LTV vs. LTI Constraints: When Did They Bind, and How Do They Interact?

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Abstract

I document that the elasticity of mortgage loan origination with respect to house prices is highly dependent on the change in personal incomes and vice versa, using U.S. county-level panel data. I rationalize this in a model with two occasionally binding borrowing constraints: a loan-to-value (LTV) constraint and a loan-to-income (LTI) constraint. A Bayesian estimation of the model infers when the LTV and LTI constraints have been binding during 1975-2017, and which shocks that caused them to bind. A macroprudential experiment shows that countercyclical LTV limits cannot dampen mortgage debt growth in expansions, but LTI limits can.

Keywords: Mortgage debt. Loan-to-value constraint. Loan-to-income constraint. Non-linear estimation of DSGE models.

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1 Introduction

Do house price growth always lead to growth in mortgage debt, or is this contingent on personal incomes also growing? When historically have loan-to-value and loan-to-income limits, respectively, restricted mortgage borrowing? Did looser loan-to-value limits or looser loan-to-income limits cause the buildup in mortgage debt prior to the Great Recession? These questions are fundamental to finance and macroeconomics. Their answers have profound implications for how we model the economy and implement macroprudential policies. For instance, if house price growth does not lead to a credit expansion when personal incomes are not also growing, models with a single borrowing constraint will either overestimate the propagation from house prices or underestimate the propagation from income growth. Consequently, macroprudential policymakers will misidentify the risks associated with house price and income growth.

The analysis starts by documenting novel facts on the relationship between mortgage debt, house prices, and personal incomes. I estimate the elasticities of mortgage loan origination with respect to house prices and personal incomes on U.S. county-level panel data covering 2008-2016. I find that house price growth is not in itself sufficient to make loan origination grow. Instead, personal incomes must also grow. If incomes are growing, the elasticity with respect to house prices is 0.38. I likewise find that personal income growth is not in itself sufficient to make loan origination grow. Instead, house prices must also grow. If house prices are growing, the elasticity with respect to personal incomes is 0.52. These results suggest that there is a substantial non-linearity in the loan origination elasticity with respect to house prices and personal incomes.

I interpret the non-linear effects of house price and income growth on mortgage loan origination in a real business cycle model with two occasionally binding borrowing constraints: a loan-to-value constraint and a loan-to-income constraint. With this setup, borrowers must fulfill a collateral requirement and a debt service requirement in order to qualify for a mortgage loan. As a consequence, the level of mortgage debt remains roughly constant even if house prices are growing whenever labor incomes are not also growing and vice versa.

I estimate the model by Bayesian maximum likelihood on time-series covering the U.S. economy in 1975-2017. I use the approach in Guerrieri and Iacoviello (2017) in order to handle the non-linearities, which the occasionally binding constraints introduce. According to the estimation, there are no periods where both borrowing constraints are slack. Thus, net-borrowers have historically always been credit constrained by at least one constraint.

This is not an imposed result of the model since both borrowing constraints could become non-binding if the patience of the net-borrowers were estimated at a sufficiently high value.

The estimation identifies when the respective two borrowing constraints have been binding and which shocks that caused them to bind. The loan-to-income constraint was binding in the end-1970s. This reflects that the oil crises and resulting stagflation had a larger contractionary effect on the real wages of the households than on the housing market. The loan-to-value constraint became binding in the start-1980s as house prices started to fall during the tight monetary policy of Paul Volcker. It remained binding during the 1980s expansion as personal incomes grew quicker than house prices. This lasted until 1986 when the house price growth finally picked up pace, and caused the loan-to-value constraint to unbind and the loan-to-income constraint to bind. In the 1990s, falling house prices and later on increased wage growth caused again caused the loan-to-value limit to bind. From around 2000, house prices started growing rapidly, leading the loan-to-value constraint to unbind and the loan-to-income constraint to bind. This lasted until the Great Recession when the house price bust caused the loan-to-value to bind again. Very recently (from around 2016), a combination of growing house prices and meager wage growth have caused the loan-to-income constraint to bind again.

The estimation also identifies shifts in the credit limits that the two borrowing constraints impose. Credit limits were roughly constant until around 2000. From that time onward, they were gradually loosened until the beginning of the Financial Crisis in 2007. The loan-to-income constraint was binding during this period. The buildup in mortgage debt prior to the recession was thus caused by looser loan-to-value limits.

I use the estimated model to investigate the optimal timing and implementation of macroprudential policy. I consider how systematic changes in the loan-to-value and loan-to-income limits would have effected the historical evolution in mortgage debt if they had been implemented. It turns out that a countercyclical loan-to-income limit is very effective at curbing increases in mortgage debt during expansions. The reason for this is that the loan-to-income constraint typically binds during expansions. The flip-side of this result is that countercyclical loan-to-value limits cannot curb increases in mortgage debt during expansions since this constraint is typically non-binding in those times. Countercyclical loan-to-value limits can, however, abate the adverse consequences of house prices that fall below their steady-state values during contractions. The results that the loan-to-value limit is only an effective macroprudential tool in house price slumps, and that the loan-to-income limit is an effective tool in house price booms are not well-documented in economics. Thus far, the literature has mostly focused on stabilization through countercyclical loan-to-value limits.

The rest of the paper is structured as follows. Section 2 discusses how the empirical evidence and theoretical model relate to the existing literature. Section 3 presents empirical evidence on the relationship between mortgage debt, house prices, and personal incomes. Section 4 presents the theoretical model. Section 5 presents the Bayesian estimation of the model. Section 6 highlights the asymmetries that the presence of two constraints introduce, and performs the historical shock decomposition of the evolution in borrowing constraints and mortgage debt. Section 7 conducts the macroprudential policy simulation. Section 8 contains concluding remarks.

2 Related Literature

The paper is to the best of my knowledge the first to include both an occasionally binding loan-to-value constraint and an occasionally binding loan-to-income constraint in the same estimated model. A small, but growing, theoretical literature already studies house price propagation through occasionally binding loan-to-value constraints. Guerrieri and Iacoviello (2017) demonstrate that the macroeconomic sensitivity to house price changes is smaller during booms (when loan-to-value constraints may unbind) than during busts (when loan-to-value constraints bind). Jensen, Ravn, and Santoro (2017) study how relaxations of loan-to-value limits lead to an increased macroeconomic volatility, up until a point where the limits become sufficiently lax and borrowing constraints thus generally unbind, after which this pattern reverts. Jensen, Petrella, Ravn, and Santoro (2017) document that the U.S. business cycle has increasingly become negatively skewed, and explain this through secularly increasing loan-to-value limits that dampen the effects of expansionary shocks and amplify the effects of contractionary shocks.

3 Empirical Evidence

I construct a county-level panel data set for the U.S. economy. The data set contains data on the sum of originated mortgage loans, house prices, and personal incomes across U.S. counties at an annual longitudinal frequency. I use the data set to estimate the elasticity of mortgage loan origination with respect to house prices and personal incomes. As a novelty, for each variable, I distinguish between the unconditional elasticity and the elasticity given that the other variable is growing.

