

LTV vs. DTI 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 debt-service-to-income (DTI) constraint. A Bayesian estimation of the model infers when the LTV and DTI 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 DTI limits can.

JEL classification: D58, E24, E32, E44.

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1 Introduction

Does income growth amplify the effect of house price growth on mortgage debt origination? How is the propagation of macroeconomic shocks affected by endogenously shifting loan-to-value and debt-service-to-income limits? When historically have loan-to-value and debt-service-to-income limits, respectively, restricted mortgage borrowing? Did looser loan-to-value limits or looser debt-service-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 significant 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 both elasticities are highly state-dependent. The elasticity with respect to house prices is zero when incomes are not growing and 0.48 when they are. Similarly, the elasticity with respect to incomes is zero when house prices are not growing and 0.41 when they are.

I interpret the state-dependent 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 debt-service-to-income constraint. With this setup, homeowners must fulfill a collateral requirement and a debt service requirement in order to qualify for a mortgage loan. The debt-service-to-income constraint is a generalization of the natural borrowing limit in [Aiyagari \(1994\)](#), and can be derived as an incentive compatibility constraint on the lender. Thus, for a particular calibration, the debt-service-to-income constraint is identical to the natural borrowing limit in [Aiyagari \(1994\)](#). The loan-to-value constraint is the solution to a debt enforcement problem, as in [Kiyotaki and Moore \(1997\)](#).

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. The

model is able to match the state-dependent effects of house price and personal income changes. In the model, the level of borrowing remains roughly constant in the face of *large* house price increases (even though the demand for loans is unsaturated) due to the debt-service-to-income constraint. Only if both house prices and labor incomes increase, may homeowners take on additional debt. Such dynamics are novelties, which existing models with only loan-to-value constraints cannot replicate.

The estimation identifies when the respective two borrowing constraints have been binding and which shocks that caused them to bind. At least one credit constraint is always binding through most of the considered period. This suggests that net-borrowers have been credit constrained through most of the period. It is not an imposed result of the model since both borrowing constraints would become non-binding if the patience of the net-borrowers were estimated to a sufficiently high value. The loan-to-value constraint was binding in 1979-1984, 1991-1997, and 2007-2015. The debt-service-to-income constraint is binding in the end-1970s, 1987-1991, 1998-2007, and 2015-2017. Both constraints were unbinding in 1985-1986. The loan-to-value constraint is generally binding during and after recessions, and the debt-service-to-income constraint is generally binding in expansions. This pattern reflects that house prices are more volatile than personal incomes. The only significant exception to the pattern was in the end-1970s when the debt-service-to-income constraint was binding during the oil crises and resulting stagflation, which affected incomes more severely than the housing market.

The estimation also identifies historical shocks to the credit limits imposed by the credit constraints. Through the whole sample, a punctual time-wise correspondence exists between historical events and credit shock innovations. Positive shocks are evident around the financial deregulation in the start/mid-1980s, the easement of risk management practices of banks in 1998-2005, and the introduction of the Home Affordable Refinance Program and the Home Affordable Modification Program in 2009-2010. Negative shocks are evident around the Black Monday Stock Market Crash of 1987, the Savings and Loan Crisis of 1986-1995, and the eruption of the Subprime Crisis of 2007-2008. The credit shock series closely matches the credit spread shocks that [Prieto et al. \(2016\)](#) find using a different approach, suggesting that the current estimates are valid.

Since the debt-service-to-income constraint was binding in 1998-2007, the buildup in mortgage debt prior to the recession must have been caused by looser debt-service-to-income limits and not necessarily looser loan-to-value limits. This is consistent with the result in [Justiniano et al. \(2017\)](#) that looser loan-to-value limits cannot explain the surge in mortgage debt. [Justiniano et al. \(2017\)](#) also argue that it was an increase in the credit

supply that caused the surge in mortgage debt. The results in the present paper do not *per se* reject this hypothesis. Rather, the present results suggest that – if an increase in credit supply occurred – then it translated into a relaxation of debt-service-to-income 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 debt-service-to-income limits would have affected the historical evolution in mortgage debt if they had been implemented. Countercyclical debt-service-to-income limits are very effective at curbing increases in mortgage debt since these increases typically occur in expansions when the debt-service-to-income constraint is binding. The flip-side of this result is that countercyclical loan-to-value limits cannot prevent mortgage debt from rising since this constraint is typically non-binding when it occurs. Countercyclical loan-to-value limits can, however, abate the adverse consequences of house price slumps on credit availability by raising credit limits. The result that the primary macroprudential tool should change over the business cycle is not well-documented in economics. Instead, the existing literature focuses on stabilization solely through countercyclical loan-to-value limits.¹

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 asymmetric and state-dependent dynamics that the two constraints introduce. Section 7 performs the historical shock decomposition of the evolution in borrowing constraints, and discusses the historical path of the common credit shock. Section 8 conducts the macroprudential policy simulation. Section 9 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 debt-service-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

¹See, e.g., the [Committee on the Global Financial System \(2010\)](#), the [IMF \(2011\)](#), [Lambertini et al. \(2013\)](#), and [Jensen, Ravn, and Santoro \(2017\)](#).

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. [Gelain et al. \(2013\)](#) show that loan-to-income constraints are more effective at stabilizing debt (but not other model variables) than loan-to-value constraints, using a linear model with always binding constraints.

Several time-series studies document the presence of substantial non-linear responses to credit shocks. [Barnichon et al. \(2017\)](#) show that shocks to the excess bond premium have asymmetric and state-dependent effects on industrial production and consumption, using a non-linear vector moving average model on U.S., U.K., and Euro area data. First, positive bond premium shocks have large and persistent negative effects on real activity, while negative bond premium have no significant effect on real activity. Second, bond premium shocks have larger and more persistent effects on real activity in contractions than in expansions. [Prieto et al. \(2016\)](#) likewise show that house price and credit spread shocks have significantly stronger effects on GDP growth in crisis periods than in non-crisis periods, using a time-varying parameter VAR model on U.S. data. [Davig and Hakkio \(2010\)](#) and [Hubrich and Tetlow \(2015\)](#) also find that financial stress has larger effects on real activity in crisis periods than in non-crisis periods, using Markov switching VAR models on U.S. data.

The existing models with occasionally binding loan-to-value constraints cannot capture the non-linear effects of credit shocks. Since these models rely on a single credit constraint only, their reactions to house price and credit shock are symmetric up until the point where the loan-to-value constraint unbinds. For realistic calibrations of the models, however, this unbinding does typically not occur for small- and medium-sized shocks. For instance, [Guerrieri and Iacoviello \(2017\)](#) need to apply a 20 pct. house price increase in order for their loan-to-value constraint to unbind. Similarly, in [Jensen, Ravn, and Santoro \(2017\)](#), the loan-to-value constraint unbinds lastingly following a large (three standard deviation) credit limit shock, but not following other same-sized shocks or with loan-to-value limits below 90 pct. This contrasts the evidence in [Barnichon et al. \(2017\)](#) and [Prieto et al. \(2016\)](#) who observe substantial non-linear effects following single-period unit standard deviation shocks.

3 Empirical Evidence

In this section, I document the presence of a substantial state-dependency in the responses of mortgage loan origination to house price and personal income movements. I construct a county-level panel data set for the U.S. economy. The data set contains data on the amount of originated mortgage loans, house prices, and personal incomes across U.S. counties at an annual longitudinal frequency. On the data set, I 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:

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

where $E\{v_{i,t}\} = 0$, $\Delta \log$ denotes a log-change, $d_{i,t}$ denotes the amount 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., $\Delta \log x_{i,t} \leq 0$).² β_{hp} measures the unconditional elasticity with respect to house prices, β_{inc}^I measures the discrete effect of personal income growth, and $\tilde{\beta}_{hp}$ 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, β_{hp}^I measures the discrete effect of house price growth, and $\tilde{\beta}_{inc}$ measures the elasticity with respect to personal incomes conditional on house prices growing.

