quarters after the shock. The responses in this table are not accumulated. Other notes are as under Table 1.

Table 3: Cumulative Effects of Monetary Policy Tightening

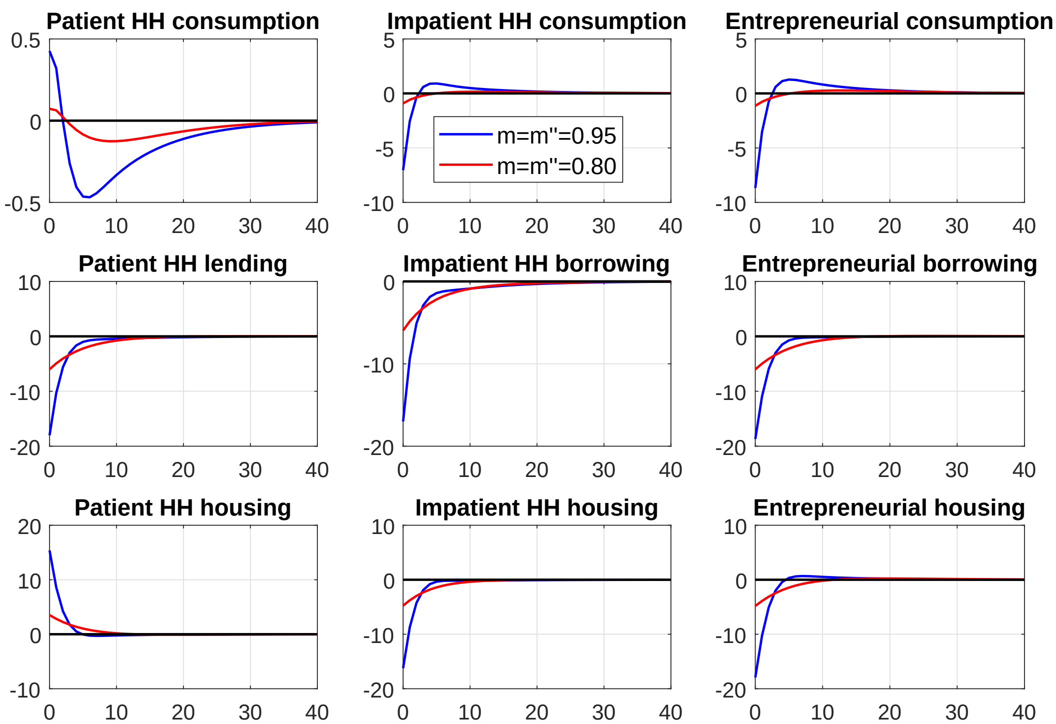
	$\sum_{s=0}^{\tau} E_t(\widehat{Y}_{t+s})$			$\sum_{s=0}^{\tau} E_t(\widehat{q}_{t+s})$			$\sum_{s=0}^{\tau} E_t(\widehat{lend'}_{t+s})$		
m, m''	$\tau = 0$	$\tau = 40$	$\tau = \infty$	$\tau = 0$	$\tau = 40$	$\tau = \infty$	$\tau = 0$	$\tau = 40$	$\tau = \infty$
0.99	-8.66	-8.68	-11.12	0.24	-1.71	-4.32	-23.17	-21.33	-23.59
0.95	-2.69	-6.45	-8.38	-0.18	-0.94	-2.99	-9.64	-23.46	-25.16
0.90	-1.63	-5.48	-7.19	-0.35	-0.76	-2.56	-6.08	-23.74	-25.15
0.85	-1.25	-4.96	-6.55	-0.43	-0.75	-2.41	-4.51	-23.51	-24.73
0.80	-1.06	-4.61	-6.12	-0.48	-0.79	-2.35	-3.60	-23.09	-24.17
0.75	-0.95	-4.35	-5.79	-0.51	-0.85	-2.33	-3.01	-22.54	-23.55
0.70	-0.88	-4.13	-5.52	-0.53	-0.90	-2.32	-2.59	-21.90	-22.89
0.65	-0.83	-3.93	-5.29	-0.55	-0.95	-2.31	-2.28	-21.16	-22.19
0.60	-0.79	-3.76	-5.08	-0.56	-0.99	-2.30	-2.03	-20.36	-21.47
0.55	-0.76	-3.59	-4.89	-0.57	-1.02	-2.28	-1.84	-19.52	-20.73

Note: this table reports cumulated responses, in percent deviations from steady state, to a one standard deviation monetary policy tightening. Other notes are as under Table 1.