The general regression specification is:

$$\begin{aligned} \Delta \log d_{i,t} = \gamma_t + \delta_i + \beta_{hp} \Delta \log hp_{i,t-1} + \beta_{inc} \Delta \log inc_{i,t-1} \\ + \beta_{hp}^{I} \mathcal{I}_{inc,i,t-1} \Delta \log hp_{i,t-1} + \beta_{inc}^{I} \mathcal{I}_{hp,i,t-1} \Delta \log inc_{i,t-1} + v_{i,t}, \end{aligned} \tag{1}$$

where $E\{v_{i,t}\} = 0$, $\Delta \log$ denotes a log-change, $d_{i,t}$ denotes the sum of originated mortgage loans that were collateralized in owner-occupied dwellings in county i at time t, γ_t denotes time fixed effects, δ_i denotes county fixed effects, $hp_{i,t}$ denotes house prices in county i at time t, and $inc_{i,t}$ denotes disposable personal income in county i at time t. $\mathcal{I}_{hp,i,t}$ and $\mathcal{I}_{inc,i,t}$ denote growth indicators for house prices and personal incomes in county i at time t. They take the value "1" if their input variable ($x_{i,t}$) is growing (i.e., $\Delta \log x_{i,t} > 0$) and the value "0" if their input variable is stagnant or falling (i.e., $\Delta \log x_{i,t} \leq 0$).[1] β_{hp} measures the unconditional elasticity with respect to house prices, and β_{hp}^{I} measures the elasticity with respect to house prices conditional on personal incomes growing. Likewise, β_{inc} measures the unconditional elasticity with respect to personal incomes, and β_{inc}^{I} measures the elasticity with respect to personal incomes conditional on house prices growing.

The house price and personal income variables in (1) are lagged in order to reduce the risk that omitted time-varying variables bias the results. For instance, a permanent income shock could cause similar changes in personal incomes, house prices, and loan origination without there being a causal effect from house prices or personal incomes to loan origination. I refrain from using a formal instrument for house prices (e.g., the housing supply elasticity that Mian and Sufi (2011) use) in order to treat house prices and personal incomes symmetrically. In the permanent income shock example, having an exogenous measure of house price movements may reduce the correlation between house prices and loan origination, while preserving the correlation between incomes and loan origination. Thus, the effect of house prices on loan origination would be underestimated relative to the effect of personal incomes on loan origination.

The longitudinal length of the sample is limited by the mortgage loan origination data, which is first available at the website of the U.S. Consumer Financial Protection Bureau from 2007. The effective sample consequently covers 2008-2016 due to the log-change transformation in (1).

[1]The data on originated mortgage loans is from the Home Mortgage Disclosure Act (HMDA) data set of the U.S. Consumer Financial Protection Bureau. As stated above, I consider originated mortgage loans that are secured by a first or subordinate lien in owner-occupied principal dwellings. The house price data is from the All-Transactions House Price Index for counties of the U.S. Federal Housing Finance Agency. The income and population data is from the Personal Income, Population, Per Capita Personal Income (CA1) table in the Regional Economic Accounts of the U.S. Bureau of Economic Analysis.

Table 1: Panel Regression: Mortgage Loan Origination, U.S. Counties (2008-2016)

	$\Delta \log b_t$			
	(1)	(2)	(3)	(4)
$\Delta \log hp_{i,t-1}$	0.291***	-0.00898		
	(0.0788)	(0.176)		
$\Delta \log inc_{i,t-1}$	0.279***	-0.0236	-0.0268	
	(0.0960)	(0.119)	(0.113)	
$\mathcal{I}_{inc,i,t-1} \Delta \log hp_{i,t-1}$		0.365*	0.357***	0.358***
		(0.215)	(0.110)	(0.107)
$\mathcal{I}_{hp,i,t-1} \Delta \log inc_{i,t-1}$		0.609***	0.611***	0.592***
		(0.207)	(0.208)	(0.169)
Year Fixed Effects	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Adjusted R^2	0.706	0.710	0.710	0.710

Note: Number of observations: 24,056. The observations are weighted by the county population in a given year. Standard errors are clustered at the county level, and reported in parentheses. ***, **, and * indicate statistical significance at 1 pct., 5 pct., and 10 pct. confidence levels, respectively.

Table 1 reports the ordinary least square estimates of (1). In specification 1, I do not condition the elasticities with respect to house prices and personal incomes on personal incomes and house prices, respectively, growing. In this case, the elasticity of loan origination is 0.29 with respect to house prices and 0.28 with respect to personal incomes. These elasticities are in the ballpark of the elasticities of debt with respect to house prices (0.65) and incomes (0.14) that Mian and Sufi (2011) find for 2002-2006. In specifications 2-4, I allow for elasticities that are conditioned on house prices and personal incomes growing. The unconditional elasticities with respect to both variables shrink markedly, and become statistically insignificant. I arrive at the parsimonious specification 4 after sequentially having restricted the most insignificant term out and re-estimated the model. In specification 4, the unconditional loan origination elasticities with respect to both house prices and personal incomes are zero. The elasticity with respect to house prices is 0.36 conditional on personal income growth. Likewise, the elasticity with respect to personal incomes is 0.59 conditional on house price growth.

Specifications 2-4 demonstrate that there is a substantial non-linearity in the mortgage debt elasticities with respect to both house prices and personal incomes. House price growth (hence equity growth) is not in itself a sufficient condition for mortgage loan origination to increase. Likewise, personal income growth is not in itself a sufficient condition for mortgage loan origination to increase. Instead, homeowners only take on additional debt if both house prices and incomes are growing. In the following, I will rationalize this non-linearity in a model with two borrowing constraints.

4 The Model

The model has a discrete infinite time-horizon with time indexed by t. The economy is populated by two representative households: a patient household and an impatient household. Households consume goods and housing, and supply labor. Goods are produced by a representative firm by combining employment and non-residential capital. The housing stock is fixed, but housing reallocation takes place between the two households. The time preference heterogeneity implies that the patient household lends funds to the impatient household. The patient household also owns and operates the firm and non-residential capital.

4.1 The Patient and Impatient Households

Variables and parameters without (with) a prime refer to the representative patient (impatient) household. The household types differ with respect to their pure time discount factors, $\beta \in (0,1)$ and $\beta' \in (0,1)$, since $\beta > \beta'$. The economic size of each household is measured by its wage share: $\alpha \in (0,1)$ for the patient household and $1-\alpha$ the impatient household.