I treat the lagged house price and personal income variables as exogenous conditional on the year and county fixed effects. The variables in (1) are lagged in order to reduce the

²The 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: MORTGAGE LOAN ORIGINATION ACROSS U.S. COUNTIES (2008-2016)

	$\Delta \log b_t$				
	(1)	(2)	(3)	(4)	(5)
$\Delta \log hp_{i,t-1}$	0.291*** (0.0788)	-0.0784 (0.170)		0.103 (0.107)	
$\Delta \log inc_{i,t-1}$	0.279*** (0.0960)	0.267** (0.115)	0.281*** (0.0909)	0.0809 (0.113)	
$\mathcal{I}_{inc,i,t-1}$		0.00678 (0.0112)			
$\mathcal{I}_{inc,i,t-1} \Delta \log hp_{i,t-1}$		0.548*** (0.191)	0.476*** (0.0899)		
$\mathcal{I}_{hp,i,t-1}$				0.0569*** (0.0141)	0.0609*** (0.00990)
$\mathcal{I}_{hp,i,t-1} \Delta \log inc_{i,t-1}$				0.315** (0.155)	0.407*** (0.117)
Observations	24056	24056	24056	24056	24141
Adjusted R^2	0.706	0.709	0.709	0.712	0.711

Note: Year and county fixed effects are included in all specifications. 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.

risk that omitted time-varying variables bias the results. I refrain from using the housing supply elasticity from [Saiz \(2010\)](#) for three reasons, following [Bhutta and Keys \(2016\)](#). First and foremost, I wish to treat house prices and personal incomes symmetrically. Having an instrument for house price movements may alter 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 misidentified relative to the effect of personal incomes on loan origination. Second, the housing supply elasticity is unfeasible as a house price instrument in panel analyses since it does not vary over time. Third, the data covers the housing bust period for which the supply elasticity is, in theory, not a good instrument. In slack periods, negative housing demand shocks should cause similar house price declines in both elastic and inelastic areas due to the durability of housing.

It is likely that large negative credit shocks are present in the data around the Great Recession. To the extent that these shocks are time-varying county-specific, they will not

Table 2: MORTGAGE LOAN ORIGINATION ACROSS U.S. COUNTIES: ROBUSTNESS CHECKS

Sample	$\Delta \log b_t$					
	2013-2016					Full
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \log hp_{i,t-1}$	0.255*** (0.0883)	-0.0299 (0.212)		0.148 (0.113)		0.218** (0.0932)
$\Delta \log inc_{i,t-1}$	0.252*** (0.0847)	0.241 (0.149)	0.204** (0.0898)	-0.285** (0.145)		0.295*** (0.0988)
$\mathcal{I}_{inc,i,t-1}$		-0.00760 (0.0134)				
$\mathcal{I}_{inc,i,t-1} \Delta \log hp_{i,t-1}$		0.324 (0.291)	0.287** (0.139)			
$\mathcal{I}_{hp,i,t-1}$				0.00485 (0.0117)		
$\mathcal{I}_{hp,i,t-1} \Delta \log inc_{i,t-1}$				0.758*** (0.184)	0.605*** (0.0979)	
$\Delta \log hp_{i,t-1} \Delta \log inc_{i,t-1}$						4.951*** (1.377)
Observations	10673	10673	10673	10673	10750	24056
Adjusted R^2	0.834	0.834	0.834	0.837	0.835	0.708

Note: Year and county fixed effects are included in all specifications. 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.

be captured by the year and county fixed effects in the model, and consequently bias the results. This should, however, cause an underestimation – not an overestimation – of the amplification between house price and personal income growth. To see this, note that a negative credit shock causes loan origination and potentially, due to collateral motives, house prices to fall. Incomes, on the contrary, should not be directly affected by the credit shock. As a consequence, the interaction terms ($\tilde{\beta}_{hp}$ and $\tilde{\beta}_{inc}$) will be downward biased. Nonetheless, despite this reasoning, I caution a too causal interpretation.

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).

Table 1 reports the ordinary least square estimates of (1). In specification 1, I do not allow for state-dependent elasticities. In this case, the elasticity of loan origination is 0.29 with respect to house prices and 0.28 with respect to personal incomes. In specifications 2-3, I introduce a house price elasticity that is conditional on personal incomes growing. The unconditional house price elasticity shrinks markedly, and becomes statistically insignificant. I arrive at the parsimonious specification 3 after sequentially having restricted the most insignificant term out and re-estimated the model. Here, the house price elasticity is 0.48 conditional on personal income growth. In specifications 4-5, I introduce a personal income elasticity that is conditional on house prices growing. The unconditional income elasticity shrinks markedly, and becomes statistically insignificant. In the parsimonious specification 5, the personal income elasticity is 0.41 conditional on house price growth.

Table 2 verifies the robustness of the results above in two dimensions. First, I re-estimate (1) on a sample only containing data for 2013-2016 in order to assess the extent to which the Great Recession drives the results. I use 2013 as the first year in the post-recession sample because the post-recession trough in the aggregate level of mortgage debt was in this year. The results from Table 1 continue to hold qualitatively with the post-recession sample. Second, if house price and personal income growth amplify each other as indicated by the conditional elasticities, then this should also show up in a continuous interaction term ($\Delta \log hp_{i,t-1} \Delta \log inc_{i,t-1}$). I add such term to specification 1 from Table 1, and find that it is positive at a 1 pct. confidence level.

The panel estimates in this section suggest that there is a substantial state-dependency in the elasticities of mortgage debt with respect to both house prices and personal incomes. House price and income growth do not by themselves cause mortgage loan origination to increase. Only if they occur simultaneously will homeowners take on additional debt. In the following, I will rationalize this state-dependency 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:

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

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

where $\chi \equiv \frac{1-\eta}{1-\beta\eta}$ and $\chi' \equiv \frac{1-\eta}{1-\beta'\eta}$,³ 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.

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

$$\begin{aligned} c_t + q_t(h_t - h_{t-1}) + R_{t-1}b_{t-1} + \frac{k_t}{s_{AK,t}} + \frac{\iota}{2 \cdot s_{AK,t}} \left[\frac{k_t}{k_{t-1}} - 1 \right]^2 k_{t-1} \\ = w_t l_t + b_t + \left(R_{K,t} z_t + \frac{1 - \delta_K}{s_{AK,t}} \right) k_{t-1}. \end{aligned} \quad (4)$$

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. $\iota \in \mathbb{R}_+$ measures capital adjustment costs.

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

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

³The scaling factors ensure that the marginal utilities of consumption are $\frac{1}{c}$ and $\frac{1}{c'}$ in steady-state.

where b'_t is borrowing.

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

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

$$b'_t \leq (1 - \rho)b'_{t-1} + \rho\xi_{DTI} s_{C,t} s_{DTI,t} \mathbb{E}_t \left\{ \frac{w'_{t+1} n'_t}{\sigma + R_t - 1} \right\}, \quad (7)$$

where $s_{C,t}$ is a common credit shock that shifts the credit limits imposed by both constraints, $s_{LTV,t}$ is a macroprudential loan-to-value limit stabilizer, and $s_{DTI,t}$ is a macroprudential debt-service-to-income limit stabilizer. $\rho \in [0, 1]$ measures inertia in borrowing limits and debt accumulation, following [Guerrieri and Iacoviello \(2017\)](#). $\xi_{LTV} \in [0, 1]$ measures the steady-state loan-to-value limit on newly issued debt, $\xi_{DTI} \in [0, 1]$ measures the steady-state debt-service-to-income limit on newly issued debt, and σ measures the amortization rate on outstanding debt. The macroprudential stabilizers ($s_{LTV,t}$ and $s_{DTI,t}$) are only active in Section 8. In Sections 5-7, $s_{LTV,t} = s_{DTI,t} = 1$ applies. The constraints require that homeowners fulfill the following collateral and debt service requirements on newly issued debt in order to qualify for a mortgage loan:

$$\mathbb{E}_t \left\{ \frac{b'_t}{q_{t+1} h'_t} \right\} \leq \xi_{LTV} s_{C,t} s_{LTV,t} \quad \text{and} \quad \mathbb{E}_t \left\{ \frac{\sigma b'_t + (R_t - 1)b'_t}{w'_{t+1} n'_t} \right\} \leq \xi_{DTI} s_{C,t} s_{DTI,t}$$

The assumption $\beta > \beta'$ implies that (6) and (7) always hold with equality in (but not necessarily around) the steady-state.

4.1.1 Derivation of the Debt-Service-to-Income Constraint

The loan-to-value constraint can be derived as the solution to a debt enforcement problem, as shown by [Kiyotaki and Moore \(1997\)](#). I will now show that the debt-service-to-income constraint can be derived separately as an incentive compatibility constraint on the patient household, and that it is a generalization of the natural borrowing limit in [Aiyagari \(1994\)](#).⁴

The impatient household faces the choice of whether or not to default in period $t+1$ on the borrowing issued to it in period t . Suppose that, if the impatient household defaults, the patient household obtains the right to repayment through a perpetual income stream, commencing at period $t+1$. The payments in the income stream are based on the impatient

⁴The derivation is separate from the loan-to-value constraint in the sense that the impatient household does not internalize loan-to-value constraint when also imposing the debt-service-to-income constraint.