Figure 1

Transitory Tightening in Lending: Individual Responses
Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

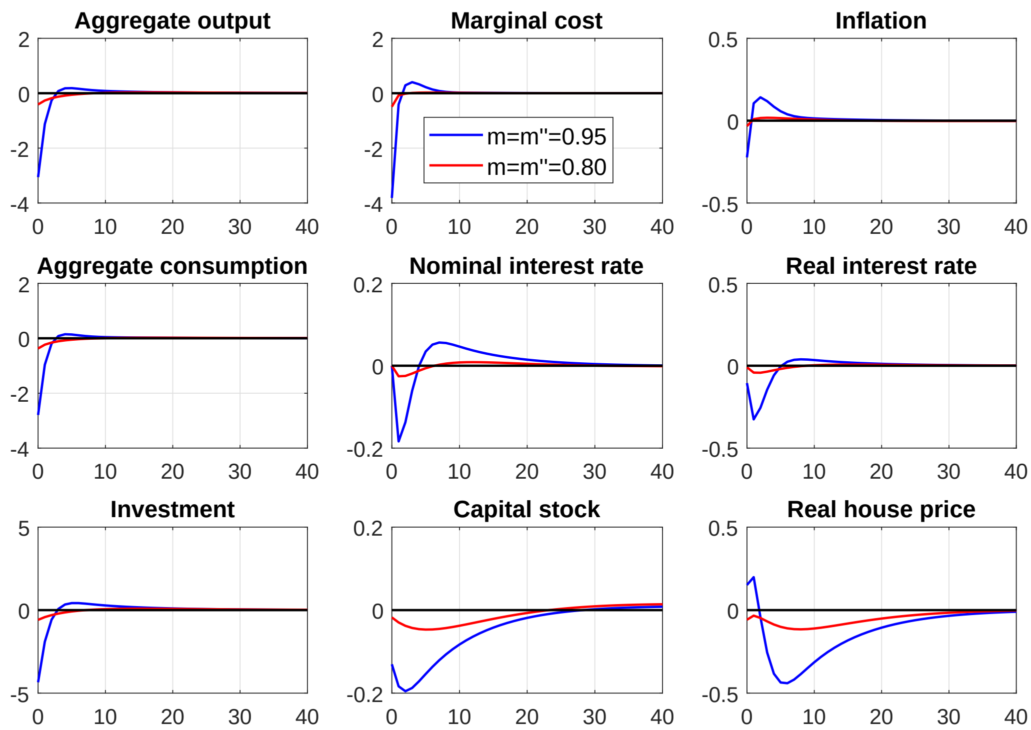


Notes: this figure plots the effects of a transitory decline in LTVs on consumption, mortgage lending/borrowing and the housing stocks of the patient household, impatient household and the entrepreneur. Blue lines pertain to the case where steady-state LTVs for entrepreneur and impatient household equal 0.95 and red lines pertain to the case where they are 0.80. The shock occurs at $t = 0$ and the horizontal axis indicates quarters since the shock. All responses are in percentage deviations from steady state.

Figure 2

Transitory Tightening in Lending: Aggregate Responses Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