The patient and impatient households maximize their utility functions:

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t s_{I,t} \left[\chi \log(c_t - \eta c_{t-1}) + \omega_H s_{H,t} \log(h_t) - \frac{\omega_L s_{L,t}}{1+\varphi} l_t^{1+\varphi} \right] \right\} \tag{2}$$

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta'^t s_{I,t} \left[\chi' \log(c'_t - \eta c'_{t-1}) + \omega_H s_{H,t} \log(h'_t) - \frac{\omega_L s_{L,t}}{1+\varphi} l_t'^{1+\varphi} \right] \right\}, \tag{3}$$

where $\chi \equiv \frac{1-\eta}{1-\beta\eta}$ and $\chi' \equiv \frac{1-\eta}{1-\beta'\eta}$,[2] c_t and c'_t denote goods consumption, h_t and h'_t denote housing, l_t and l'_t denote labor supply, $s_{I,t}$ denotes an intertemporal preference shock, $s_{H,t}$ denotes a housing preference shock, and $s_{L,t}$ denotes a labor preference shock. $\eta \in (0,1)$ measures habit formation in goods consumption. $\omega_H \in \mathbb{R}_+$ and $\omega_L \in \mathbb{R}_+$ weight the (dis)utilities of housing and labor supply relative to the utility of goods consumption.

[2]The scaling factors ensure that the marginal utilities of consumption are $\frac{1}{c}$ and $\frac{1}{c'}$ in steady-state.

Utility maximization of the patient household is subject to a budget constraint:

$$c_t + q_t(h_t - h_{t-1}) + R_{t-1}b_{t-1} + \frac{k_t}{s_{AK,t}} + \frac{f(z_t)}{s_{AK,t}}k_{t-1} + \frac{g(k_t,k_{t-1})}{s_{AK,t}}k_{t-1} \\ = w_t l_t + b_t + \left(R_{K,t}z_t + \frac{1-\delta_K}{s_{AK,t}}\right)k_{t-1}, \tag{4}$$

where $f(z_t) \equiv R_K\left[\frac{1}{2}\frac{\zeta}{1-\zeta}z_t^2 + \left(1 - \frac{\zeta}{1-\zeta}\right)z_t + \frac{1}{2}\frac{\zeta}{1-\zeta} - 1\right]$ captures capital utilization costs, and $g(k_t, k_{t-1}) \equiv \frac{\iota}{2}\left[\frac{k_t}{k_{t-1}} - 1\right]^2$ captures capital adjustment costs. Not previously mentioned variables in (4) denote: q_t is the real house price, R_t is the real gross interest rate, b_t is borrowing, k_t is non-residential capital, $s_{AK,t}$ is an investment-specific technology shock, z_t is the utilization rate of non-residential capital, $R_{K,t}$ is the real gross rental rate of non-residential capital, and R_K is the steady-state real gross rental rate of non-residential capital. $\zeta \in (0,1)$ measures capital utilization costs, and $\iota \in \mathbb{R}_+$ measures capital adjustment costs.

Utility maximization of the impatient household is subject to a budget constraint:

$$c'_t + q_t(h'_t - h'_{t-1}) + R_{t-1}b'_{t-1} = w'_t l'_t + b'_t, \tag{5}$$

where b'_t is borrowing.

Utility maximization of the impatient household is also subject to two occasionally binding borrowing constraints:

$$b'_t \leq (1-\rho)b'_{t-1} + \rho\xi_{LTV}s_{C,t}s_{LTV,t}\mathbb{E}_t\left\{\frac{q_{t+1}h'_t}{R_t}\right\} \tag{6}$$

$$b'_t \leq (1-\rho)b'_{t-1} + \rho\xi_{LTI}s_{C,t}s_{LTI,t}\mathbb{E}_t\left\{w'_{t+1}n'_t\right\}, \tag{7}$$

where $s_{C,t}$ is a common credit shock that affects both borrowing constraints, $s_{LTV,t}$ is a macroprudential loan-to-value limit stabilizer, and $s_{LTI,t}$ is a macroprudential loan-to-income limit stabilizer. $\rho \in [0,1]$ measures the share of workers who refinance, $\xi_{LTV} \in [0,1]$ measures the steady-state loan-to-value limit on newly issued debt, and $\xi_{LTI} \in [0,1]$ measures the steady-state loan-to-income limit on newly issued debt. The macroprudential stabilizers ($s_{LTV,t}$ and $s_{LTI,t}$) are only active in Section 7. In Sections 5-6, $s_{LTV,t} = s_{LTI,t} = 1$ applies. The assumption $\beta > \beta'$ implies that (6) and (7) always hold with equality in (but not necessarily around) the steady-state.

4.2 The Firm

The representative firm produces goods by hiring labor from the patient and impatient households and renting capital from the patient household. The firm operates under perfect competition. The goods are sold as goods consumption, and non-residential investments.

The firm maximizes profits,

$$Y_t - w_t n_t - w'_t n'_t - R_{K,t} z_t k_{t-1}, \tag{8}$$

subject to the available goods production technology,

$$Y_t = (z_t k_{t-1})^{\mu} (s_{Y,t} n_t^{\alpha} n_t'^{1-\alpha})^{1-\mu}, \tag{9}$$

where Y_t denotes goods production, n_t and n'_t denote employment rates, and $s_{Y,t}$ denotes a labor-augmenting technology shock. $\mu \in (0, 1)$ measures the goods production elasticity with respect to non-residential capital. (9) is identical to the goods production function in Iacoviello and Neri (2010). They thus also aggregate the labor inputs from the two households through a Cobb-Douglas function. This assumption implies a complementarity across the labor skills of the two households, but simplifies the dynamic and steady-state equilibrium conditions of the model considerably.

4.3 Equilibrium

The model contains a goods market, a housing market, a loan market, and two labor markets. The market clearing conditions are:

$$c_t + c'_t + \frac{k_t - (1-\delta_K)k_{t-1}}{s_{AK,t}} + \frac{f(z_t)}{s_{AK,t}} k_{t-1} + \frac{g(k_t, k_{t-1})}{s_{AK,t}} k_{t-1} = Y_t \tag{10}$$

$$h_t + h'_t = H \tag{11}$$

$$b_t = -b'_t \tag{12}$$

$$n_t = l_t \tag{13}$$

$$n'_t = l'_t \tag{14}$$

4.4 Stochastic Processes

The intertemporal preference, housing preference, common credit, labor-augmenting technology, investment-specific technology, and labor preference shocks follow AR(1) processes. Each shock process has an independent and identically distributed normal stochastic innovation with a constant standard deviation.

5 Solution and Estimation of the Model

5.1 Solution and Estimation Techniques

The model is solved with the piecewise linear solution technique from Guerrieri and Iacoviello (2015). It is necessary to apply a non-linear solution technique such as this one in order to account for the two occasionally binding borrowing constraints. The model is estimated by Bayesian maximum likelihood with the approach in Guerrieri and Iacoviello (2017) to handle the piecewise linear solution of the model.

The model economy will always be in one of four regimes depending on whether the loan-to-value constraint binds or not and depending on whether the loan-to-income constraint binds or not. A complicating feature of the model is the regime where both constraints bind. In Guerrieri and Iacoviello (2017), the two occasionally binding constraints (a loan-to-value constraint and a zero lower bound) restrict two variables (borrowing and the nominal interest rate). By contrast, in the present model, the two occasionally binding borrowing constraints only restrict one variable (borrowing). Consequently, in the regime where both constraints bind, the debt limits imposed by the loan-to-value and loan-to-income constraints must be identical. This implies that the right-hand side of (6) must be equal to the right-hand side of (7) in the regime where both constraints bind.