household's labor income ($w'_{t+1}n'_t$), and decrease by the amortization rate (σ) reflecting a gradual repayment of the loan. The net present value of the perpetual income stream is from a period t perspective consequently:

$$P_t = \frac{w'_{t+1}n'_t}{1+r_t} + (1-\sigma)\frac{w'_{t+1}n'_t}{(1+r_t)^2} + (1-\sigma)^2\frac{w'_{t+1}n'_t}{(1+r_t)^3} + \dots,$$

where r_t is the net real interest rate. Since the income stream is a converging infinite geometric series ($\frac{1-\sigma}{1+r_t} < 1$ applies), its net present value can be expressed as:

$$P_t = \frac{w'_{t+1}n'_t}{\sigma + r_t}$$

Suppose next that it is uncertain whether or not the patient household will receive the income stream that it is entitled to in the case of default. With probability ξ_{DTI} , the household will receive the full stream, and with complementary probability $1 - \xi_{DTI}$, the household will not receive anything. The debt-service-to-income constraint now arises as an incentive compatibility constraint in period t on the patient household. Incentive compatibility requires that the value of the loan about to be lend to the impatient household is not greater than the expected income stream in the event of default:

$$b'_t \leq \xi_{DTI} \mathbb{E}_t \left\{ \frac{w'_{t+1}n'_t}{\sigma + R_t - 1} \right\} + (1 - \xi_{DTI}) \cdot 0,$$

since $r_t \equiv R_t - 1$. This constraint is a generalization of the natural borrowing limit in [Aiyagari \(1994\)](#). In his seminal paper, he assumed that households may borrow up to the discounted sum of all their future labor incomes, giving him the following constraint: $b'_t \leq \frac{wn_{min}}{r}$. [Aiyagari \(1994\)](#) thus, in the phrasing of the present paper, assumed that stream payments are certain ($\xi_{DTI} = 1$) and not amortized ($\sigma = 0$).

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,

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

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:

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

$$h_t + h_t' = H \quad (11)$$

$$b_t = -b_t' \quad (12)$$

$$n_t = l_t \quad (13)$$

$$n_t' = l_t' \quad (14)$$

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 \(2017\)](#) in order 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 debt-service-to-income constraint binds or not. When a constraint binds, the households do not expect it to become unbinding. Once a constraint becomes unbinding, however, the households will expect it to become binding again. The households will consequently base their decisions on the expected duration of the current regime. This duration expectation, in turn, depends on the state vector. As a result, the solution to the model will be non-linear in two dimensions. First, it will be non-linear *between* the regimes, depending on which regime that applies. Second, it will be non-linear *within* each regime, depending on the duration expectation of the regime.

A complicating feature of the model is the regime where both constraints bind. In [Guerrieri and Iacoviello \(2017\)](#), the two 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 constraints only restrict one variable (borrowing). Consequently, in the regime where both constraints bind, the borrowing limits imposed by the loan-to-value and debt-service-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.⁵ As a consequence, the calibrated loan-to-value and debt-service-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. Instead, as will be evident in Subsection 5.3, a very plausible calibration can be reached.

Borrowing is an observed variable when the model is estimated. It is the common credit shock which ensures that the theoretical borrowing variable matches its empirical

⁵I 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.

measure. When a (or both) borrowing constraint is binding, the common credit shock has a direct effect on borrowing through the binding constraint. When both constraints are unbinding, the common credit shock has an effect on borrowing through the first order condition of the impatient household with respect to borrowing:

$$u'_{c,t} + \beta' \mathbb{E}_t \{ (1 - \rho)(\lambda_{LTV,t+1} + \lambda_{DTI,t+1}) \} = \beta' \mathbb{E}_t \{ u'_{c,t+1} R_t \} + \lambda_{LTV,t} + \lambda_{DTI,t}. \quad (15)$$

In order to understand this, consider the following rewriting of the first order condition through recursive substitution as:

$$\begin{aligned} u'_{c,t} = & \beta'^v \mathbb{E}_t \left\{ u'_{c,t+v} \prod_{j=0}^{v-1} R_{t+j} \right\} + \sum_{i=1}^{v-1} \beta'^i \mathbb{E}_t \left\{ (\lambda_{LTV,t+i} + \lambda_{DTI,t+i}) \prod_{j=0}^{i-1} R_{t+j} \right\} \\ & - \sum_{i=1}^{v-1} \beta'^{i+1} \mathbb{E}_t \left\{ (1 - \rho)(\lambda_{LTV,t+i+1} + \lambda_{DTI,t+i+1}) \prod_{j=0}^{i-1} R_{t+j} \right\} \\ & + \lambda_{LTV,t} + \lambda_{DTI,t} - \beta' \mathbb{E}_t \{ (1 - \rho)(\lambda_{LTV,t+1} + \lambda_{DTI,t+1}) \}, \end{aligned}$$

for $v \in \{v \in \mathbb{Z} | v > 1\}$. According to this expression, the current levels of consumption and (via the budget constraint) borrowing are pinned down by the current and expected future Lagrange multipliers for $v \rightarrow \infty$. The current multipliers are zero ($\lambda_{LTV,t} = \lambda_{DTI,t} = 0$) when both constraints are unbinding. The expected future multipliers will, however, be positive at some forecast horizon due to the stochastic innovations having a zero mean. The current common credit shock can consequently – through its persistent effects on future credit limits – determine the expected future Lagrange multipliers and consequently consumption and borrowing in the current period.

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 time-series: 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 detrended by a one-sided HP filter (with a smoothing parameter of 100,000) in order to remove the low-frequency components of the series, following [Guerrieri and Iacoviello \(2017\)](#). Detailed names of the series and data sources are reported in the Online Appendix.

Table 3: 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	0.10	Normalization ^b
Steady-state loan-to-value limit	ξ_{LTV}	0.774	See text
Steady-state debt-service-to-income limit	ξ_{DTI}	0.364	See text
Amortization rate on outstanding debt	σ	1/104.2	Average original loan term ^c
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 average 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 \(2017\)](#).

^c The model is calibrated to match the average loan term (104.2 quarters) on originated loans weighted by the original loan balance during 2000-2016 in Fannie Mae's Single Family Loan Acquisition Data.

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 3 reports the calibrated parameters and information on their calibration. The calibrated steady-state debt-service-to-income limit ($\xi_{DTI} \approx 0.36$) implies that debt services relative to labor incomes *before taxes* may maximally be 28 pct. This number is identical to the typical front-end (i.e., excluding recurring debt) debt-service-to-income limit in the U.S. For instance, the U.S. Consumer Financial Protection Bureau writes in its 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 \(2015, p. 5\)](#)). Since there are no taxes in the model, the labor incomes that the households receive should be treated like after tax incomes. The average labor tax rate was 23.1 pct. in the postwar U.S., according to [Jones \(2002\)](#). The debt-service-to-income limit accordingly becomes $\frac{0.28}{1-0.231} \approx 0.36$ for incomes *after taxes*.⁶

The calibrated steady-state loan-to-value limit ($\xi_{LTV} \approx 0.77$) ensures that the borrowing limits imposed by the loan-to-value and debt-service-to-income constraints are

⁶A sanity check of this calibration is to compare the implied steady-state annual loan-to-income limit, which is $\frac{b}{4 \cdot w' n'} \approx 6.2$, to the loan-to-income limit that the Prudential Regulation Authority of the Bank of England has implemented for the U.K. Under this regulation, mortgage lenders may maximally extent 15 pct. of all regulated mortgage loans to households whose loan-to-income ratios are above 4.5 *before income taxes* (see [Bank of England \(2014a,b\)](#)). For mortgage lending outside the most risky 15 pct., the loan-to-income limit accordingly becomes $\frac{4.5}{1-0.231} \approx 5.9$ times their annual income *after taxes*.

Table 4: PRIOR AND POSTERIOR DISTRIBUTIONS

Prior Distribution				Posterior Mode		
	Type	Mean	SD	Value	5 pct.	95 pct.
Structural Parameters						
α	B	0.66	0.15	0.6209	0.6137	0.6281
β'	B	0.984	0.006	0.9943	0.9942	0.9944
η	B	0.50	0.15	0.5883	0.5740	0.6026
φ	N	4.00	0.50	5.9359	5.7090	6.1628
ρ	B	0.25	0.15	0.1769	0.1660	0.1878
ι	N	10.0	2.00	2.8883	2.6496	3.1270
Deterministic Structure of Shock Processes						
IP	B	0.50	0.20	0.7311	0.7182	0.7440
HP	B	0.50	0.20	0.9889	0.9876	0.9902
CC	B	0.50	0.20	0.9489	0.9437	0.9541
AY	B	0.50	0.20	0.9320	0.9257	0.9383
LP	B	0.50	0.20	0.9991	0.9987	0.9995
Standard Deviations of Innovations						
IP	IG	0.01	0.10	0.0373	0.0316	0.0430
HP	IG	0.01	0.10	0.0412	0.0353	0.0471
CC	IG	0.01	0.10	0.0180	0.0138	0.0222
AY	IG	0.01	0.10	0.0514	0.0450	0.0578
LP	IG	0.01	0.10	0.0113	0.0077	0.0149

Distributions: N: Normal. B: Beta. IG: Inverse-Gamma.

Shocks: IP: Intertemporal preference. HP: Housing preference. CC: Common credit. AY:

Labor-augmenting technology. LP: Labor preference.