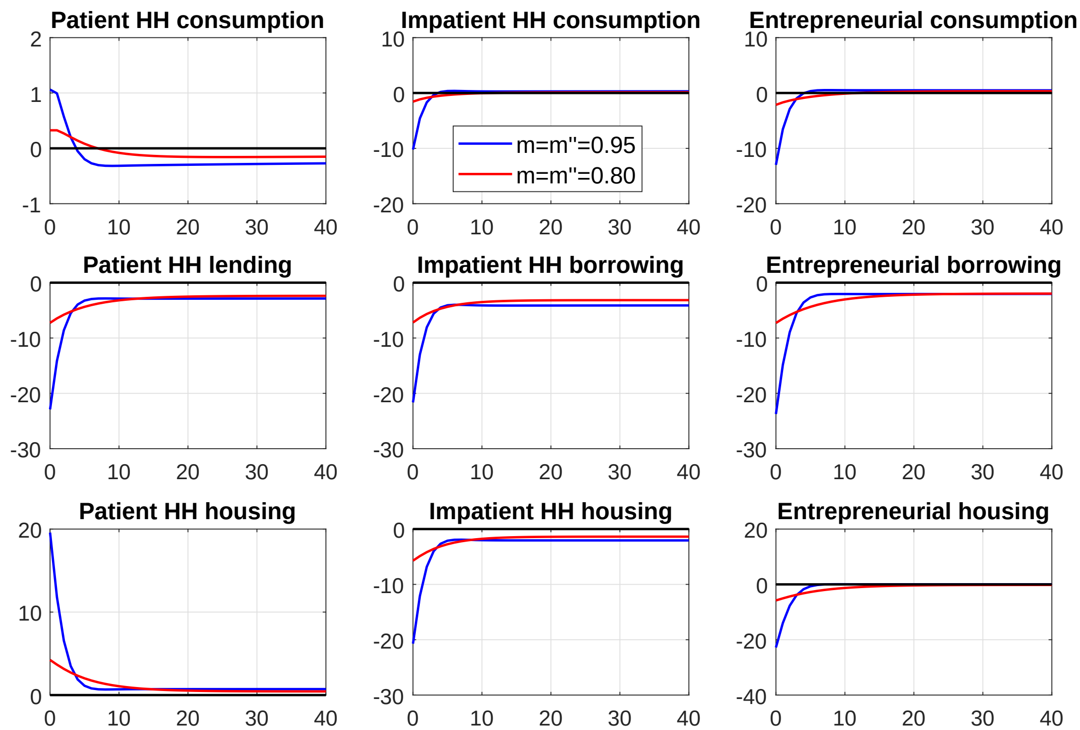


Notes: this figure plots the effects of a transitory one percentage point decline in LTVs on aggregate variables. Other notes are as under Figure 1.

Figure 3

Permanent Tightening in Lending: Individual Responses
Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

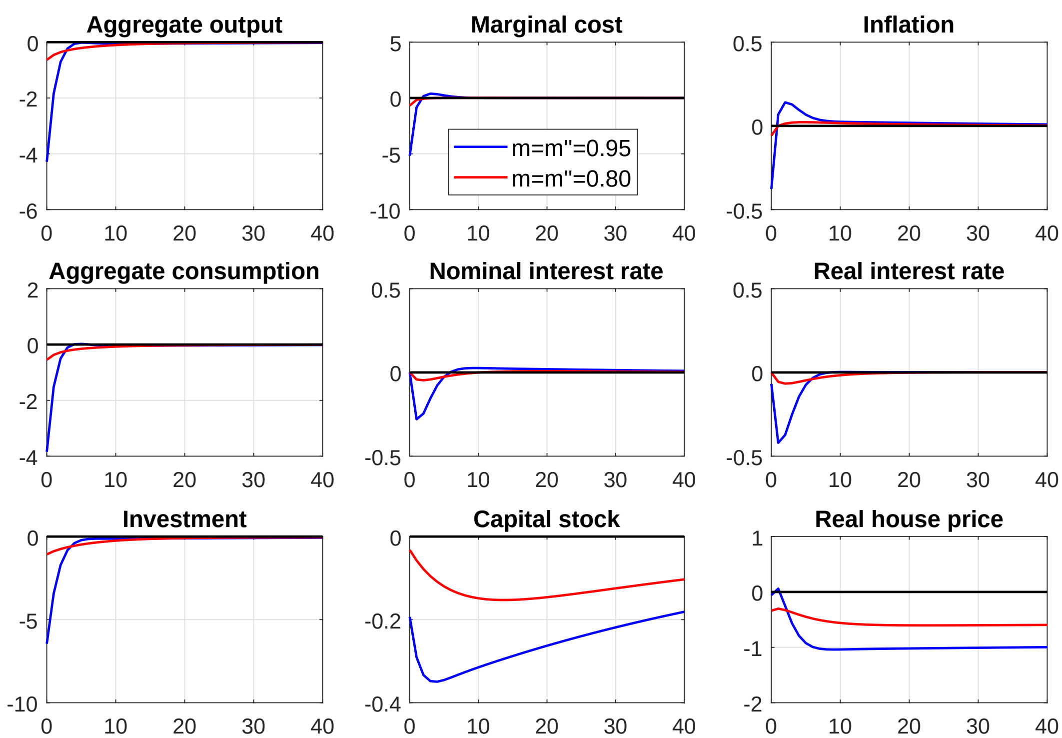


Notes: this figure plots the effects of a quasi-permanent one percentage point decline in LTVs on consumption, mortgage lending/borrowing and the housing stock of the patient household, impatient household and the entrepreneur. In this case, I set the persistence parameter for the LTV processes of impatient households and entrepreneurs to $\rho_m = \rho_{m''} = 1 - 10^{-10}$. Other notes are as under Figure 1.

Figure 4

Permanent Tightening in Lending: Aggregate Responses
Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