The solution technique from Guerrieri and Iacoviello (2015) performs a first-order approximation of each of the four regimes around the steady-state of a reference regime (one of the four regimes). As a reference regime, I choose the regime where both constraints bind.[3] As a consequence, the calibrated loan-to-value and loan-to-income limits must ensure that – in steady-state, but not necessarily outside steady-state – the right-hand side of (6) is equal to the right-hand side of (7). This restriction on the calibration of the model does, however, not imply that it is not possible to calibrate the model realistically.

[3] I wish to treat the borrowing constraints symmetrically. I therefore avoid specifying a reference regime where only one constraint binds since this could bias the model towards that regime. The regime where both constraints are non-binding is furthermore unfeasible as a reference regime since the time preference heterogeneity is inconsistent with households that are not credit restricted in steady-state.

Instead, as will be evident in Subsection 5.3, a very plausible calibration can be reached.

5.2 Data

The sample frequency is quarterly, and the sample covers the U.S. economy in 1975Q1-2017Q1. The estimation sample contains the following five variables: 1. Real personal consumption expenditures per capita. 2. Real home mortgage loan liabilities per capita. 3. Real house prices. 4. Real disposable personal income per capita. 5. Aggregate weekly hours per capita.

All series are normalized relative to 1975Q1 and then log-transformed. The series are lastly HP detrended (with a smoothing parameter of 100,000) in order to remove their low-frequency components. Detailed names of the series and data sources are reported in the Online Appendix.

5.3 Calibration and Prior Distribution

Some parameters are difficult for the estimation to identify. These parameters are calibrated using previous studies or steady-state targets. Table 2 reports the calibrated parameters and information on their calibration. The calibrated steady-state loan-to-income limit ($\xi_{LTI} = 24$) implies that households can maximally borrow six times their annual income *after taxes*. This value is inspired by the loan-to-income limit that the Prudential Regulation Authority of the Bank of England implemented for the U.K. in 2014. Under this regulation, mortgage lenders may maximally extent 15 pct. of all regulated mortgages to households whose loan-to-income ratios are above 4.5 *before income taxes* (see Bank of England (2014a,b)). The average labor tax rate was 23.1 pct. in the postwar U.S., according to Jones (2002). For mortgage lending outside the most risky 15 pct., the loan-to-income limit accordingly becomes $\frac{4.5}{1-0.231} = 5.9$ times their annual income *after taxes.*[4] A further sanity check of this calibration is to compare the implied debt service-to-income limit to the typical debt service-to-income limits in the U.S. The ratio of interest and repayment to labor incomes before taxes is 28 pct. in steady-state.[5] This number perfectly matches the typical front-end (i.e., excluding recurring debt) debt service-to-income limit

[4] It is necessary to apply the after-tax equivalent of the loan-to-income limit since there is no taxation in the model.

[5] The debt service-to-income limit is calculated as $b'/(4 \cdot 30) + rb'$ where r is the steady-state real net interest rate and it is assumed that the mortgage loan is repaid over 30 years. The before-tax equivalent income is calculated as $w'n'/(1 - 0.231)$, again following Jones (2002).

Table 2: CALIBRATED PARAMETERS

Description		Value	Source or Steady-State Target
Time discount factor, pt. household	β	0.995	Guerrieri and Iacoviello (2017)
Housing utility weight	ω_H	0.20	Steady-state target[a]
Labor supply disutility weight	ω_L	0.001	Normalization[b]
Steady-state loan-to-value limit	ξ_{LTV}	0.84	See text
Steady-state loan-to-income limit	ξ_{LTI}	24.0	See text
Depreciation rate, non-residential capital	δ_K	0.025	Standard value
Capital income share of total production	μ	0.33	Standard value
Supply of housing	H	1.00	Normalization

[a] The model is calibrated to match the empirical ratio of owner-occupied residential fixed assets to durable goods consumption expenditures (37.8) over the sample period.
[b] The labor supply disutility weight only affects the scale of the economy, as in Justiniano et al. (2015) and Guerrieri and Iacoviello (2017).

of 28 pct. in the U.S.[6]

The calibrated steady-state loan-to-value limit ($\xi_{LTV} \approx 0.84$) ensures that the debt limits imposed by the loan-to-value and loan-to-income constraints are identical in the steady-state (cf., the discussion on the solution of the model in Subsection 5.1). The limit is well within the range of typically applied loan-to-value limits (e.g., Justiniano et al. (2017) use 0.80, Iacoviello and Neri (2010), Lambertini et al. (2013), and Justiniano et al. (2015) use 0.85, and Guerrieri and Iacoviello (2017) use 0.90).

Table 3 reports the prior distributions of the estimated parameters. The prior means of the wage share parameter ($\alpha = 0.66$), the impatient time discount factor ($\beta' = 0.984$), and debt inertia ($\rho = 0.25$) follow the prior means in Guerrieri and Iacoviello (2017). The prior mean of the elasticity of the marginal disutility of labor supply ($\varphi = 4.00$) follows the prior mean in Smets and Wouters (2007) and the estimate in Galí et al. (2012). The prior means of the remaining estimated parameters are identical to the prior means of the corresponding parameters in Iacoviello and Neri (2010).

5.4 Posterior Distribution

Table 3 reports the estimated posterior distribution. The estimates of the wage share parameter ($\alpha = 0.55$), the impatient time discount factor ($\beta' = 0.9936$), and debt inertia ($\rho = 0.23$) are similar to the estimates of the corresponding parameters in Guerrieri and Iacoviello (2017) (0.50, 0.9922, and 0.30). This is comforting considering that these

[6] The U.S. Consumer Financial Protection Bureau for instance write in their home loan guide: "A mortgage lending rule of thumb is that your total monthly home payment should be at or below 28% of your total monthly income before taxes." (see Consumer Financial Protection Bureau (2015, p. 5)).