Note: The prior distribution of β' is truncated with an upper bound at 0.9949.

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., [Liu et al. \(2013\)](#) and [Liu et al. \(2016\)](#) use 0.75, [Justiniano et al. \(2017\)](#) use 0.80, and [Iacoviello and Neri \(2010\)](#), [Lambertini et al. \(2013\)](#), and [Justiniano et al. \(2015\)](#) use 0.85).

Table 4 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 4 reports the estimated posterior distribution. The estimates of the wage share parameter ($\alpha = 0.62$), the impatient time discount factor ($\beta' = 0.9943$), and debt inertia ($\rho = 0.18$) 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 parameters are important in determining when the borrowing constraints bind. In addition to this, the confidence bounds surrounding the three estimates are considerably smaller than in [Guerrieri and Iacoviello \(2017\)](#). One explanation for this is that the mortgage debt time-series, which is intimately related to these parameters, is included in my estimation sample but not in [Guerrieri and Iacoviello's \(2017\)](#) sample. Another explanation is that, while there is only one fewer variable in my estimation sample than in [Guerrieri and Iacoviello's \(2017\)](#) sample, there are five fewer estimated structural parameters, hence making my point estimates more precise.

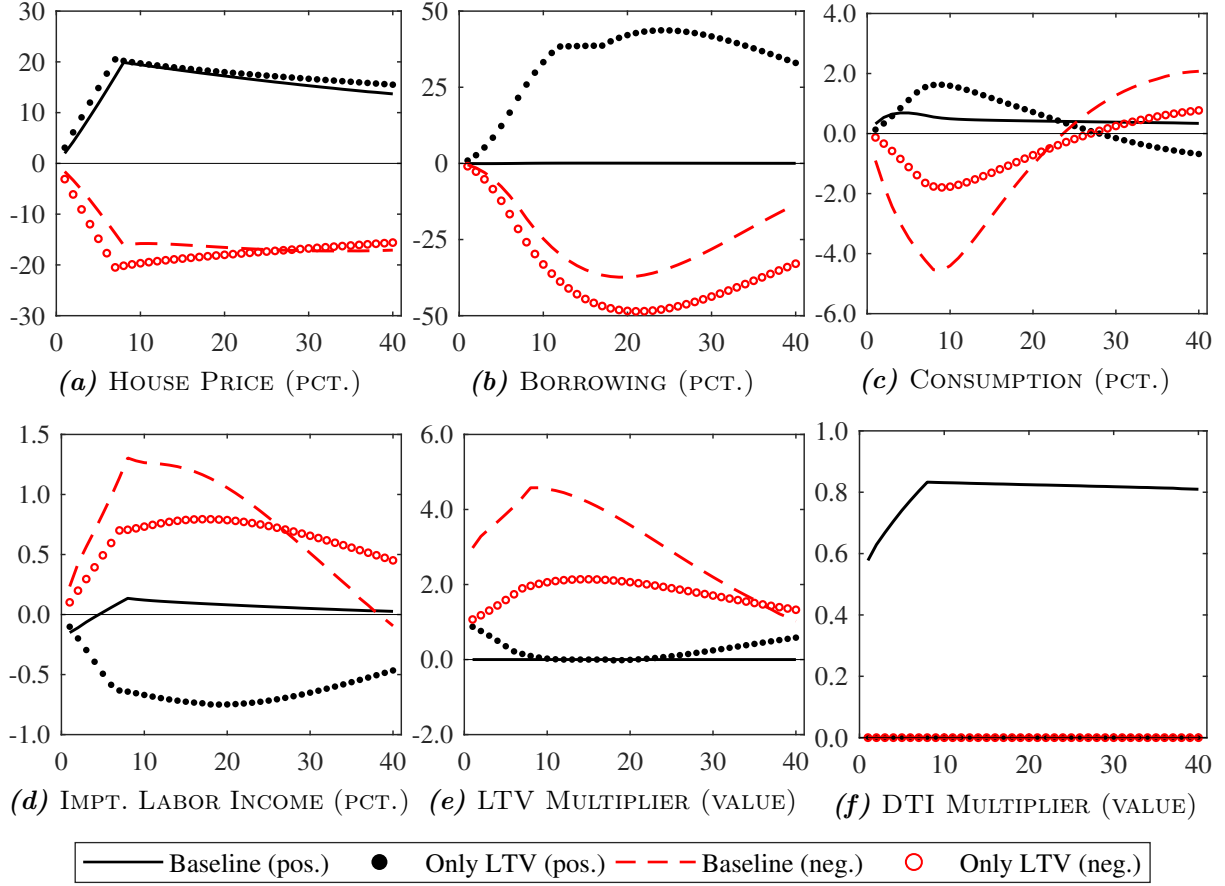
6 Asymmetric and State-Dependent Dynamics

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 shocks to the baseline model and to a version of the model with only an occasionally binding loan-to-value constraint. The series of shocks occur in periods 1-8, and shift the house price by 20 pct. in the baseline model in either direction, following an experiment in [Guerrieri and Iacoviello \(2017\)](#).

The positive housing preference shocks cause the house price to increase. In the model with only a loan-to-value constraint, 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. Once this happens, the loan-to-value constraint is only operative in expectation, as discussed in Subsection 5.1. The effects of this expectation can be observed in Figure 1b. The economy is initially far away from the point when the constraint will bind again. Borrowing consequently stops increasing and remains constant for some time since the borrowing demand of the impatient household is saturated. As the point approaches when the constraint will bind again, the household increases its borrowing above the unconstrained level in order to buffer itself from

Figure 1: ASYMMETRIC RESPONSES TO SERIES OF HOUSING PREFERENCE SHOCKS



Note: Both models are calibrated to the posterior mode of the baseline model. The series of equally-sized positive and negative shocks occur in periods 1-8, and shift the house price by 20 pct. in either direction by period 8 in the baseline model. Vertical axes measure deviations from the steady-state (Figures 1a-1d) or levels (Figures 1e-1f).

the impending constraint.⁷ The reactions of the model to the positive housing preference shocks closely resembles the reactions in Guerrieri and Iacoviello (2017) both in terms of qualitative and quantitative effects.

In the baseline model with both constraints, borrowing remains roughly constant even though the house price has increased. As a result, the response of borrowing is indistinguishable from the horizontal axis in Figure 1b. This reflects that labor incomes are roughly unchanged so the debt-service-to-income constraint is still binding. The debt-service-to-income multiplier thus increases since it is now the only restricting constraint. The response of consumption is consequently curbed. This difference depending on whether a debt-service-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

⁷This behavior is not identical to precautionary behavior. With precautionary behavior, agents will internalize the uncertainty relating to future shocks. In the present model, by contrast, the impatient household simply has the unbiased expectation that all future shocks are zero. Unbinding constraints are consequently expected to become binding, causing households to act accordingly.

preference shocks. The muted response of borrowing in the face of lone house price increases is in line with the empirical evidence in Section 3. There, house price growth was in itself not sufficient to make mortgage loan origination to households increase. Instead, loan origination would only increase if both house prices and personal incomes grow.