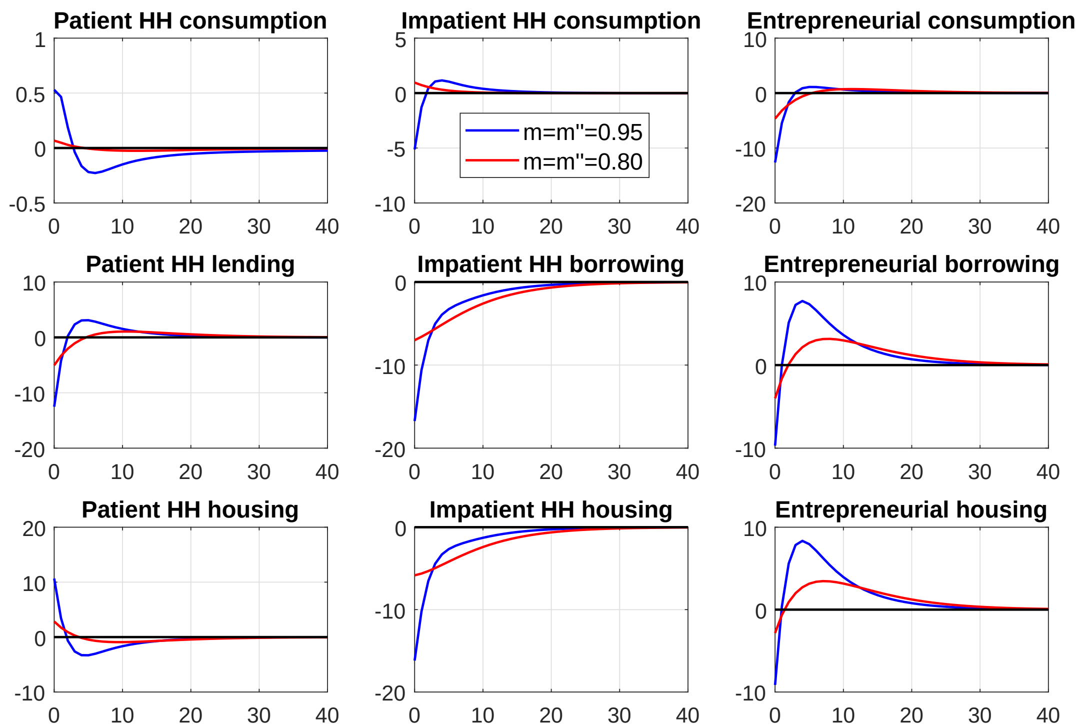


Notes: this figure plots the effects of a quasi-permanent one percentage point decline in LTVs on aggregate variables. Other notes are as under Figure 3.

Figure 5

Transitory Decline in Housing Demand: Individual Responses Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

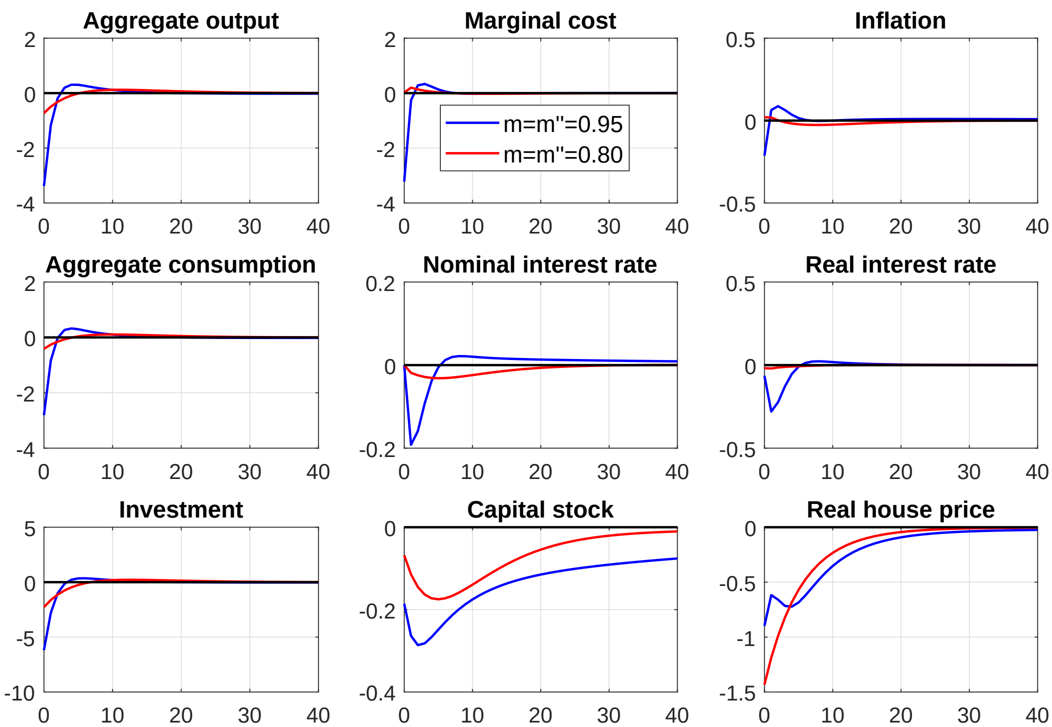


Notes: this figure plots the effects of a transitory one standard deviation decline in housing demand on consumption, mortgage lending/borrowing and the housing stocks of the patient household, impatient household and the entrepreneur. Other notes are as under Figure 1.