Table 3: PRIOR AND POSTERIOR DISTRIBUTIONS

	Prior Distribution			Posterior Distribution		
	Type	Mean	SD	Mode	5 pct.	95 pct.
Structural Parameters						
α	B	0.66	0.15	0.5533		
β'	B	0.984	0.006	0.9936		
η	B	0.50	0.15	0.6100		
φ	N	4.00	0.50	5.2346		
ρ	B	0.25	0.15	0.2318		
ζ	B	0.50	0.15	0.7519		
ι	N	10.0	2.00	4.6084		
Deterministic Structure of Shock Processes						
IP	B	0.50	0.20	0.7024		
HP	B	0.50	0.20	0.9871		
CC	B	0.50	0.20	0.9047		
AY	B	0.50	0.20	0.9103		
LP	B	0.50	0.20	0.9858		
Standard Deviations of Innovations						
IP	IG	0.01	0.10	0.0297		
HP	IG	0.01	0.10	0.0531		
CC	IG	0.01	0.10	0.0243		
AY	IG	0.01	0.10	0.0516		
LP	IG	0.01	0.10	0.0125		

Abbreviations: N: Normal. B: Beta. IG: Inverse-Gamma.
Note: [POSTERIOR SIMULATION TO BE DONE]

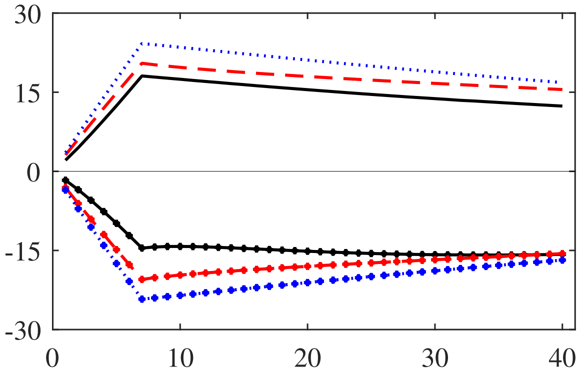
parameters are important in determining when the borrowing constraints bind or not. The patience of the impatient household is relatively high, compared to a standard calibration of 0.97 (e.g., Iacoviello and Neri (2010)). Thus, an annual real interest rate of $(\frac{1}{0.9936})^4 - 1 \approx 2.6$ pct. would make the impatient household unconstrained in steady-state. This high patience is expected considering that the fraction of impatient households is sizable.

6 Model Dynamics

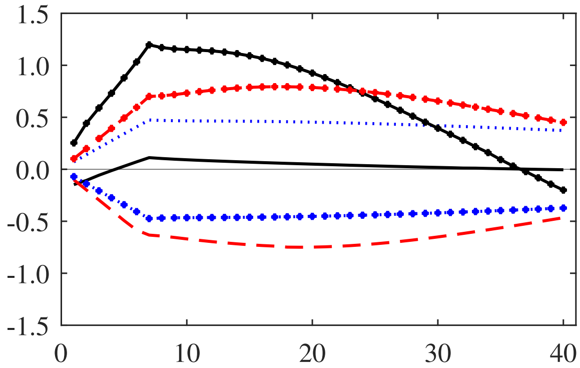
6.1 Responses to House Price Shocks

This section illustrates the asymmetries that arise from having two occasionally binding borrowing constraints in the same model. Figure 1 plots the effects of two series of equally-sized positive and negative housing preference shock in three versions of the model. The versions are: the baseline model, the model with only an occasionally binding loan-to-value constraint, and the model with only an occasionally binding loan-to-income constraint.

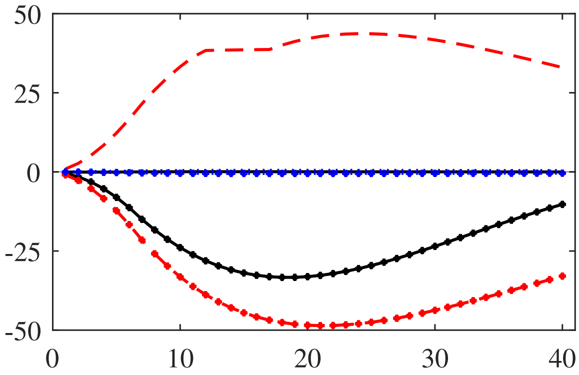
Figure 1: Impulse Response of Housing Preference Shocks



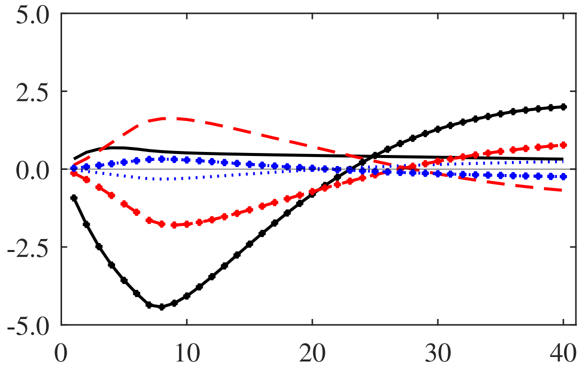
(a) House Price (dev. from SS)



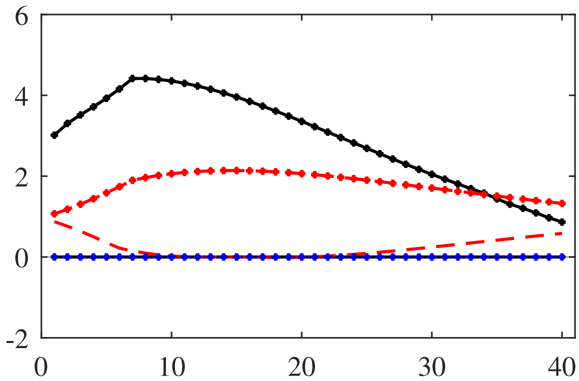
(b) Wage Income (dev. from SS)



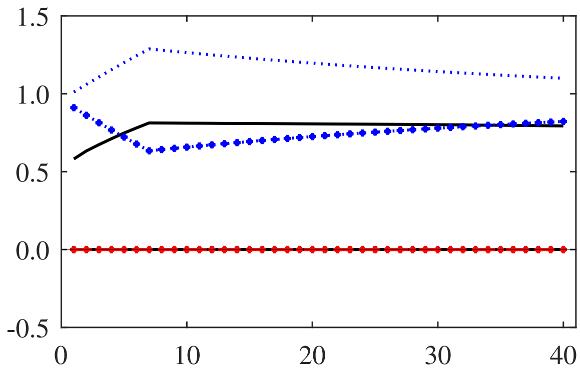
(c) Borrowing (dev. from SS)



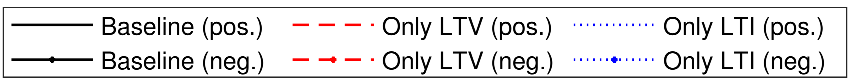
(d) Consumption (dev. from SS)



(e) LTV Lagrange Multiplier (level)



(f) LTI Lagrange Multiplier (level)



Note: The models are calibrated to the posterior mode. Second axes measure percentage deviations from the steady-state (Figures 1a-1d) or levels (Figures 1e-1f).

The shock series occur in periods 1-8, and raise and lower, respectively, the house price by 20 pct. in the baseline model.

The positive housing preference shocks cause the house price to increase. If the loan-to-value constraint is the only constraint in the model, borrowing increases until the impatient household is no-longer credit constrained. Consumption also increases, and the Lagrange multiplier on the loan-to-value constraint turns to zero. This scenario closely resembles the reaction in Guerrieri and Iacoviello (2017) both in terms of qualitative and quantitative effects. If the loan-to-income constraint is present (possibly as the only constraint) in the model, the loan-to-income multiplier increases since it is (now) the only restricting constraint. Mortgage debt remains roughly unchanged since incomes are roughly constant (only house prices have moved). The response of consumption is consequently muted. This difference depending on whether a loan-to-income constraint is present or not is important; it suggests that models with only a loan-to-value constraint overestimate the propagation from *lone* housing preference shocks.