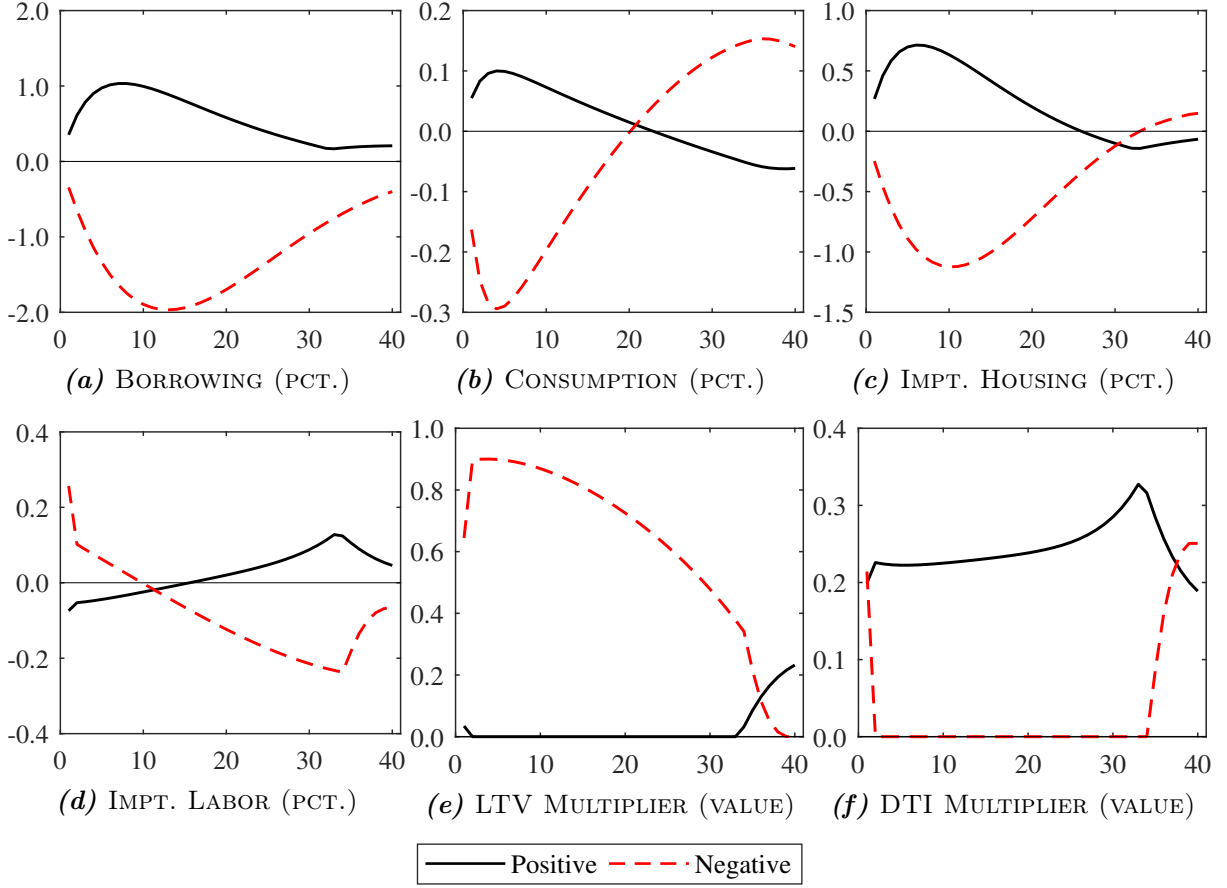
The negative housing preference shocks cause the house price to fall. This highlights an important asymmetry in the baseline model. While a house price increase is not able to increase borrowing due to the debt-service-to-income constraint, a house prices fall is able to reduce borrowing. This reflects that the house price fall causes the loan-to-value constraint to tighten, consequently forcing 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 borrowing here may move in tandem with house prices. In these cases, the only difference compared to a model with an always binding loan-to-value constraint is that the effect of the house price increase is curbed once the loan-to-value constraint unbinds. While this unbinding could be an important source of business cycle asymmetry, the responses in Figures 1b-1c suggest that it may not be the case. First, even though the loan-to-value constraint unbinds for an appreciable period of time, the response of borrowing is not dramatically skewed. Second, for smaller shocks where no unbinding occurs, the model with only the loan-to-value constraint will be completely symmetric.

6.2 Responses to Credit Shocks

This subsection illustrates how the response of borrowing and consumption to credit shocks is both highly asymmetric and state-dependent due to the two borrowing constraints. Figure 2 plots the effects of two equally-sized, single-period positive and negative common credit shocks to the baseline model. A positive shock causes borrowing and consumption to increase, and a negative shock causes borrowing and consumption to fall. The size of the responses are, however, highly asymmetric. Thus, the response of borrowing to a negative shock is twice as large as the response to a positive shock, measured at the peak of the impulse response. Likewise, the response of consumption to a negative shock is three times as large as the response to a positive shock.

The degree of asymmetry in Figure 2 is comparable to the asymmetric response to bond premium shocks in [Barnichon et al. \(2017\)](#). They find that a positive one-standard deviation shock reduces consumption significantly for five years (0.4 pct.), while a negative one-standard deviation shock only has a small (0.1 pct.) insignificant expansionary effect.

Figure 2: ASYMMETRIC IMPULSE RESPONSES OF COMMON CREDIT SHOCKS

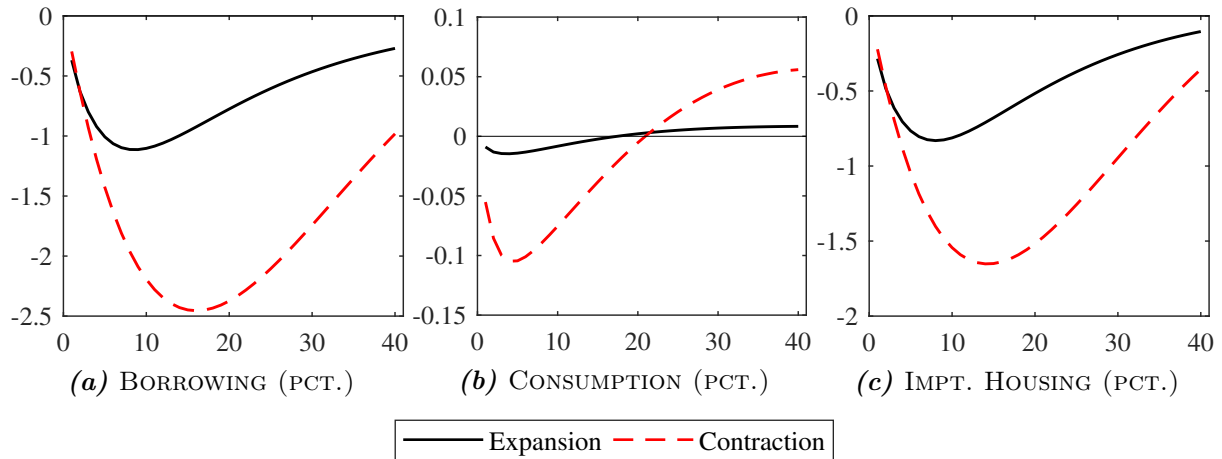


Note: The model is calibrated to the posterior mode. Vertical axes measure deviations from the steady-state (Figures 2a-2d) or levels (Figures 2e-2f), following positive and negative unit standard deviation shocks.

Thus, the effect of a contractionary shock is roughly four times greater than the effect of an expansionary shock, compared to three times greater in the model.

The model suggests that the asymmetric responses in [Barnichon et al. \(2017\)](#) are caused by differences across the sign of the shocks in labor supply, housing demand, and eventually the constraint that binds. Following the positive shock, the impatient household increases its housing stock and reduces its labor supply because its marginal utility of consumption is lower. This causes the loan-to-value constraint to unbind and the debt-service-to-income constraint to bind. Importantly, however, because the debt-service-to-income constraint binds, the reduction in labor supply dampens the increase in credit limits, consequently muting the increase in debt and consumption. Following the negative shock, the impatient household reduces its housing stock and increases its labor supply because its marginal utility of consumption is higher. This causes the debt-service-to-income constraint to unbind and the loan-to-value constraint to bind. Importantly, now, because the loan-to-value constraint binds, the reduction in the housing stock amplifies

Figure 3: STATE-DEPENDENT IMPULSE RESPONSES OF COMMON CREDIT SHOCKS



Note: The model is calibrated to the posterior mode. The impulse responses are computed in the following way. First, the model is simulated with expansionary and contractionary impulse matrices, based on unit standard deviations to the four non-credit shocks in period 1. Second, positive and negative unit standard deviation credit shocks are added to the expansionary and contractionary impulse matrices also in period 1, and the model is simulated again. Third, differences between the simulations with and without the credit shocks are computed. Vertical axes hence measure deviations that are caused by the credit shock.

drop in credit limits, consequently amplifying the drop in debt and consumption.

Figure 3 plots the effects of two equally-sized negative common credit shocks when the economy is in an expansion and a contraction. The economy contracts in both cases, but the sizes of the contractions are highly state-dependent. Borrowing drops by two-and-a-half times more in contractions than in expansions, measured at the peak of the impulse response. Likewise, consumption drops by about six times more in contractions than in expansions. This degree of state-dependency is again comparable to the state-dependent response to bond premium shocks in [Barnichon et al. \(2017\)](#). They find that the effects of a positive one-standard deviation shock is four times larger in contractions (1.1 pct. drop in real activity) than in expansions (0.3 pct. drop in real activity).

The model suggests that the state-dependent responses in [Barnichon et al. \(2017\)](#) are caused by differences across the business cycle in the constraint that binds. In Figure 3, the loan-to-value constraint binds in the contractionary state, and the debt-service-to-income constraint binds in the expansionary state since the house price is more volatile than the labor income. In both states, a negative credit shock reduces goods consumption, increases the marginal utility of consumption, and thus leads the impatient household to reduce its housing stock. However, the implications of this lower housing demand are highly dependent on the constraint that binds. In contractions when the loan-to-value constraint binds, the housing reduction will amplify the deleveraging. In expansions when the debt-service-to-income constraint binds, by contrary, the response of the housing stock

will not have any effects since it is wage income – not the housings stock – that restricts borrowing.

