Countercyclical loan-to-value ratios and monetary policy
Preliminary and incomplete[*]

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Abstract

Housing boom-busts are often associated with widespread problems for the financial system. An emerging policy debate is concerned with how best to reduce the amplitude or incidence of these boom busts. In this paper we add a countercyclical regulatory loan-to-value (LTV) to a DSGE model with housing and borrowing secured by housing collateral. We consider shocks that create features of a housing boom–including a shock that increases the borrowing limit to constrained households. We then examine the merits of using the traditional monetary policy instrument (short-term interest rates) against the alternative of a regulatory mortgage loan-to-value ratio in responding to these booms.

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1 Introduction

Imbalances in the housing market and housing finance played a central role in the recent financial crisis in the United States. More generally, many financial crises have been preceded by booming housing markets during which real estate prices and borrowing backed by real-estate collateral have risen sharply (Kaminsky and Reinhart, 1999; Reinhart and Rogoff, 2008; Borio and Drehmann, 2009). Historically, banking problems have frequently arisen as a result of bank lending activities in real estate.

There is also growing evidence that the institutional details of mortgage finance, in particular the loan-to-value ratio (LTV) available on a mortgage, contribute to the procyclicality of the housing market. Lamont and Stein (1999) use U.S. city-level data to show that the sensitivity of house prices to income shocks is higher in cities with more high levered (high LTV ratio) homeowners. Almeida, Campello, and Liu (2006) show that cross-country differences in the maximum loan-to-value (LTV) ratio available on a mortgage can explain cross-country variation in the sensitivity of house prices and credit demand to income shocks. Calza, Monacelli, and Stracca (2009) show that features of mortgage markets can also explain differences in the transmission of monetary policy across countries. This evidence suggests that features of the financial system amplify swings in the real economy, particularly the housing market, exacerbating boom-bust cycles in asset prices and financial instability.

Countercyclical financial sector regulation and monetary policy are two broad types of policy being considered by many countries as potential tools to reduce the impacts and incidence of housing boom-bust cycles.[1] We focus on housing finance and consider the advantages and disadvantages of a direct control on lending: altering a regulatory loan-to-value (LTV hereafter) ratio on residential

[1] Changes to the regulation and supervision of banks, their risk management practices, and accounting and compensation frameworks have been proposed to address the procyclicality in the financial system.

mortgages. This type of regulatory policy is attracting interest in a number of countries as a potential macroprudential instrument. Regulatory changes to LTV ratios have already been implemented in some emerging market economies and Hong Kong. Alternatively, the monetary policymakers might take emerging financial vulnerabilities into account when setting short-term interest rates, that is they could "lean against the wind". This might occur if these vulnerabilities are expected to affect inflation over the policy horizon or if central banks also seek to maintain financial stability in addition to price stability. [2]

Our goal is to assess the relative merits of responding to financial imbalances, in this case booms in the housing market, using a regulatory LTV ratio versus monetary policy. Ohe objective of this paper is therefor to examine the macroeconomic consequences of using a LTV ratio to address financial imbalances. We contrast this impact to that of a monetary response to the imbalance and compare the dynamics of inflation and output over the traditional policy horizon. Finally, we consider circumstances under which a macroprudential LTV policy may conflict with the objective of monetary policy.

We examine these policies in the context of a dynamic general equilibrium model with housing, borrowing constraints, and a role for monetary policy. Models of this type have been used to assess the impact of housing market developments on the business cycle (Iacoviello and Neri, 2009; Christensen, Corrigan, Mendicino, and Nishiyama, 2009) and implications of durable goods and housing for monetary policy (Iacoviello, 2005; Monacelli, 2009). The borrowing constraint is a key feature in these models because it leads to an amplification (procyclicality) of housing market developments and spillovers to the rest of the economy. Two important and novel features of our model environment are that we: 1) examine the impact of financial shocks, particularly a shock to household debt capacity; and 2) we examine the use of a countercyclical loan-to-value ratio on mortgages as a

[2] An earlier literature examines whether monetary policy should respond to asset prices and typically finds that inflation targeting monetary policy is the best policy for containing asset-price misalignments (see for example (Bernanke and Gertler, 2000)). In the wake of the financial crisis this conclusion is being revisited.

macroprudential policy instrument. We operationalize the notion of a macroprudential response to the credit boom by assuming that the regulatory authority adjusts the LTV in response to aggregate variables such as credit or house prices. [3] In the context of our model, credit booms arise when exogenous shocks drive up housing investment, house prices and mortgage credit simultaneously. We focus on two shocks: a financial shock that raises the borrowing capacity of households and an aggregate productivity shock. Importantly, we do not attempt to model housing market bubbles.

We next consider 4 economies each differing in the instrument(s) used to lean against the credit boom:

1. A benchmark economy with a standard Taylor-type monetary policy rule (referred to as the traditional rule)
2. An economy with a traditional monetary policy rule and a regulatory LTV ratio that responds to the credit boom.
3. An economy in which monetary policy can respond directly to the boom absent a LTV rule.
4. An economy in which both policy instruments are present and respond to the boom.