Figure 6

Transitory Decline in Housing Demand: Aggregate Responses Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

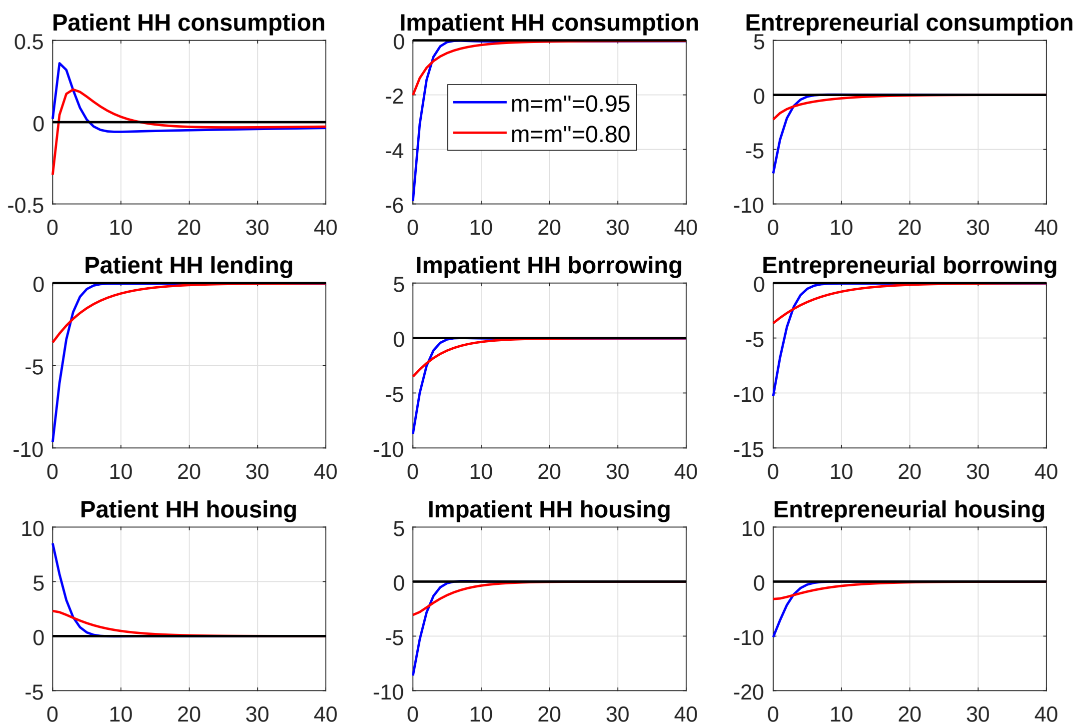


Notes: this figure plots the effects of a transitory one standard deviation decline in housing demand on aggregate variables. Other notes are as under Figure 5.

Figure 7

Monetary Policy Tightening: Individual Responses
Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State

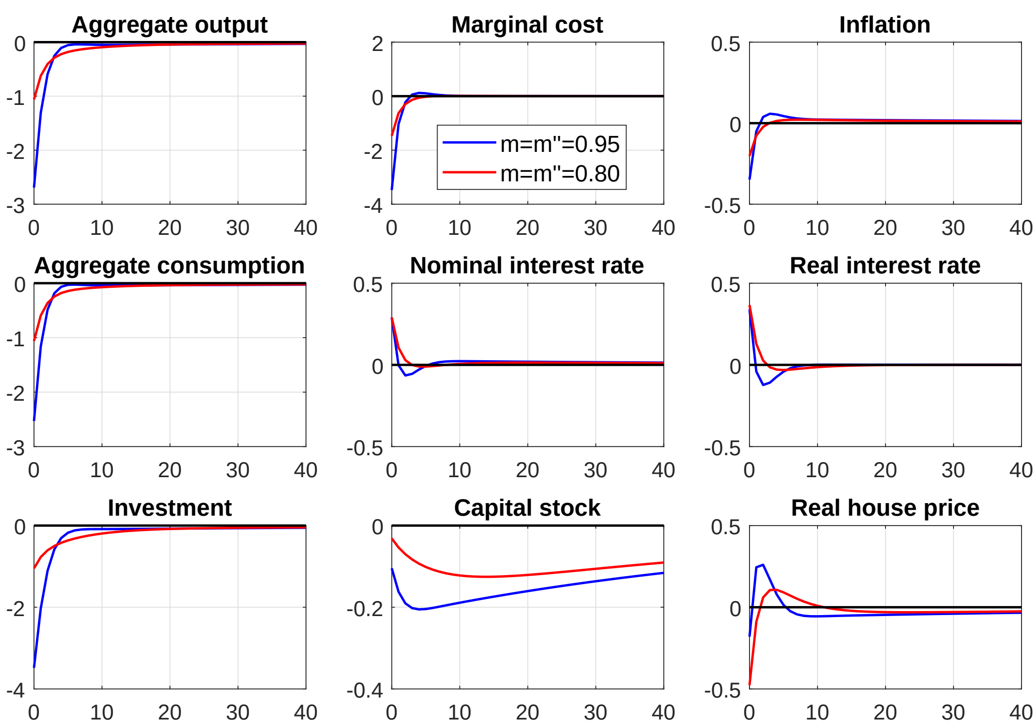


Notes: this figure plots the effects of a one standard deviation monetary policy tightening on consumption, mortgage lending/borrowing and housing stocks of the patient household, impatient household and the entrepreneur. Other notes are as under Figure 1.