7 The Historical Development in Credit Constraints

7.1 Loan-to-Value vs. Debt-Service-to-Income Constraints

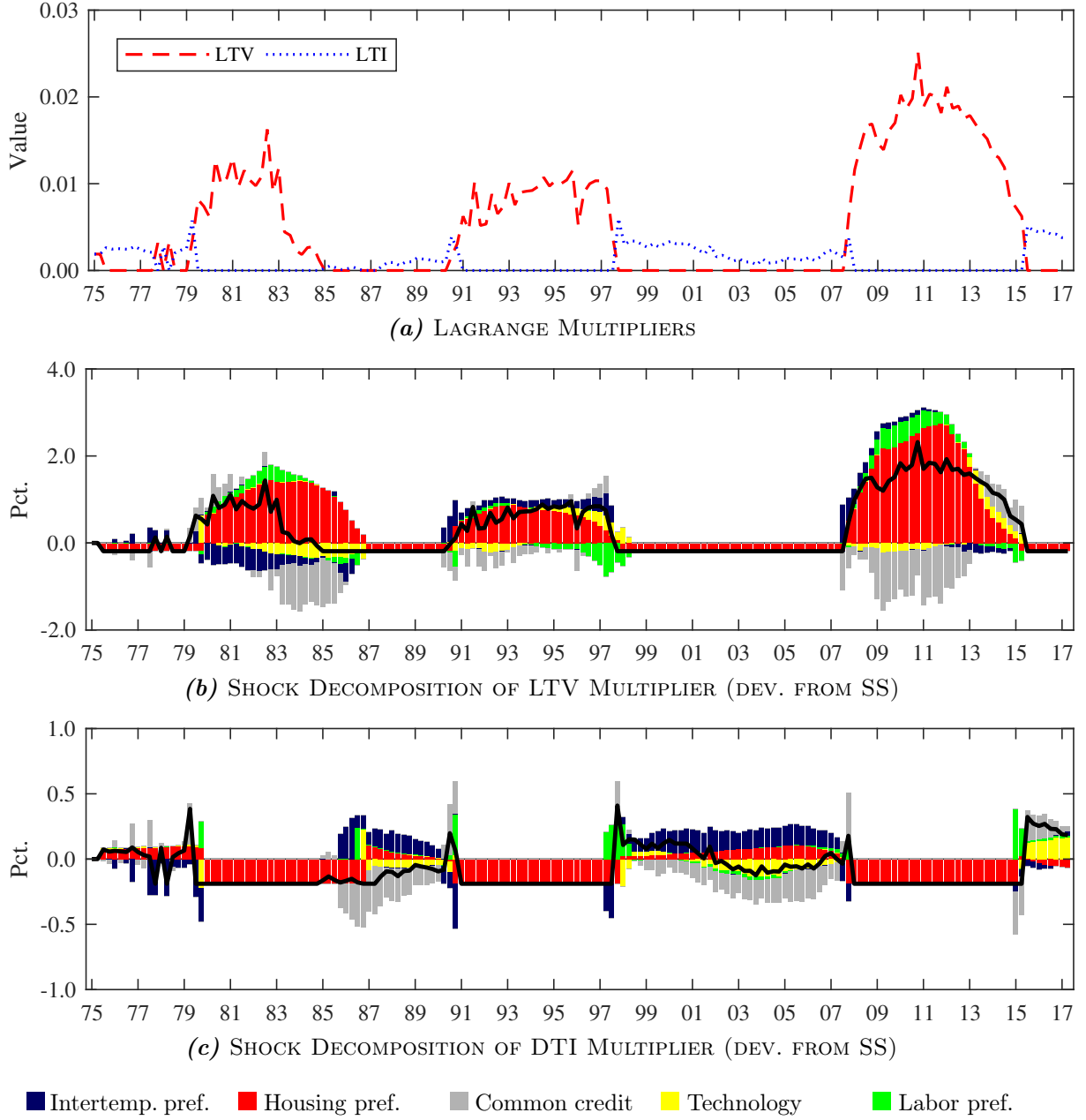
This subsection gives a historical account of how macroeconomic conditions have determined when the credit constraints were binding. Figure 4a plots the smoothed posterior Lagrange multipliers on the two borrowing constraints. The loan-to-value constraint binds when $\lambda_{LTV} > 0$, and the debt-service-to-income constraint binds when $\lambda_{DTI} > 0$. Figure 4b-4c plot the historical shock decomposition of the Lagrange multipliers in deviations from steady-state.⁸

At least one Lagrange multiplier is always positive through most of 1975-2017. Net-borrowing households have thus been credit constrained through most of the considered period. In the end-1970s, the debt-service-to-income constraint was binding most of the time, reflecting that the oil crises and resulting stagflation had a larger contractionary effect on labor incomes than on the housing market. The loan-to-value constraint became binding during the two recessions of the early-1980s. Here, house prices fell due to a deteriorated employment situation (negative labor preference shocks) contracting housing demand and the tight monetary policy of Paul Volcker affecting the housing market disproportionately (negative housing preference shocks). From 1983, three factors contributed to keeping the debt-service-to-income constraint nonbinding and gradually loosening the loan-to-value constraint. Firstly, the mid-1980s boom improved the employment and housing market conditions (incumbent adverse labor and housing preference shocks disappearing) and caused real wages to grow (positive technology shocks). Secondly, the Great Moderation caused economic optimism (negative intertemporal preference shocks). Thirdly, financial deregulation raised credit limits (positive common credit shocks). As a result, both constraints ended up being nonbinding in 1985Q1-1987Q2. The U.S. thus entered the only period in the sample where the issuance of mortgage loans was not restricted by credit requirements facing borrowers, but by the loan demand of borrowers.

The debt-service-to-income constraint started to bind again from 1987 because of tighter credit limits and an increased uncertainty about the future (positive intertemporal

⁸The steady-state values of the Lagrange multipliers are positive and identical since both constraint are binding in steady-state.

Figure 4: SMOOTHED POSTERIOR VARIABLES



Note: The shocks are identified and the decomposition is performed at 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) housing preference shock, (2) labor-augmenting technology shock, (3) labor preference shock, (4) intertemporal preference shock, and (5) common credit shock.

preference shocks).⁹ The loan-to-value constraint became binding again in the early-1990s recession as house prices started to fall, and remained binding until 1998 when house prices started growing rapidly. In the following mid-2000s economic boom, the debt-service-to-income constraint would remain binding, albeit gradually relaxing due to real wage growth (positive technology shocks) and higher credit limits (positive common credit shocks).

⁹The first optimism and then pessimism are reflected in the University of Michigan Consumer Sentiment Index, which grew by 43.4 pct. from 1982 to 1984 and fell by 7.1 pct. from 1984 to 1987.

This lasted until the onset of the Great Recession when the house price bust caused the loan-to-value constraint to bind again. Recently, from around 2015, a combination of growing house prices and meager wage growth (negative technology shocks) have caused the debt-service-to-income constraint to bind again.

The shock decomposition confirms the result in [Guerrieri and Iacoviello \(2017\)](#) that the loan-to-value constraint became slack during the housing boom of 1998-2007. However, the decomposition also shows that this unbinding did not imply that homeowners were free to borrow, contrary to the finding of [Guerrieri and Iacoviello \(2017\)](#). Instead, they remained credit constrained because of debt service requirements.

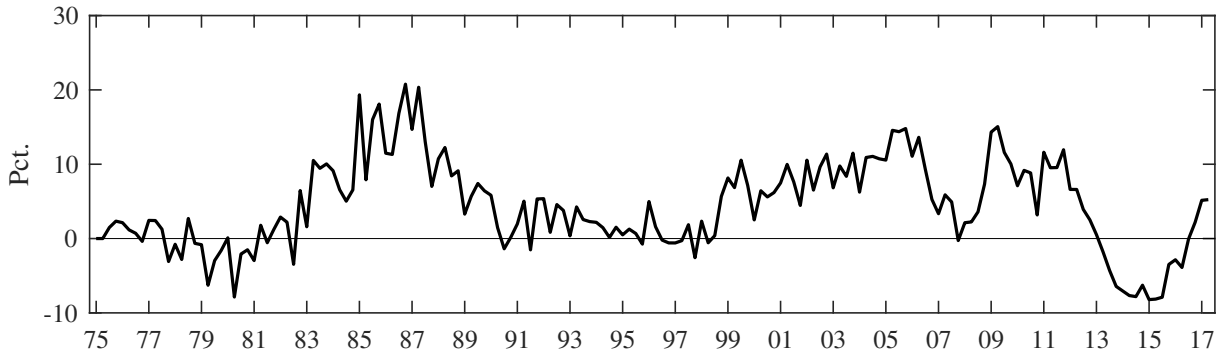
7.2 The Role of Credit Shocks

This subsection focuses on how historical events have shifted the credit limits imposed by the two credit constraints exogenously. Figure 5 plots the estimated values of the common credit shock ($s_{C,t}$). The shock has shifted the credit limits decidedly several times during the past four decades. The borrowing constraints are the only wedges between the credit supply of the patient household and the credit demand of the impatient household. The common credit shock consequently captures exogenous shocks to both credit supply and credit demand.