We then compare macroeconomic outcomes and outcomes for the housing market and financial system across the various sets of policies. The goal is to better understand the tradeoffs between stabilizing inflation and output and responding to credit booms. In addition, it is important to understand how regulatory measures will interact with monetary policy. When will the presence of a countercyclical regulatory rule work in the same direction as monetary policy and when will regulation work against it?

[3] We think these rules are consistent with the spirit of macroprudential rules that have been proposed elsewhere.

The ultimate goal of macroprudential policies (or financial stability policy) is to mitigate risks to the functioning of the financial system and ultimately real losses in terms of economic performance. Though this model does not attempt the challenging task of explicitly modeling systemic risk (i.e. the risk of widespread financial distress), we think it is still a useful framework for considering alternative policy actions to reduce procyclical aspects of the financial system that are associated with the buildup of this risk. In addition, our analysis is silent on a number of important aspects to the debate on the appropriate tools including whether the public authorities exercise sufficient control of the tools in practice and whether they would have the credibility required to duly influence agent's expectations.

There is a small, but growing literature that seeks to model macroprudential policy in a DSGE framework and compare the relative efficacy of using macroprudential rules and monetary rules in responding to housing booms. Kannan, Rabanal, and Scott (2009) consider a macroprudential policy that influences the interest rate spread between mortgage rates and the risk-free rate. In contrast, our focus is on a mortgage loan-to-value ratio. Two other papers that we know of analyse the potential impact of countercyclical loan-to-value ratio policy. Angelini, Neri, and Panetta (2011) use a loss-function approach to compare the benefits of capital charges and LTVs in a model with banking and explore the nature of the interaction with monetary policy. As in our model, they find the LTV to have an advantage at responding to disturbances arising in the housing market. Lambertini, Mendicino, and Punzi (2011) evaluates the welfare implications of LTV and monetary policies in an economy where there are many sources of aggregate fluctuations, including changes in expectations (news) about the future.

In the following section we describe the model. In section 4 we discuss the calibration. In the remainder of the paper we discuss the experiments conducted and the main findings.

2 Model

We consider a sticky-price economy populated by two types of households. Credit flows are generated by assuming ex-ante heterogeneity in agents' subjective discount factors. Impatient consumers differ from patient consumers in that they discount the future at a faster rate. Hence, in equilibrium, patient agents are net lenders while impatient agents are net borrowers. To prevent borrowing from growing without limit, we assume that borrowers face credit constraints tied to the expected future value of collateral. We also assume perfectly competitive intermediate-good-producing firms, retailers that operate in a monopolistically competitive market, and a monetary authority.

2.1 Households

Households supply labour and derive utility from consumption, housing services, and real money holdings. They maximize expected utility:

$$\max E_0 \sum_{t=0}^{\infty} (\beta_i)^t \epsilon_{b,t} \left[\ln (c_{i,t} - b_c C_{i,t-1}) + \epsilon_{j,t} j (h_{i,t}) - \frac{\epsilon_{L,t}}{1+\eta} (L_{i,t})^{1+\eta} + x \ln \frac{M_{i,t}}{P_t} \right], \tag{1}$$

where households can be one of two types, denoted $i = 1, 2$, that are distinguished by their time-discount rates β_1 and β_2. $b_c C_{i,t-1}$ represents external habits in consumption, $\epsilon_{b,t}$ represents a shock to the discount rate that affects the intertemporal substitution of households, $\epsilon_{j,t}$ is a shock to the preference for housing services and $\epsilon_{L,t}$ is a shock to labour supply. We will refer to $\epsilon_{j,t}$ as a housing demand shock.

Lenders Patient households (denoted by 1), have a higher propensity to save, i.e. $\beta_1 > \beta_2$. So, in equilibrium, they supply loans to impatient households, $b_{1,t}$, and accumulate properties for housing purposes, $h_{1,t}$.[4] Patient households also buy foreign bonds, b_t^*. The return on foreign debt depends on a country specific risk premium ς_t. Lenders also receive dividends, F_t, from the final-good-producing firms. They maximize their expected future utility (1) subject to the budget constraint

$$\begin{aligned} & c_{1,t} + q_t^H \left(h_{1,t} - (1-\delta_H)h_{1,t-1}\right) + q_t^k (k_t - (1-\delta_k)k_{t-1}) + s_t \left(\frac{R_{t-1}^* \varsigma_{t-1} b_{t-1}^*}{\pi_t} - b_t^* \right) = \\ & w_{1,t} L_{1,t} + r_t^k k_{t-1} - \frac{R_{t-1} b_{1,t-1}}{\pi_t} + b_{1,t} + F_t + T_t - \frac{\Delta M_{1,t}}{P_t}, \end{aligned} \tag{2}$$