Figure 8

Monetary Policy Tightening: Aggregate Responses
Benchmark vs. Lower Loan-to-Value Ratios

Quarters Since Shock; Percentage Deviations from Steady State



Notes: this figure plots the effects of a one standard deviation monetary policy tightening on aggregate variables. Other notes are as under Figure 7.

Appendix: Full Log-Linearized Model

Below, $lend'$ is lending by the patient household, I is investment in plant and equipment, K is the capital stock, MC is marginal cost, A is aggregate productivity, μ is the elasticity of output to capital, ν the elasticity of output of housing and the last terms in equations (A16) through (A21) are shocks. Other symbols are as defined in Section 2. Variables without a time subscript are in steady state and hats denote percentage deviations from steady state. "pat. HH" stands for "patient household", "imp. HH" stands for "impatient household" and "ent." for "entrepreneur".

$$\text{Goods market clearing} \quad : \quad \widehat{Y}_t = \frac{c}{Y}\widehat{c}_t + \frac{c'}{Y}\widehat{c}'_t + \frac{c''}{Y}\widehat{c}''_t + \frac{I}{Y}\widehat{I}_t \tag{A1}$$

$$\text{Lending market clearing} \quad : \quad \widehat{lend}'_t = \frac{b}{lend'}\widehat{b}_t + \frac{b''}{lend'}\widehat{b}''_t \tag{A2}$$

$$\text{Housing market clearing} \quad : \quad \widehat{h}_t\frac{h}{h'} + \widehat{h}'_t + \widehat{h}''_t\frac{h''}{h'} = 0 \tag{A3}$$

$$\text{Pat. HH consumption Euler} \quad : \quad \widehat{c}'_t = E_t\widehat{c}'_{t+1} - \widehat{rr}_t \tag{A4}$$

$$\text{Investment/capital ent.} \quad : \quad \widehat{I}_t - \widehat{K}_{t-1} = E_t \begin{bmatrix} \frac{1}{\psi}(\widehat{c}_t - \widehat{c}_{t-1}) + \gamma(\widehat{I}_{t+1} - \widehat{K}_t) \\ +\frac{1-\gamma+\gamma\delta}{\psi}(\widehat{MC}_{t+1} + \widehat{Y}_{t+1} - \widehat{K}_t) \end{bmatrix} \tag{A5}$$

$$\begin{aligned} \text{Consumption/housing ent.} \quad : \quad \widehat{q}_t &= [(1-m)\gamma + m\beta]\ E_t\widehat{q}_{t+1} - \beta m\ \widehat{rr}_t \\ &+(m\beta - 1)(E_t\widehat{c}_{t+1} - \widehat{c}_t) + \gamma\varphi_e(E_t\widehat{h}_{t+1} - \widehat{h}_t) \\ &+[m(\beta-\gamma)]\widehat{m}_t - \varphi_e(\widehat{h}_t - \widehat{h}_{t-1}) \\ &-[1-(1-m)\gamma - m\beta][\widehat{h}_t - E_t\widehat{MC}_{t+1} - E_t\widehat{Y}_{t+1}] \end{aligned} \tag{A6}$$

$$\begin{aligned} \text{Cons./housing imp. HH} \quad : \quad \widehat{q}_t &= [\beta'' + (\beta - \beta'')m''] \ E_t\widehat{q}_{t+1} - \varphi_h(\widehat{h}''_t - \widehat{h}''_{t-1}) \\ &+\beta''\varphi_h(E_t\widehat{h}''_{t+1} - \widehat{h}''_t) - \beta m''\ \widehat{rr}_t + [m''(\beta - \beta'')]\widehat{m}''_t \\ &+(1-\beta m'')\left[\widehat{c}''_t + \frac{\beta''(m''-1)}{1-\beta m''}E_t\widehat{c}''_{t+1}\right] \\ &+[1-(\beta-\beta'')m'' - \beta''](\widehat{j}_t - \widehat{h}''_t) \end{aligned} \tag{A7}$$

$$\text{Cons./housing pat. HH} \quad : \quad \widehat{q}_t = \frac{\varphi_h}{h'}\left[\begin{array}{c} h(\widehat{h}_t - \widehat{h}_{t-1}) + h''(\widehat{h}''_t - \widehat{h}''_{t-1}) \\ -\beta h(\widehat{h}_{t+1} - \widehat{h}_t) - \beta h''(\widehat{h}''_{t+1} - \widehat{h}''_t) \end{array}\right]$$