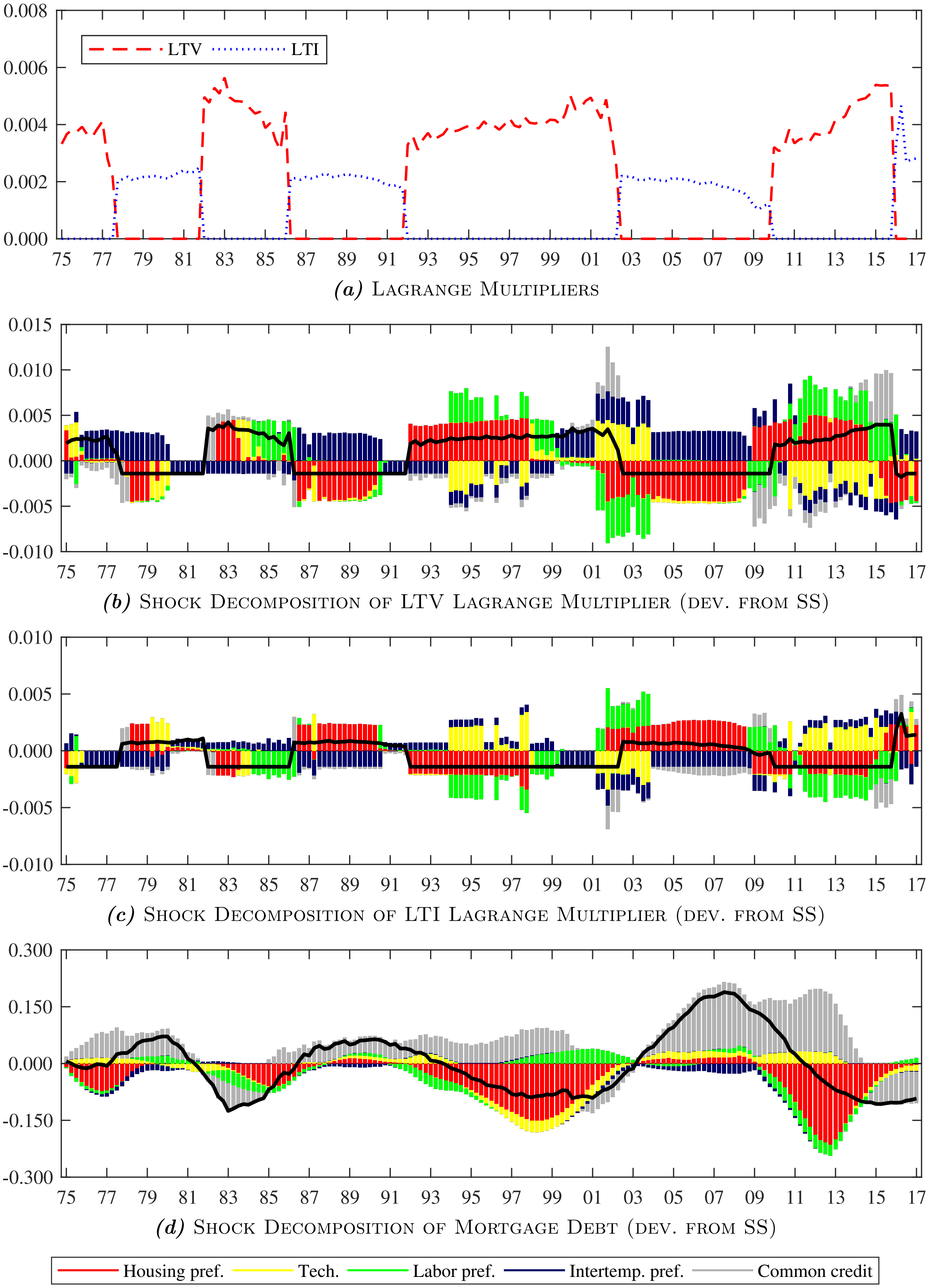
The negative housing preference shocks cause the house price to fall. This highlights an important asymmetry in the model with both loan-to-value and loan-to-income constraints. While a house price increase was not able to increase borrowing because of the loan-to-income constraint, a house prices fall is able to reduce it. This reflects that a house price fall causes the loan-to-value constraint to tighten and borrowing to fall. Consumption falls, and the loan-to-value multiplier increases. The asymmetry is not present in the model with only a loan-to-value constraint or in Guerrieri and Iacoviello (2017) since debt here may move in tandem with house prices. In these cases, the only difference relative to a model with an always binding loan-to-value constraint is that the effect of the house prices increase is curbed once the loan-to-value constraint unbinds. The asymmetry is also not present in the model with only a loan-to-income constraint since there is no propagation of house price shocks through the loan-to-income constraint.

6.2 Credit Constraints and Mortgage Debt Historically

This section gives an account of the historical evolution in credit constraints and mortgage debt. The focus is on the interaction between macroeconomic conditions and the borrowing constraints. Figure 2a plots the smoothed posterior Lagrange multipliers on the two borrowing constraints. The loan-to-value constraint binds when $\lambda_{LTV} > 0$, and the loan-to-income constraint binds when $\lambda_{LTI} > 0$. Figure 2b-2d plot the historical shock decomposition of the Lagrange multipliers and mortgage debt in deviations from steady-state. Note that both constraints bind in steady-state – hence, their values are positive (and identical) in steady-state.

One Lagrange multiplier is always positive, as evident in Figure 2a. This implies that net-borrowing households on average have historically always been credit constrained by

Figure 2: Smoothed Posterior Variables



(a) Lagrange Multipliers

(b) Shock Decomposition of LTV Lagrange Multiplier (dev. from SS)

(c) Shock Decomposition of LTI Lagrange Multiplier (dev. from SS)

(d) Shock Decomposition of Mortgage Debt (dev. from SS)

Note: The model is calibrated to the mode of the posterior distribution. Each bar indicates the contribution from the respective shock to the considered variable. The shocks were marginalized in the following order: (1) intertemporal preference shock, (2) labor preference shock, (3) labor-augmenting technology shock, (4) housing preference shock, and (5) common credit shock.

at least one constraint.[7] As a consequence, the shocks that cause one constraint to bind causes the other constraint to unbind and vice versa. Hence, the decompositions in Figures 2b-2c are mirror images of each other.