where $\pi_t = P_t / P_{t-1}$ is the gross inflation rate, q_t^H is the price of housing, q_t^k is the price of capital, $w_{1,t}$ real wages of type-1 households, and s_t the real exchange rate. All the variables, except for the gross nominal interest rates on domestic and foreign bonds, R_t, and R_t^*, are expressed in real terms. We assume that the housing stock is variable. Thus, differently from (Iacoviello, 2005), households accumulate properties that depreciate at a rate δ_H. By using $\lambda_{c_{1,t}}$ as the Lagrange multiplier on the budget constraint, lenders' optimal choices for $c_{1,t}$, $h_{1,t}$, $k_{1,t}$, $b_{1,t}$ and $b_{1,t}^*$ are characterized by

$$\lambda_{c_{1,t}} = \frac{\epsilon_{b,t}}{c_{1,t} - b_c C_{1,t-1}} \tag{3}$$

$$\frac{\epsilon_{b,t} \epsilon_{j,t} j}{h_{1,t}} = \lambda_{c_{1,t}} q_t^H - \beta_1 E_t \left[\lambda_{c_{1,t+1}} q_{t+1}^H (1-\delta_H) \right], \tag{4}$$

$$\lambda_{c_{1,t}} q_t^k = \beta_1 E_t \left[\lambda_{c_{1,t+1}} \left(r_{t+1}^k + q_{t+1}^k (1-\delta_k) \right) \right], \tag{5}$$

$$\lambda_{c_{1,t}} = \beta_1 E_t \left[\frac{\lambda_{c_{1,t+1}} R_t}{\pi_{t+1}} \right], \tag{6}$$

and

$$\lambda_{c_{1,t}} s_t = \beta_1 E_t \left[s_{t+1} \left(\frac{\lambda_{c_{1,t+1}} \varsigma_t R_t^*}{\pi_{t+1}} \right) \right]. \tag{7}$$

[4]We use the convention that $b \geq 0$ is debt and $b \leq 0$ is savings.

Unlike Iacoviello (2005) we augment our model with a demand function for foreign loanable funds (7). The introduction of the risk-premium, ς_t, is required for the model to feature a stationary distribution[5]. Following Adolfson, Laseen, Linde, and Villani (2007), we assume that the risk premium depends on the ratio of net foreign debt to domestic output and the expected exchange rate

$$\varsigma_t = \exp\left[\phi\left(\frac{s_t b_t^*}{P_t^d Y_t}\right) + \phi_s\left(\frac{E_t s_{t+1}}{s_t}\frac{s_t}{s_{t-1}} - 1\right) + \epsilon_{s,t}\right].$$

The inclusion of the expected exchange rate in the risk premium is motivated by empirical findings of a strong negative correlation between the risk premium and the expected depreciation, as reported by Fama (1984) and Duarte and Stockman (2005). The demand for foreign funds combined with the demand function for domestic loanable funds, implies an uncovered interest parity condition, which in log-linearized form obeys

$$\hat{r}_t - \hat{r}_t^* = (1 + \phi_s) E_t \Delta s_{t+1} + \phi_s \Delta s_t + \phi$$

where $r_t = R_t - E_t \pi_{t+1}$.

Borrowers Impatient households (denoted by 2) maximize their stream of expected future utility (1) subject to a budget constraint

$$c_{2,t} + q_t^H (h_{2,t} - (1 - \delta_H) h_{2,t-1}) = w_{2,t} L_{2,t} - \frac{R_{t-1}^m b_{2,t-1}}{\pi_t} + b_{2,t} - \frac{\Delta M_{2,t}}{P_t}, \tag{8}$$

and a borrowing constraint,

$$b_{2,t} \leq m_t \chi_t E_t\left[\frac{q_{t+1}^H \pi_{t+1} h_{2,t} (1 - \delta_H)}{R_t^m}\right], \tag{9}$$

where R_t^m is the gross interest rate charged on mortgage loans.

[5] See, e.g., Schmitt-Grohe and Uribe (2003) for further details.

Following Iacoviello (2005) we assume that borrowing is limited to a fraction, m_t, of the value of borrowers housing stock, where $(1 - m_t)$ represents the cost that lenders have to pay in order to repossess the asset in case of default. m_t is a parameter set by the regulator that restricts the LTV ratio in mortgage contracts. We also introduce a financial shocks into this borrowing constraint. χ_t is a shock to the value of housing collateral. We interpret this shock as capturing changes in the lender's view on the quality of the collateral similar in spirit to the exogenous shocks to asset quality in Gertler and Karadi (2010) and Gertler and Kiyotaki (2010). The interest rate paid on mortgage debt, R_t^m, is the risk-free interest rate plus a premium. This premium that is subject to a shock that causes the spread $R_t^m - R_t$ to vary over time.