Credit limits were first eased by approx. 20 pct. of their steady-state values in the start/mid-1980s. This relaxation was the likely cause of the first major deregulation of the financial sector since the Great Depression. Notably, the Depository Institutions Deregulation and Monetary Control Act of 1980 and the Garn-St. Germain Depository Institutions Act of 1982 deregulated and increased competition between banks and thrift institutions. As a consequence, greater access to alternative borrowing instruments (including adjustable-rate loans) reduced effective down payments and allowed households to delay repayment through cash-out mortgage refinancing, according to [Campbell and Hercowitz \(2009\)](#).

During the Black Monday Stock Market Crash of 1987 and the Savings and Loan Crisis, credit limits were subsequently tightened and eventually returned to steady-state. Importantly, out of 3,234 thrift institutions in 1986, 1,043 institutions were as closed due to losses on mortgage loans before the end of 1995, according to [Curry and Shibut \(2000\)](#). There is a punctual time-wise match between these failures and the negative common credit innovations. Out of \$ 519 billion in assets of thrift institutions failing, \$ 97 billion failed in 1988, \$ 135 billion failed in 1989, \$ 130 billion failed in 1990, and \$ 79 billion

Figure 5: SMOOTHED COMMON CREDIT SHOCK



Note: The historical common credit shocks are identified at the posterior mode.

failed in 1991, also according to [Curry and Shibut \(2000\)](#).

Credit limits were again eased in 1998-2005; this time by approx. 15 pct. above their steady-state levels. This observation fits with the widely recognized understanding that the risk management practices of banks were eased in those years due to an excess supply of mortgage loans, which the banks wished to pass on to homeowners. [Justiniano et al. \(2017\)](#) point to various sources of this excess supply. They mention the pooling and tranching of mortgage bonds into mortgage-backed securities, which created assets that were rated safe out of pools of risky mortgage bonds.¹⁰ They also mention the global savings influx into the U.S. mortgage market following the late-1990s Asian financial crisis. The debt-service-to-income constraint was binding in 1998-2007, according to [Figure 4a](#). The buildup in mortgage debt prior to the recession was thus caused by looser debt-service-to-income limits rather than looser loan-to-value limits. This is consistent with the result in [Justiniano et al. \(2017\)](#) that looser loan-to-value limits cannot explain the surge in mortgage debt. [Justiniano et al. \(2017\)](#) also argue that it was an increase in the credit supply that caused the surge in mortgage debt. The results in the present paper do not *per se* reject this hypothesis. Rather, the present results suggest that – if an increase in credit supply occurred – then it translated into a relaxation of debt-service-to-income limits.

Credit limits were tightened already in mid-2006, reflecting the slowdown of credit markets prior to the eruption of the Subprime Crisis of 2007-2008 (e.g., with the bankruptcy of *Merit Financial, Inc.* in May 2006). The tightening, however, turned out to be short-lived; credit limits were thus rising again already in 2009. This increase coincides with

¹⁰[Justiniano et al. \(2017\)](#) argue that the securitization (i) channeled savings aimed at fixed-income securities with high ratings into mortgage loans, (ii) freed up intermediary capital which had previously been kept due to leverage requirements, and (iii) allowed banks to combine liquid deposits and illiquid loans into liquid funds.

the introduction of the Home Affordable Refinance Program and the Home Affordable Modification Program in March 2009. These programs lowered the debt service payments for existing homeowners who had high loan-to-value ratios or were in delinquency via exemption from mortgage insurance, interest rate and principal reductions, forbearance, and term extension.¹¹ The increase also coincides with the sharp reduction in mortgage rates in 2008Q4-2009Q2, which the loan-to-value constraint would likely capture as credit shocks.

The validity of the credit shock estimates in Figure 5 is corroborated by Prieto et al. (2016), using a different approach. They find that credit spread shocks contributed negatively to GDP growth in 2007-2008 and positively in 2009-2012, and attribute these latter contributions to the unconventional monetary policy programs launched then. Prieto et al. (2016) also find traces of the start/mid-1980s' deregulation, the Savings and Loan Crisis, and the start-2000s' lax risk management.

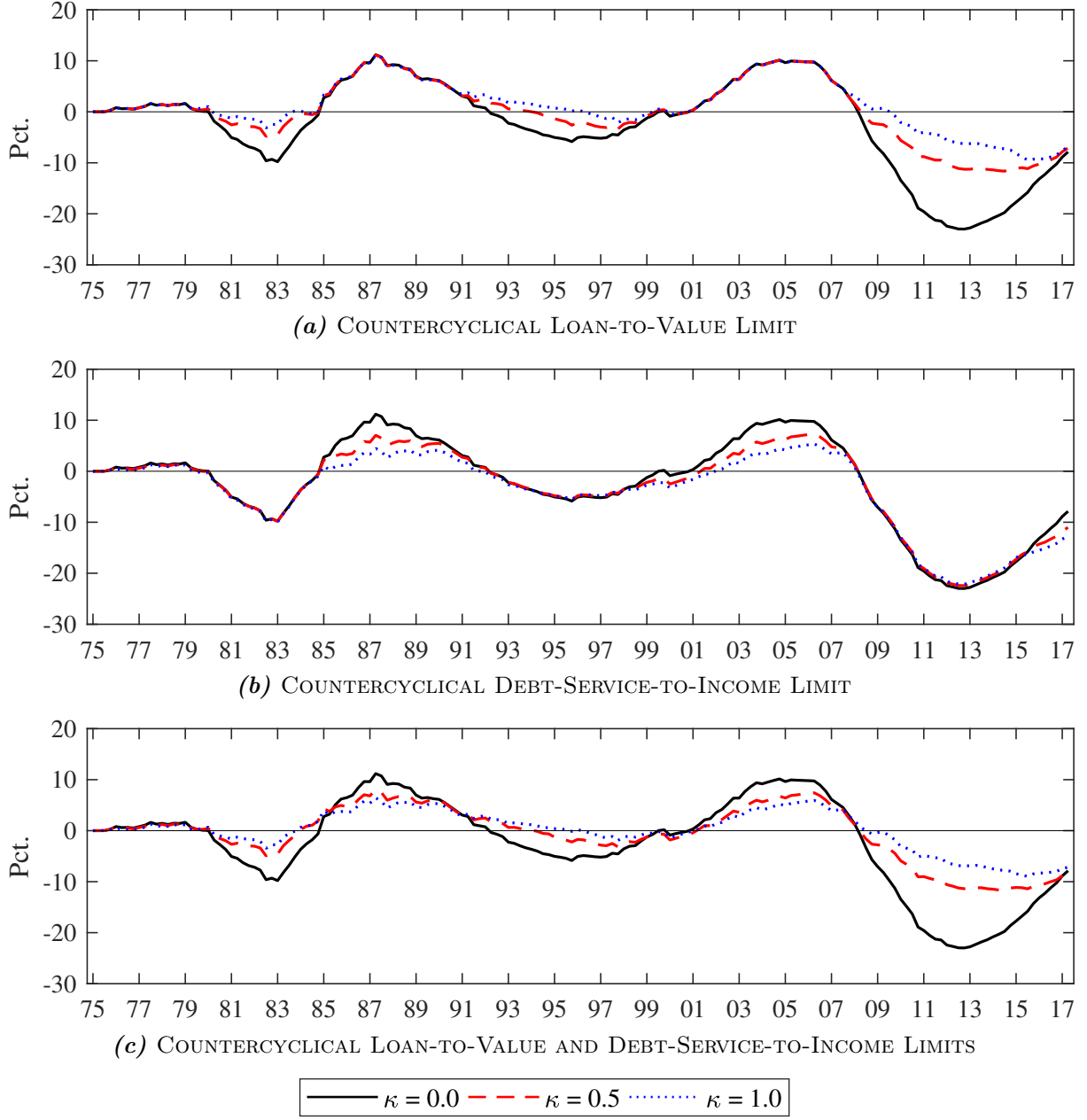
8 Macprudential Policy Implications

This section examines the implications of countercyclical loan-to-value and debt-service-to-income limits in the face of occasionally binding loan-to-value and debt-service-to-income constraints. Figure 6 plots the reaction of borrowing 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 debt-service-to-income limit, and countercyclical loan-to-value and debt-service-to-income limits. The corresponding reactions of consumption and house prices are reported in the Online Appendix. Table 5 reports the standard deviations of borrowing, consumption, and house prices under the four macroprudential regimes.

The countercyclical loan-to-value and debt-service-to-income limits are introduced as

¹¹Recent studies find sizable impacts of these programs. Agarwal et al. (2017) find that the Home Affordable Modification Program resulted in a 25 pct. reduction in loan payments on average for the one-third of eligible homeowners who participated. Agarwal et al. (2015) find that the Home Affordable Refinance Program resulted in a 20 pct. reduction in loan payments on average for more than 3 million homeowners.