$$+(1-\beta)\widehat{j}_t + (1-\beta)\frac{h}{h'}\widehat{h}_t + (1-\beta)\frac{h''}{h'}\widehat{h}''_t$$

$$-\beta E_t \widehat{c}'_{t+1} + \widehat{c}'_t + \beta E_t \widehat{q}_{t+1} \tag{A8}$$

$$\text{Credit constraint ent.} \quad : \quad \widehat{b}_t = \widehat{m}_t + \; E_t \widehat{q}_{t+1} + \widehat{h}_t - \widehat{rr}_t \tag{A9}$$

$$\text{Credit constraint imp. HH} \quad : \quad \widehat{b}''_t = \widehat{m}''_t + \; E_t \widehat{q}_{t+1} + \widehat{h}''_t - \widehat{rr}_t \tag{A10}$$

$$\text{Production/labor market} \quad : \quad \widehat{Y}_t = \frac{\eta}{\eta + \mu + \nu - 1}\left[\widehat{A}_t + \mu \widehat{K}_{t-1} + \nu \widehat{h}_{t-1}\right]$$

$$-\frac{1-\mu-\nu}{\eta+\mu+\nu-1}\left[\alpha \widehat{c}'_t + (1-\alpha)\widehat{c}''_t - \widehat{MC}_t\right] \tag{A11}$$

$$\text{Phillips curve} \quad : \quad \widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \kappa \widehat{MC}_t + \widehat{u}_t \tag{A12}$$

$$\text{Capital accumulation} \quad : \quad \widehat{K}_t = \delta \widehat{I}_t + (1-\delta)\widehat{K}_{t-1} \tag{A13}$$

$$\text{IBC entrepreneur} \quad : \quad \frac{b}{Y}\widehat{b}_t = \frac{c}{Y}\widehat{c}_t + \frac{qh}{Y}(\widehat{h}_t - \widehat{h}_{t-1})\frac{b}{Y}\frac{1}{\beta}(\widehat{R}_{t-1} + \widehat{b}_{t-1} - \widehat{\pi}_t)$$

$$+ + \frac{I}{Y}\widehat{I}_t - \left[\frac{1}{X}(\mu+\nu)\right]\left(\widehat{Y}_t - \widehat{X}_t\right) \tag{A14}$$

$$\text{IBC impatient HH} \quad : \quad \frac{b''}{Y}\widehat{b}''_t = \frac{c''}{Y}\widehat{c}''_t + \frac{qh''}{Y}(\widehat{h}''_t - \widehat{h}''_{t-1}) + \frac{b''}{Y}\frac{1}{\beta}(\widehat{R}_{t-1} + \widehat{b}''_{t-1} - \widehat{\pi}_t)$$

$$-\frac{1}{X}(1-\alpha)(1-\mu-\nu)(\widehat{Y}_t - \widehat{X}_t) \tag{A15}$$

$$\text{Monetary policy rule} \quad : \quad \widehat{R}_t = r_R \widehat{R}_{t-1} + (1-r_R)(1+r_\pi)\widehat{\pi}_{t-1}$$

$$+(1-r_R)r_Y \widehat{Y}_{t-1} + \widehat{e}_{Rt} \tag{A16}$$

$$\text{Lending shock ent.} \quad : \quad \widehat{m}_t = \rho_m \widehat{m}_{t-1} + \widehat{e}_{m,t} \tag{A17}$$

$$\text{Lending shock imp. HH} \quad : \quad \widehat{m}''_t = \rho_{m''} \widehat{m}''_{t-1} + \widehat{e}_{m'',t} \tag{A18}$$

$$\text{Housing demand shock} \quad : \quad \widehat{j}_t = \rho_j \widehat{j}_{t-1} + \widehat{e}_{jt} \tag{A19}$$

$$\text{Generic supply shock} \quad : \quad \widehat{u}_t = \rho_u \widehat{u}_{t-1} + \widehat{e}_{ut} \tag{A20}$$

$$\text{Technology shock} \quad : \quad \widehat{A}_t = \rho_A \widehat{A}_{t-1} + \widehat{e}_{At} \tag{A21}$$

References

[1] Akinci, Ozge, and Jane Olmstead-Rumsey. (2018). "How Effective Are Macroprudential Policies? An Empirical Investigation." *Journal of Financial Intermediation* 33, 33-57.

[2] Alam, Zohair, Adrian Alter, Jesse Eiseman, Gaston Gelos, Heedon Kang, Machiko Narita, Erlend Nier, and Naixi Wang. (2019). "Digging Deeper - Evidence on the Effects of Macroprudential Policies from a New Database." IMF Working Paper 19/66.