We also assume that impatient households do not have access to the foreign bond market. By using $\lambda_{c_{2,t}}$ as the Lagrange multiplier on the budget constraint, borrowers' optimal choices for $c_{2,t}$, $h_{2,t}$ and $b_{2,t}$ are characterized by

$$\lambda_{c_{2,t}} = \frac{\epsilon_{b,t}}{c_{2,t} - b_c c_{2,t-1}}, \tag{10}$$

$$\frac{\epsilon_{b,t}\epsilon_{j,t}j}{h_{2,t}} + \mu_t m_t \chi_t E_t \left[\frac{q_{t+1}^h \pi_{t+1} (1 - \delta_H)}{R_t^m} \right] = \lambda_{c_{2,t}} q_t^H - \beta_2 E_t \left[\lambda_{c_{2,t+1}} q_{t+1}^H (1 - \delta_H) \right], \tag{11}$$

$$\lambda_{c_{2,t}} - \mu_t = \beta_2 E_t \left[\frac{\lambda_{c_{2,t}} R_t^m}{\pi_{t+1}} \right], \tag{12}$$

and the borrowing constraint holds with equality,

$$b_{2,t} = m_t E_t \left[\frac{q_{t+1}^h \pi_{t+1} \chi_t h_{2,t} (1 - \delta_H)}{R_t^m} \right], \tag{13}$$

where μ_t is the Lagrange multiplier associated to the borrowing constraint[6]. For the borrowers, the

[6] Impatient households borrow up to the maximum in the neighborhood of the deterministic steady state. In fact, if we consider the Euler equation of the impatient household evaluated at the deterministic steady state $\mu_2 = \left(1 - \frac{\beta_2}{\beta_1 \pi}\right) U_{c_2} > 0$.

marginal benefit of holding one extra unit of housing also takes into account the marginal benefit of being allowed to borrow more.

Finally, as in Erceg, Henderson, and Levin (2000), each household is a monopoly supplier of differentiated labour services which allows them to set their own wage. Wage setting is subject to a Calvo style rigidity with each household facing a probability θ_w that it will not be able to reset its wage in given period. Those households who do not reoptimize their wage, $w_{i,t}$, index to the steady state rate of inflation. Note that the wages for each household type are determined separately, but we assume that both household types face the same degree of wage stickiness.

Specifically, each household $z \in (0,1)$ of type $i \in \{1,2\}$ sets their nominal wage $\widetilde{W}_{i,t}(z)$ such that

$$\sum_{k=0}^{\infty} (\beta_i \theta_w)^k E_t \left\{ \left(\epsilon_{b,t+k} U_{c_{i,t+k}} \frac{\widetilde{W}_{i,t}}{P_{t+k}} - \left(L^d_{i,t+k}(z) \right)^{\eta} \right) L_{i,t+k}(z) \right\} = 0. \tag{14}$$

In the special case that $\theta_w = 0$ labour supply satisfies a more standard first order condition

$$\frac{\widetilde{W}_{i,t}(z)}{P_t} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{\left(L^d_{i,t}(z) \right)^{\eta}}{U_{c_{1,t}}}. \tag{15}$$

Overall labour supply of type i, $L_{i,t}$, is a composite of the individual labour supplies aggregated using a Dixit-Stiglitz aggregator, such that

$$L_{i,t} = \left[\int_o^1 (L_{i,t}(z))^{\frac{\epsilon_w - 1}{\epsilon_w}} dz \right]^{\frac{\epsilon_w}{\epsilon_w - 1}}, \tag{16}$$

where the price elasticity ϵ_w is subject to a shock. This implies that the nominal wage $W_{i,t}$, is given by

$$W_{i,t} = \left[\int_{o}^{1} (W_{i,t}(z))^{1-\epsilon_w} dz \right]^{\frac{1}{1-\epsilon_w}} \tag{17}$$

and individual labour supplies $L_{i,t}(z)$ satisfy $L_{i,t}(z) = \left(\frac{W_{i,t}(z)}{W_{i,t}} \right)^{-\epsilon_w} L_{i,t}$.

As all households of each type are the same, the wage aggregator implies a process for the nominal wage $W_{i,t}$

$$W_{i,t} = \left(\theta_w (W_{i,t-1})^{1-\epsilon_w} + (1-\theta_w)(\widetilde{W}_{i,t})^{1-\epsilon_w} \right)^{\frac{1}{1-\epsilon_w}}. \tag{18}$$

2.2 Production

Domestic producers make the intermediate input, $Y^{d,int}$ using rented capital, k, and labour supplied by patient agents, L_1, and impatient agents, L_2. The hours worked of the two households enter into the production function in a Cobb-Douglas form implying that the two labour types are complements.[7] Under this formulation the parameter α is a measure of the labour income share of the unconstrained households. Intermediate goods are produced in a perfectly competitive market by the following technology

$$Y_t^{d,int} = z_t \left(L_{1,t}^{\alpha} L_{2,t}^{1-\alpha} \right)^{1-\gamma} k_{t-1}^{\gamma}, \tag{19}$$

where z_t is an aggregate productivity shock. Intermediate domestic goods are sold at the competitive price mc_t^d, i.e. at domestic marginal cost.

[7] As in Iacoviello and Neri (2009), the primary motivation for this is to allow us to obtain a closed-form solution for the steady-state of the model.