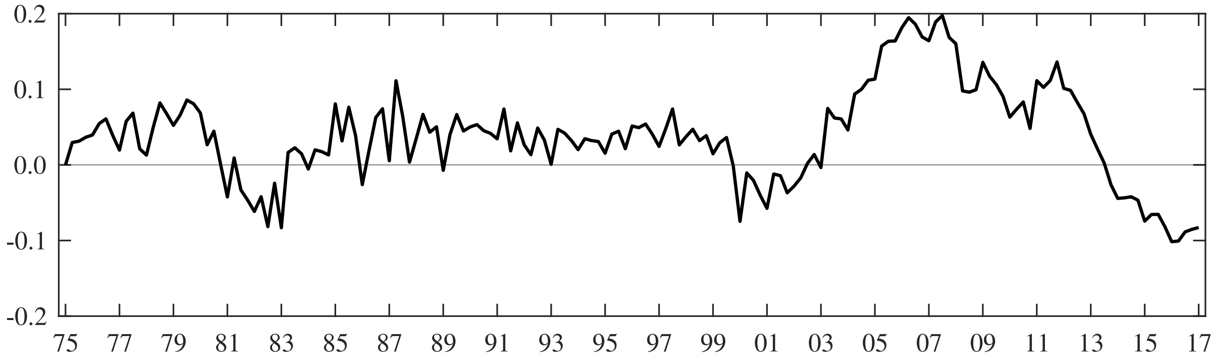
Housing preference shocks always play an important part in making the constraints bind or unbind. This reflects that the loan-to-value constraint becomes unbinding when house prices are high and vice versa when they are low, combined with the high volatility of housing preference shocks. Positive housing preference shocks and negative technology shocks caused the loan-to-income constraint to bind in the end-1970s. This reflects that the oil crises and resulting stagflation had a larger contractionary effect on the real wages of the households than on the housing market. The loan-to-value constraint became binding in the start-1980s as house prices started to fall during the tight monetary policy of Paul Volcker. It remained binding during the 1980s expansion when technology and labor preference shocks caused personal incomes to growth quicker than house prices. This lasted until 1986 when the house price growth finally picked up pace, and caused the loan-to-value constraint to unbind. In 1992, following the early 1990s recession, house prices again started falling, which caused the loan-to-value limit to bind. This shift was later (around 1994) reinforced by positive technology shocks, as real wages started growing quicker during the 1990s. From around 2000, house prices started growing rapidly, leading the loan-to-value constraint to unbind and the loan-to-income constraint to bind. This lasted until the Great Recession when the house price bust caused the loan-to-value to bind again. Very recently (from around 2016), a combination of growing house prices and meager wage growth have caused the loan-to-income constraint to bind again.

Which borrowing constraint that binds has important implications for the impact of shocks on mortgage debt. A shock may have a large effect at a specific point in time because a constraint whose value it affects binds, but no effect at other times where the constraint does not bind. When the loan-to-value constraint was binding (e.g., during 1992-2001 and 2010-2015), debt was largely driven by housing preference shocks. The effects of common credit shocks are discussed in the following. By contrast, when the loan-to-income constraint was binding (e.g., during 1986-1991 and 2002-2009), debt was largely driven by labor preference and technology shocks. These shocks are not normally considered by the literature to drive mortgage debt.

Figure 3 plots the smoothed posterior common credit shock ($s_{CC,t}$). The common credit shock does not by itself affect which constraint that binds since the shock has the same

[7] Remember that this is not an imposed result of the model since both borrowing constraints could become non-binding if the patience of the net-borrowers were estimated to be sufficiently high.

Figure 3: Smoothed Common Credit Shock



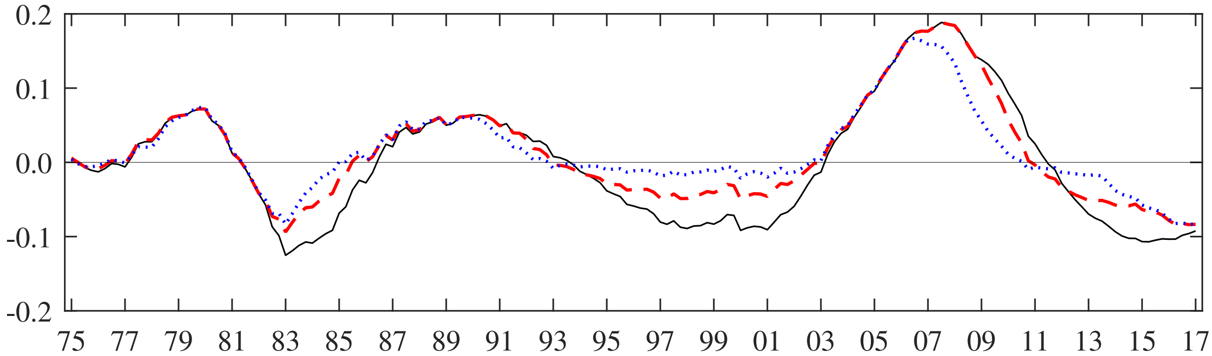
Note: The credit shock process is identified at the posterior mode. The second axis measures percentage deviations from the steady-state.

relative effect on the credit limit imposed by both constraints. Credit limits were roughly constant until around 2000. From that time onward, they were gradually loosened until the beginning of the Financial Crisis in 2007. The loan-to-income constraint was binding during this period. Thus, the buildup in mortgage debt prior to the recession was caused by looser loan-to-value limits. The effect of credit liberalizations prior to the recession is also evident in Figure 2d. Here, roughly three-quarters of the increase in debt was caused by lax credit conditions.

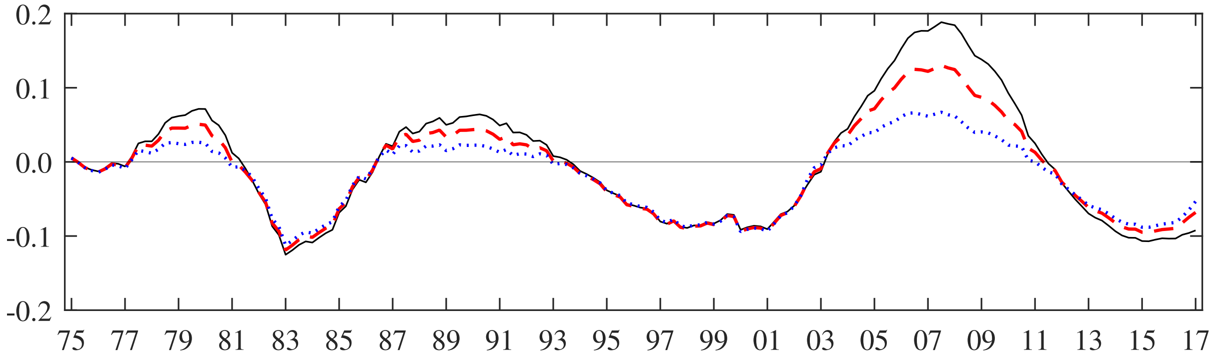
The historical decompositions provide the following narrative of credit conditions around the Great Recession. Rapidly growing house prices relaxed the loan-to-value limits facing borrowers, thereby weakening the link between house prices and mortgage debt. Borrowers at the same time remained credit constrained by the loan-to-income constraint. Loan-to-income limits were, however, weakened from around 2000, implying that homeowners could take on increasing amounts of debt relative to their incomes. This relaxation could make sense from the bank's perspective since – as house prices were growing rapidly – homes were constituting a rapidly improving collateral. This process was stopped by the Great Recession, which led house prices to fall. The credit relaxations were furthermore rolled back since – as house prices were falling – homes were constituting a secularly deteriorating collateral.