[3] Almeida, Heitor, Murillo Campello, and Crocker Liu. (2006). "The Financial Accelerator: Evidence from International Housing Markets." *Review of Finance* 10(3), 321-352.

[4] Bachmann, Rüdiger, and Sebastian Rueth. (2020). "Systematic Monetary Policy and the Macroeconomic Effects of Shifts in Residential Loan-to-Value Ratios." *International Economic Review* 61(2), 503-530.

[5] Boz, Emine and Enrique G. Mendoza. (2014). "Financial Innovation, the Discovery of Risk, and the U.S. Credit Crisis." *Journal of Monetary Economics* 62, 1-22.

[6] Calvo, Guillermo A. (1983). "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12(3), 383-398.

[7] Cerutti, Eugenio, Stijn Claessens, and Luc Laeven. (2017). "The Use and Effectiveness of Macroprudential Policies: New Evidence." *Journal of Financial Stability* 28, 203-224.

[8] Cesa-Bianchi, Ambrogio, Andrea Ferrero and Alessandro Rebucci. (2018). "International Credit Supply Shocks", *Journal of International Economics* 112, 219-237.

[9] Davis, Morris A., and Jonathan Heathcote. (2007). "The Price and Quantity of Residential Land in the United States." *Journal of Monetary Economics* 54, 2595-2620.

[10] De Jong, Jasper, and Emmanuel De Veirman. (2019). "Heterogeneity and Asymmetric Macroeconomic Effects of Changes in Loan-to-Value Limits." De Nederlandsche Bank Working Paper 635.

[11] De Veirman, Emmanuel and Ashley Dunstan. (2011). "Time-Varying Returns, Intertemporal Substitution and Cyclical Variation in Consumption." *The B.E. Journal of Macroeconomics (Topics)* 11, Article 23.

[12] Duca, John V., John Muellbauer, and Anthony Murphy. (2011). "House Prices and Credit Constraints: Making Sense of the US Experience." *Economic Journal* 121, 533-551.

[13] Favilukis, Jack, Sydney C. Ludvigson, and Stijn van Nieuwerburgh. (2017). "The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk Sharing in General Equilibrium." *Journal of Political Economy* 125(1), 140-223.

[14] Ferrero, Andrea. (2012). "House Price Booms, Current Account Deficits, and Low Interest Rates." *Journal of Money, Credit and Banking* 47(1), 261-293.

[15] Gelain, Paolo, Kevin J. Lansing and Gisle J. Natvik. (2018). "Explaining the Boom-Bust Cycle in the U.S. Housing Market: A Reverse-Engineering Approach." *Journal of Money, Credit and Banking* 50(8), 1751-1783.

[16] Guerrieri, Luca and Matteo Iacoviello. (2017). "Collateral Constraints and Macroeconomic Asymmetries." *Journal of Monetary Economics*, 90, 28-49.

[17] Huo, Zhen and Jose Victor Rios Rull. (2018). "Financial Frictions, Asset Prices, and the Great Recession." Mimeo, University of Pennsylvania.

[18] Iacoviello, Matteo. (2005). "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle." *American Economic Review* 95, 739-764.

[19] Jensen, Henrik, Soren Hove Ravn and Emiliano Santoro. (2018). "Changing Credit Limits, Changing Business Cycles." *European Economic Review* 102, 211-239.

[20] Jensen, Henrik, Ivan Petrella, Soren Hove Ravn and Emiliano Santoro. (2020). "Leverage and Deepening Business-Cycle Skewness." *American Economic Journal: Macroeconomics* 12(1), 245-281.

[21] Justiniano, Primiceri, and Tambalotti. (2015). "Household Leveraging and Deleveraging." *Review of Economic Dynamics* 18, 3-20.

[22] Kaplan, Greg,Kurt Mitman and Giovanni L. Violante. (2020). "The Housing Boom and Bust: Model Meets Evidence." *Journal of Political Economy* 128(9), 3285-3345.

[23] Kiyotaki, Nobuhiro, Alexander Michaelides, and Kalin Nikolov. (2011). "Winners and Losers in Housing Markets." *Journal of Money, Credit and Banking* 43, 255-296.

[24] Kiyotaki, Nobuhiro, Alexander Michaelides, and Kalin Nikolov. (2020). "Housing, Distribution and Welfare." Mimeo, Princeton University.

[25] Lamont, Owen and Jeremy C. Stein. (1999). "Leverage and House-Price Dynamics in U.S. Cities." *RAND Journal of Economics* 30, 498-514.

[26] Maffezzoli and Monacelli. (2015). "Deleverage and Financial Fragility."CEPR Discussion Paper 10531.

[27] Shim, Ilhyock, Bilyana Bogdanova, Jimmy Shek, and Agne Subelyte. (2013). "Database for Policy Actions on Housing Markets." *BIS Quarterly Review* 83-95.

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