Firms solve the following static problem

$$\max \frac{Y_t}{X_t} - \left\{ w_{1,t} L_{1,t} + w_{2,t} L_{2,t} + r_t^k k_{t-1} \right\} \tag{20}$$

where $X_t = \frac{P_t^w}{P_t}$ is the markup of final over wholesale goods. First order conditions for the firms are standard and available in the Technical Appendix.

2.3 Wholesaler's Problem

Domestic brands The producers of domestic brands buy the domestic intermediate input, $Y^{d,int}$, from entrepreneurs, at price mc^d, and transform it using a linear technology into $Y_t^d\left(z^d\right)$. Each firm faces a Calvo price rigidity, with a non-zero probability θ_d of being unable to adjust its nominal price in a given period. Firms maximize the expected present value of their real dividends setting $\tilde{P}_t^d$ such that

$$\sum_{k=0}^{\infty} (\beta_i \theta_d)^k E_t \left\{ \epsilon_{b,t+k} U_{c_{1,t+k}} \left(\frac{\tilde{P}_t^d}{P_{t+k}} - mc_{t+k}^d \right) Y_{t+k}^d \left(z^d \right) \right\}. \tag{21}$$

The demand curve for each good obeys

$$Y_t^d(z) = \left(\frac{P_t^d(z^d)}{P_t^d} \right)^{-\epsilon_{p,t}} Y_t^d, \tag{22}$$

where the price elasticity ϵ_p follows an exogenous AR(1) process. We interpret this as a cost-push or markup shock. Each domestic brand is then aggregated into a domestic wholesale good, Y^d. Specifically,

$$Y_t^d = \left[\int_o^1 (Y_t^d(z^d))^{\frac{\epsilon_{p,t}-1}{\epsilon_{p,t}}} dz^d \right]^{\frac{\epsilon_{p,t}}{\epsilon_{p,t}-1}}. \tag{23}$$

This implies that the price of the domestic intermediate good, P_t^d, is given by

$$P_t^d = \left[\int_o^1 (P_t^d(z^d))^{1-\epsilon_{p,t}} dz^d \right]^{\frac{1}{1-\epsilon_{p,t}}}. \tag{24}$$

The Calvo adjustment process implies the following price index

$$P_t^d = \left(\theta_d (P_{t-1}^d)^{1-\epsilon_{p,t}} + (1-\theta_d)(\tilde{P}_t^d)^{1-\epsilon_{p,t}} \right)^{\frac{1}{1-\epsilon_{p,t}}}. \tag{25}$$

Imported brands Finally, there is a continuum of intermediate-good-importing firms $z^m \in [0,1]$. They import a homogeneous intermediate foreign good at price P_t^* to produce a differentiated good $Y_t^m(z^m)$. Importers face a Calvo price rigidity, with each firm facing a non-zero probability, θ_m, of being unable to adjust its nominal price in a given period. Firms that are able to revise the price, choose $\tilde{P}_t^m$ such that

$$\sum_{k=0}^{\infty} (\beta_i \theta_m)^k E_t \left\{ \epsilon_{b,t+k} U_{c_{1,t+k}} \left(\frac{\tilde{P}_t^m}{P_{t+k}} - s_{t+k} \right) Y_{t+k}^m(z^m) \right\}, \tag{26}$$

where the demand curve for each good obeys

$$Y_t^m(z^m) = \left(\frac{P_t^m(z^m)}{P_t^m} \right)^{-\epsilon_{p,t}} Y_t^m. \tag{27}$$

Imported intermediate goods are imperfect substitutes in the production of the composite imported good Y_t^m, where

$$Y_t^m = \left[\int_o^1 (Y_t^m(z^m))^{\frac{\epsilon_{p,t}-1}{\epsilon_{p,t}}} dz^m \right]^{\frac{\epsilon_{p,t}}{\epsilon_{p,t}-1}}. \tag{28}$$

Thus, the price of the intermediate imported good, P_t^m, is a composite of the individual prices for the inputs,

$$P_t^m = \left[\int_o^1 (P_t^m(z^m))^{1-\epsilon_p} dz^m \right]^{\frac{1}{1-\epsilon_{p,t}}}. \tag{29}$$

The Calvo adjustment process implies a process for the price index of

$$P_t^m = \left(\theta_m (P_{t-1}^m)^{1-\epsilon_{p,t}} + (1-\theta_m)(\widetilde{P}_t^m)^{1-\epsilon_{p,t}} \right)^{\frac{1}{1-\epsilon_{p,t}}}. \tag{30}$$