Figure 6: BORROWING UNDER ALTERNATIVE MACROPRUDENTIAL REGIMES



Note: The model is calibrated to the posterior mode, and the historical shocks are identified at the posterior mode. Vertical axes measure deviations from the steady-state.

systematic responses to the quarterly year-on-year growth rate of borrowing:

$$\log s_{LTV,t} = 0.75 \cdot \log s_{LTV,t-1} - \kappa_{LTV}(\log b'_t - \log b'_{t-4}) \quad (16)$$

$$\log s_{DTI,t} = 0.75 \cdot \log s_{DTI,t-1} - \kappa_{DTI}(\log b'_t - \log b'_{t-4}), \quad (17)$$

where $\kappa_{LTV} \geq 0$ and $\kappa_{DTI} \geq 0$ measure the degree of countercyclical macroprudential policy. (16)-(17) enter into (6)-(7) so that $s_{LTV,t} = s_{DTI,t} = 1$ no-longer holds.

Table 5: STANDARD DEVIATIONS UNDER ALTERNATIVE MACROPRUDENTIAL REGIMES

Regime Type	None	LTV		DTI		Both	
Regime Strength	0.0	0.5	1.0	0.5	1.0	0.5	1.0
Borrowing	8.98	6.06	4.98	8.10	7.57	5.44	3.94
Consumption	2.53	2.41	2.35	2.51	2.50	2.40	2.34
House Price	9.13	9.08	9.07	9.13	9.14	9.09	9.10

Note: The model is calibrated to the posterior mode, and the historical shocks are identified at the posterior mode. Standard deviations are reported in percent.

A strong countercyclical loan-to-value policy ($\kappa_{LTV} = 1.0$) is able to reduce the standard deviations of borrowing and consumption by 45 pct. and 7 pct. relative to the historical baseline. It does so by mitigating the adverse effects of house price slumps on credit availability when the loan-to-value constraint is binding. This stabilization potential was particularly pronounced during and after the Great Recession when the house price drop forced homeowners to delever below the steady-state borrowing level. The flip-side of this result is that countercyclical loan-to-value policy cannot curb increases in borrowing during house price booms since the loan-to-value constraint is typically non-binding here. Macroprudential policymakers would thus not have been able to prevent the buildup in borrowing in 1998-2005 even if they had reduced the loan-to-value limit by 12 pct., which is the reduction implied by (16) under $\kappa_{LTV} = 1.0$.

A strong countercyclical debt-service-to-income policy ($\kappa_{DTI} = 1.0$) is able to reduce the standard deviations of borrowing and consumption by 16 pct. and 1 pct. relative to the historical baseline. Unlike the loan-to-value policy, this policy is very effective at curbing increases in borrowing during housing market booms since the debt-service-to-income constraint is typically binding here. Macroprudential policymakers could thus have avoided the buildup in borrowing in 1998-2005 through stricter debt-service-to-income requirements.

The lowest volatility in borrowing and consumption is reached by combining the loan-to-value and debt-service-to-income policies. This reduces the standard deviations of borrowing and consumption by 56 pct. and 8 pct. relative to the historical baseline. In this case, the macroprudential policy effectively changes over the business cycle with a debt-service-to-income policy in expansions and a loan-to-value policy in contractions. The potential benefits of such policy are not well-documented in economics. The existing literature mostly focuses on stabilization solely through countercyclical loan-to-value limits.¹²

¹²The [Committee on the Global Financial System \(2010\)](#) and the [IMF \(2011\)](#) recommend to employ

The ineffectiveness of loan-to-value limits in expansions and debt-service-to-income limits in contractions emphasize the necessity of models with both constraints in order to determine the optimal timing and implementation of macroprudential policy.

9 Concluding Remarks

[TO BE DONE]

References

- Agarwal, S., G. Amromin, I. Ben-David, S. Chomsisengphet, T. Piskorski, and A. Seru (2017, June). Policy Intervention in Debt Renegotiation: Evidence from the Home Affordable Modification Program. *Journal of Political Economy* 125(3), 654–712.
- Agarwal, S., G. Amromin, S. Chomsisengphet, T. Landvoigt, T. Piskorski, A. Seru, and V. Yao (2015, August). Mortgage Refinancing, Consumer Spending, and Competition: Evidence from the Home Affordable Refinancing Program. NBER Working Papers, National Bureau of Economic Research, Inc.
- Aiyagari, S. R. (1994, August). Uninsured Idiosyncratic Risk and Aggregate Saving. *The Quarterly Journal of Economics* 109(3), 659–684.
- Bank of England (2014a, June). Financial Stability Report, June 2014. Number 35 in Financial Stability Report. Bank of England.
- Bank of England (2014b, October). Implementing the Financial Policy Committee’s recommendation on loan to income ratios in mortgage lending. Number 9 in Policy Statement. Bank of England.
- Barnichon, R., C. Matthes, and A. Ziegenbein (2017, July). Theory Ahead of Measurement? Assessing the Nonlinear Effects of Financial Market Disruptions. Technical report.

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.

- Bhutta, N. and B. J. Keys (2016, July). Interest Rates and Equity Extraction during the Housing Boom. *American Economic Review* 106(7), 1742–1774.
- Campbell, J. R. and Z. Hercowitz (2009, January). Welfare implications of the transition to high household debt. *Journal of Monetary Economics* 56(1), 1–16.
- Committee on the Global Financial System (2010, May). Macroprudential instruments and frameworks: a stocktaking of issues and experiences. Number 38 in CGFS Papers. Bank for International Settlements.
- Consumer Financial Protection Bureau (2015, August). Your home loan toolkit: A step-by-step guide. Consumer Financial Protection Bureau.
- Curry, T. and L. Shibut (2000). The Cost of the Savings and Loan Crisis: Truth and Consequences. *FDIC Banking Review* 13(2), 26–35.
- Davig, T. and C. Hakkio (2010). What Is the Effect of Financial Stress on Economic Activity. *Economic Review* (2), 35–62.
- Galí, J., F. Smets, and R. Wouters (2012). Unemployment in an Estimated New Keynesian Model. *NBER Macroeconomics Annual* 2011 26, 329–360.
- Gelain, P., K. J. Lansing, and C. Mendicino (2013, June). House Prices, Credit Growth, and Excess Volatility: Implications for Monetary and Macroprudential Policy. *International Journal of Central Banking* 9(2), 219–276.
- Guerrieri, L. and M. Iacoviello (2015, March). OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily. *Journal of Monetary Economics* 70(C), 22–38.
- Guerrieri, L. and M. Iacoviello (2017, October). Collateral constraints and macroeconomic asymmetries. *Journal of Monetary Economics* 90, 28–49.
- Hubrich, K. and R. J. Tetlow (2015, March). Financial stress and economic dynamics: The transmission of crises. *Journal of Monetary Economics* 70(C), 100–115.
- Iacoviello, M. and S. Neri (2010, April). Housing Market Spillovers: Evidence from an Estimated DSGE Model. *American Economic Journal: Macroeconomics* 2(2), 125–64.
- IMF (2011, March). Macroprudential Policy: An Organizing Framework. International Monetary Fund (IMF).

- Jensen, H., I. Petrella, S. H. Ravn, and E. Santoro (2017, August). Leverage and Deepening Business Cycle Skewness. Technical report.
- Jensen, H., S. H. Ravn, and E. Santoro (2017, October). Changing Credit Limits, Changing Business Cycles. Technical report.
- Jones, J. B. (2002, May). Has fiscal policy helped stabilize the postwar U.S. economy? *Journal of Monetary Economics* 49(4), 709–746.
- Justiniano, A., G. E. Primiceri, and A. Tambalotti (2015, January). Household leveraging and deleveraging. *Review of Economic Dynamics* 18(1), 3–20.
- Justiniano, A., G. E. Primiceri, and A. Tambalotti (2017). Credit Supply and the Housing Boom. Technical report.
- Kiyotaki, N. and J. Moore (1997, April). Credit Cycles. *Journal of Political Economy* 105(2), 211–248.
- Lambertini, L., C. Mendicino, and M. Teresa Punzi (2013). Leaning against boom–bust cycles in credit and housing prices. *Journal of Economic Dynamics and Control* 37(8), 1500–1522.
- Liu, Z., J. Miao, and T. Zha (2016, June). Land prices and unemployment. *Journal of Monetary Economics* 80, 86–105.
- Liu, Z., P. Wang, and T. Zha (2013, May). Land-Price Dynamics and Macroeconomic Fluctuations. *Econometrica* 81(3), 1147–1184.
- Prieto, E., S. Eickmeier, and M. Marcellino (2016, November). Time Variation in Macro-Financial Linkages. *Journal of Applied Econometrics* 31(7), 1215–1233.
- Saiz, A. (2010, August). The Geographic Determinants of Housing Supply. *The Quarterly Journal of Economics* 125(3), 1253–1296.
- Smets, F. and R. Wouters (2007, June). Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review* 97(3), 586–606.