The shock decomposition confirms the result in Guerrieri and Iacoviello (2017) that loan-to-value constraints became slack during the housing boom of 2001-2006. The decomposition, however, also nuance the Guerrieri and Iacoviello (2017) result since the slack loan-to-value constraints did not imply that homeowners were free to borrow. Instead, they remained credit constrained by the loan-to-income constraint.

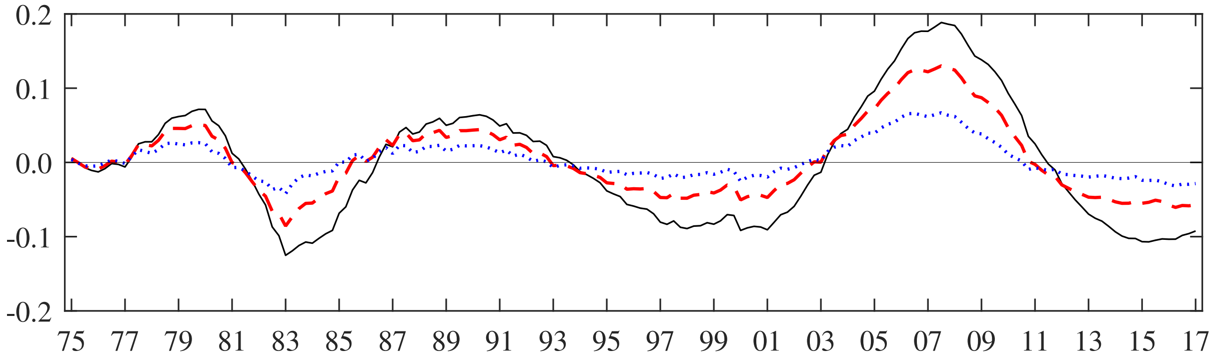
Figure 4: Alternative Macroprudential Regimes



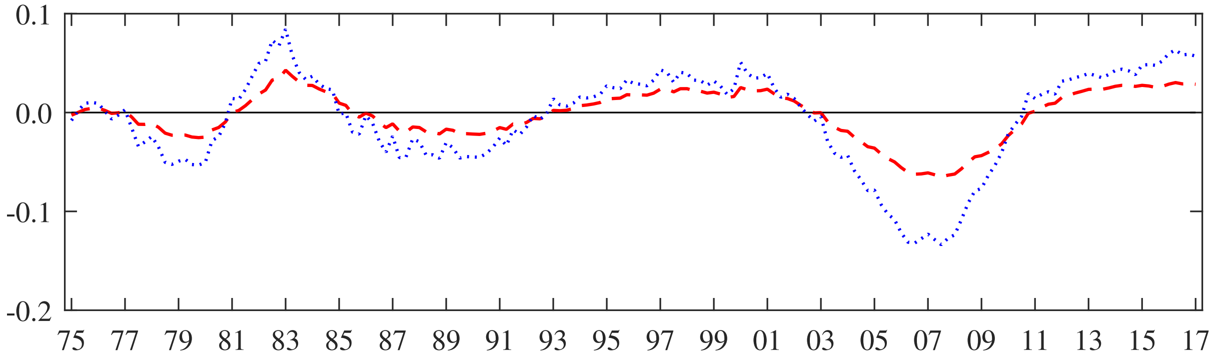
(a) Mortgage Debt with a Countercyclical Loan-to-Value Limit



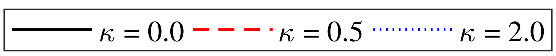
(b) Mortgage Debt with a Countercyclical Loan-to-Income Limit



(c) Mortgage Debt with Countercyclical Loan-to-Value and Loan-to-Income Limits



(d) Size of the Credit Limit Stabilizer



Note: The model is calibrated to the mode of the posterior distribution. The historical shocks are identified at the posterior mode. The second axes measure percentage deviations from the steady-state.

7 Macroprudential Policy Implications

This section examines the implications of countercyclical loan-to-value and loan-to-income limits in the face of occasionally binding loan-to-value and loan-to-income constraints. Figure 4 plots the reaction of the model to the estimated sequence of shocks under four different macroprudential regimes. In the first regime, there is no active macroprudential policy so the credit limits are only shifted by the common credit shock, as in the estimated model. Thus, the observed variables in the model by construction match the data. In the three other regimes, the following policies apply: a countercyclical loan-to-value limit, a countercyclical loan-to-income limit, and both countercyclical loan-to-value and loan-to-income limits.

The countercyclical loan-to-value and loan-to-income limits are introduced through the following systematic responses:

$$\log s_{LTV,t} = -\kappa_{LTV} \log \left(\frac{b'_t}{b'} \right) \qquad \text{and} \qquad \log s_{LTI,t} = -\kappa_{LTI} \log \left(\frac{b'_t}{b'} \right),$$

where b' denotes steady-state borrowing. $\kappa_{LTV} \geq 0$ and $\kappa_{LTI} \geq 0$ measure the degree of countercyclical macroprudential policy. The equations above enter into (6) and (7). Hence, $s_{LTV,t} = s_{LTI,t} = 1$ no-longer applies.

A countercyclical loan-to-value policy is able to mitigate the adverse effects of falling house prices when the loan-to-value constraint is binding. This stabilization potential was most pronounced during the mid-1980s, in the end-1990s, and in the later part of the Great Recession. The flip-side of this result is, however, that countercyclical loan-to-value policy cannot curb increases in mortgage debt during housing market booms since the loan-to-value constraint will typically be non-binding. Macroprudential policymakers would thus not have been able to curb the buildup in mortgage debt prior to the Great Recession even if they had lowered the loan-to-value limit.

A countercyclical loan-to-income policy turns out to be very effective at curbing increases in mortgage debt during housing market booms. The reason for this is that the loan-to-income constraint will typically be the binding constraint during these periods. Macroprudential policymakers could thus have avoided the buildup in mortgage debt during 2003-2007 through stricter loan-to-income requirements.

The results that the loan-to-income limit is an effective macroprudential tool in house price booms and that the loan-to-value limit is not, are not well-documented in economics. The reason for this is that the literature has mostly focused on macroprudential stabilization through loan-to-value limits.[8] The results above highlight the need for models with both loan-to-value and loan-to-income limits when determining the optimal timing and implementation of macroprudential policy.

8 Concluding Remarks

[TO BE DONE]

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[8] The Committee on the Global Financial System (2010) and the IMF (2011) recommend to employ loan-to-value limits as countercyclical automatic stabilizers around a fixed cap. Lambertini et al. (2013) demonstrate that a loan-to-value limit which responds countercyclically to credit growth moderates the fluctuations in output, using a model with an always binding constraint. Jensen, Ravn, and Santoro (2017) demonstrate that a loan-to-value limit which responds countercyclically to output growth likewise moderates the fluctuations in output, using a model with an occasionally binding constraint. The two latter papers furthermore show that a countercyclical loan-to-value limit is welfare-improving compared to a constant limit.

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