2.4 Retailer's Problem

Retailers combine domestic brands of intermediate goods Y^d, and imported intermediate goods Y^m, to form a final good Y. Retailers operate in a perfectly competitive market using a CES production function

$$Y_t = \left[(1-\omega)^{\frac{1}{\phi}} \left(Y_t^d \right)^{\frac{\phi-1}{\phi}} + \omega^{\frac{1}{\phi}} \left(Y_t^m \right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}, \tag{31}$$

where $\omega > 0$ is the share of imported goods in the final domestic goods basket and $\phi > 0$ is the elasticity of substitution between domestic and imported intermediate goods. Cost minimization entails the following demand curves for Y^d and Y^m

$$Y_t^d = (1-\omega) \left[\frac{P_t^d}{P_t} \right]^{-\phi} Y_t \tag{32}$$

$$Y_t^m = \omega \left[\frac{P_t^m}{P_t} \right]^{-\phi} Y_t + \epsilon_{m,t}, \tag{33}$$

and a domestic aggregate price level P corresponding to the CPI, such that

$$P_t = \left[(1-\omega)\left(P_t^d\right)^{1-\phi} + \omega (P_t^m)^{1-\phi}\right]^{\frac{1}{1-\phi}}. \tag{34}$$

2.5 Housing producer's problem

Housing producers are competitive firms that use final goods and rented housing to produce new units of installed housing capital that they sell for price q_t^H. Thus they choose the level of I_t^H that maximizes the profits

$$\max E_t \sum_{s=0}^{\infty} \left(\frac{\lambda_{t+s} P_t}{\lambda_t} \left(q_{t+s}^H \left(H_{t+s} - (1-\delta_H) H_{t+s-1}\right) - \frac{I_{t+s}^H}{A_{t+s}^H} \right) \right),$$

where

$$I_{t+s}^H = H_{t+s} - (1-\delta_H) H_{t+s-1} + \frac{\psi_H}{2} \left(\frac{I_{t+s}^H}{I_{t+s-1}^H} - 1 \right)^2 I_{t+s}^H$$

We assume a quadratic cost of adjusting the housing investment where ψ_H governs the slope of the housing investment adjustment cost function. In addition, we include A_t^H, i.e. an AR(1) shock to the equilibrium condition of housing investment. Since this is a shock to the marginal efficiency of producing housing, we interpret it as a housing-specific technology shock. New housing capital goods are sold at price q_t^H

$$\begin{aligned} q_t^H \quad = \quad & \frac{1}{A_t^k} \left(1 - \frac{\psi_H}{2} \left(\frac{I_t^H}{I_{t-1}^H} - 1 \right)^2 + \psi_H \left(\frac{I_t^H}{I_{t-1}^H} - 1 \right) \frac{I_t^H}{I_{t-1}^H} \right) \\ & + \beta \frac{\lambda_{c_{1,t+1}}}{\lambda_{c_{1,t}}} \left(q_{t+1}^H (1-\delta_H) - \frac{1}{A_{t+1}^k} \left((1-\delta_H) + \psi_H \left(\frac{I_{t+1}^H}{I_t^H} - 1 \right) \frac{I_{t+1}^H}{I_t^H} \right) \right) \end{aligned} \tag{35}$$

This equation is similar to the Tobin's q relationship for investment, in which the marginal cost of a unit of housing is related the marginal cost of adjusting the housing stock. Note that a positive shock to the housing specific technology will reduce the price of installed housing.

2.6 Capital producer's problem

Capital producers take final goods and transform them into capital in a way that is analogous to the housing producers, only they face adjustment costs related to the change in investment as in Christiano, Eichenbaum, and Evans (2005). ψ_k governs the slope of the capital producers adjustment cost function. Thus they choose the level of I_t^k that maximizes the profits

$$\max E_t \sum_{s=0}^{\infty} \left(\frac{\lambda_{t+s} P_t}{\lambda_t} \left(q_{t+s}^k \left(k_{t+s} - (1-\delta_k) k_{t+s-1} \right) - \frac{I_{t+s}^k}{A_{t+s}^k} \right) \right),$$

where

$$I_{t+s}^k = k_{t+s} - (1-\delta_k) k_{t+s-1} + \frac{\psi_k}{2} \left(\frac{I_{t+s}^k}{I_{t+s-1}^k} - 1 \right)^2 I_{t+s}^k$$

where $\frac{\psi_k}{2} \left(\frac{I_t^k}{I_{t-1}^k} - 1 \right)^2 I_t^k$ is the adjustment cost function. Producers sell the capital at price q_t^k,

$$\begin{aligned} q_t^k \quad &= \quad \frac{1}{A_t^k} \left(1 - \frac{\psi_k}{2} \left(\frac{I_t^k}{I_{t-1}^k} - 1 \right)^2 + \psi_k \left(\frac{I_t^k}{I_{t-1}^k} - 1 \right) \frac{I_t^k}{I_{t-1}^k} \right) \\ &\quad + \beta \frac{\lambda_{c_1,t+1}}{\lambda_{c_1,t}} \left(q_{t+1}^k (1-\delta_k) - \frac{1}{A_{t+1}^k} \left((1-\delta_k) + \psi_k \left(\frac{I_{t+1}^k}{I_t^k} - 1 \right) \frac{I_{t+1}^k}{I_t^k} \right) \right) \end{aligned} \tag{36}$$

where A_t^k is an AR(1) shock that we interpret as a capital-investment-specific shock as in Greenwood, Hercowitz, and Krusell (1998) and Fisher (2006).

2.7 Macroprudential policy

We assume that the macroprudential policy conducted by the government takes the form of a regulatory control over the loan-to-value ratio specified in mortgage contracts. The government adjusts this loan-to-value ratio in response to indicators of financial vulnerability. This rule takes the general form:

$$\frac{m_t}{m} = \left(\frac{\xi_t}{\xi}\right)^{\phi_\xi} \tag{37}$$

where m_t is the regulatory loan-to-value ratio, ξ_t is an indicator of financial vulnerability, and ϕ_ξ governs the strength of the response of the authorities to movements in that indicator. In log-linearized form an LTV rule that responds to deviation of mortgage credit from its steady-state value will take the form:

$$\hat{m}_t = \phi_b \hat{b}_t. \tag{38}$$

Though we do not do so here, we could also investigate the properties of a number of different indicators that have been proposed in policy discussions including mortgage debt, its growth rate, house prices and the debt-to-GDP ratio.

2.8 Monetary policy

For simplicity we assume that the central bank uses the Taylor-type interest rate rule:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\rho_\pi(\hat{\pi}_t - \hat{\pi}_t^*) + (1-\rho_R)\rho_Y \widehat{GDP}_t + \epsilon_{MP,t}. \tag{39}$$

The monetary authority adjusts the nominal interest rate in response to deviations of inflation from its target, and deviations of GDP from its steady state value. We also allow for interest-rate smoothing behaviour. The central bank's target, $\hat{\pi}_t^*$, is assumed to be time varying and is subject to an AR(1) shock as in Smets and Wouters (2003) and Adolfson, Laseen, Linde, and Villani (2007). $\epsilon_{MP,t}$ is an i.i.d. monetary policy shock.

We also consider alternative policy rules that adjust the policy rate in response to a measure of financial vulnerability in addition to the standard variables described above. Our objective is to consider the relative performance of responding to these imbalances using monetary policy versus other instruments that are more regulatory in nature. Specifically, we consider an interest rate rule that responds to a credit gap

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\rho_\pi(\hat{\pi}_t - \hat{\pi}_t^*) + (1-\rho_R)\rho_Y \widehat{GDP}_t + (1-\rho_R)\rho_b \hat{b}_t + \epsilon_{MP,t}. \tag{40}$$

2.9 Market clearing conditions

Domestic output Y_t, can be consumed, invested or exported

$$Y_t = c_{1,t} + c_{2,t} + I_t^k + I_t^H + Y_t^x + \omega_t d_t \tag{41}$$

and real GDP[8] is

$$GDP_t = c_{1,t} + c_{2,t} + I_t^k + I_t^H + Y_t^x + \omega_t d_t - s_t Y_t^m. \tag{42}$$

[8] As in Iacoviello and Neri (2009) and Davis and Heathcote (2005) we set the relative prices q^H, q^k and s equal to their steady state values.

Housing stock is accumulated according to

$$I_t^H = A_t^H \left(H_t - (1-\delta_H) H_{t-1} + \frac{\psi_H}{2} \left(\frac{I_t^H}{I_{t-1}^H} - 1 \right)^2 I_t^H \right)$$

where the aggregate stock of housing is $H_t = h_{1,t} + h_{2,t}$, and the usual capital accumulation equation holds

$$I_t^k = A_t^k \left(k_t - (1-\delta_k) k_{t-1} + \frac{\psi_k}{2} \left(\frac{I_t^k}{I_{t-1}^k} - 1 \right)^2 I_t^k \right)$$

The domestic loan market condition implies that total borrowed funds are equal to funds lent out by patient households

$$b_{2,t} = -b_{1,t} \tag{43}$$

Finally, the trade balance equals economy-wide net saving, so that

$$Y_t^x - s_t Y_t^m = \left[s_t \left(\frac{R_t^f \varsigma_{t-1}}{\pi_t^f} \right) b_{t-1}^f - b_t^f \right]. \tag{44}$$

2.10 Rest of the World

We assume Canada to be a small open economy. Thus, domestic developments do not affect the rest of the world economy. By analogy with the import demand function of the local economy, the demand for the domestic economy's exports is captured by

$$\hat{Y}_t^x = \hat{Y}_t^g - \phi \hat{P}_t^x + \epsilon_{ex,t}$$

and $\hat{P}_t^x = \frac{P_t^x}{P_t^g}$ is the real price of local brands in the global economy and $\epsilon_{ex,t}$ is an export demand shock. It can be shown that the process for $\pi_t^x \equiv \frac{P_t^x}{P_{t-1}^x}$ obeys

$$\hat{\pi}_t^x - \beta_f E\hat{\pi}_{t+1}^x = \frac{(1-\theta_x)(1-\beta\theta_x)}{\theta_x}(-\hat{s}_t - \hat{P}_t^x), \tag{45}$$

where θ_x is the probability that the price of a local brand will remain sticky in the global economy in a given period.

2.11 Autoregressive processes

Apart from $\epsilon_{MP,t}$, a zero-mean i.i.d. shock with variance σ_{MP}, the other structural shocks in the model, $\Theta_t = \left\{\epsilon_{b,t}, \epsilon_{j,t}, \epsilon_{s,t}, z_t, A_t^H, A_t^k, \epsilon_{IO,t}, \epsilon_{L,t}, \epsilon_{ex,t}, \epsilon_{m,t}, \epsilon_{p,t}\right\}$, perturbed the model via an AR(1) process

$$\ln \Theta_t = \rho_\Theta \ln \Theta_{t-1} + \varepsilon_{\Theta_t}, \qquad \varepsilon_{\Theta_t} \backsim^{iid} N(0, \sigma_{\varepsilon_\Theta}), \quad 0 < \rho_\Theta < 1. \tag{46}$$

3 Calibration

We calibrate the parameters based on estimates from a Christensen, Corrigan, Mendicino, and Nishiyama (2009), evidence from micro and macro econometric studies, and sample means. The full set of calibrated parameters is reproduced in Table 1.

We set the housing preference parameter j to match the ratio of personal sector residential housing (land plus structures in the National Balance Sheet Accounts) to quarterly GDP, which for our sample period averages about 6.9[9]. We follow Iacoviello (2005) who draws from micro-studies of the range of discount factors of consumers, in setting the discount factor of patient agents β_1 to 0.99 and the discount factor of impatient agents β_2 to 0.95[10]. The patient agent's discount factor implies a steady-state real interest rate of 4 per cent on an annual basis.

We set the elasticity of demand for individual domestic intermediate goods ϵ so as to give an average markup of five percent in steady-state. Individual imported intermediate goods have the same elasticity of demand. The share of imported goods in the final domestic goods basket, ω, is set to 0.3.

As a typical house has a much longer lifetime than a typical piece of equipment, the housing depreciation rate, δ_H, should be lower than δ_k. The value of δ_H compatible with the housing investment to GDP ratio is 0.01, implying an annual depreciation rate that is somewhat higher than the range of values reported in Kostenbauer (2001). However, this value is much lower than the depreciation rate for capital which is set to $\delta_k = 0.023$, implying an annual depreciation of the capital stock of 9.5 per cent. We treat non-residential construction as part of business fixed investment, but exclude residential construction. Consistent with this classification, the capital share in the production of final goods, $\gamma = 0.23$, is lower than is typically used in models that aggregate all types of capital. The depreciation rate for capital along with the capital share in production of final goods imply a ratio of business fixed investment to GDP of about 0.165, approximately that seen in the data.

We set a value for the loan-to-value ratio m that reflects the typical loan-to-value ratio for a constrained household. This household, who we think of as being a first-time home buyer, borrows

[9]To calculate these ratios we measure Gross Domestic Product as the sum of the consumption, residential investment, business fixed investment (i.e. excluding inventory accumulation) and net exports. Since the real National Accounts aggregates are produced on a Chain Fisher basis we calculate these ratios using the nominal series.

[10]This value is in accordance with estimates of discount factors for poor or young households (see Samwick (1998) and Lawrence (1991)) and falls into the empirical distribution for discount factors estimated by Carroll and Samwick (1997).

the maximum possible against their real estate holdings. Canadian law requires all mortgages issued in excess of 80 per cent of the value of the property to be insured.[11] In practice, home buyers are able to obtain loans at considerably higher loan-to-value ratios with insurance. The minimum downpayment required by mortgage insurers is 5 per cent. Thus, loan-to-value ratios for constrained households are likely to fall in the 0.8 to 0.95 range. Allen (2011) finds that most of the insured mortgage borrowers in Canada have an LTV of 90 or 95 per cent at the time the contract is signed. In the experiments reported below we consider values for m in the 0.8 to 0.95 range. A similar range of values, based on U.S. data on new-home buyers, is considered in Iacoviello and Neri (2009).

We set a number of parameters based on the estimates for Canada found in Christensen, Corrigan, Mendicino, and Nishiyama (2009). The income share of unconstrained households, α, is set to 0.62 so the constrained agents represent 38 per cent. This is within the range of estimates of the fraction of households who are financially constrained reported in the literature. Campbell and Mankiw (1991) estimate the fraction of constrained agents from Canadian macro data to be near 50 per cent. Estimates based on micro data for the U.S. (Jappelli, 1990) and the U.K. (Benito and Mumtaz, 2006) put the share of the population that is liquidity constrained between 20 and 40 per cent.

The parameter governing habit persistence in consumption is set to 0.7 and the elasticity of labour supply, η is set to 1. Both are within the ranges typically used for these types of models.

We set ρ_π, the inflation weight in the monetary policy rule, to 2.5, while the weight on output, ρ_y, is 0.0. The interest rate smoothing term, ρ_R, is set to 0.8. The policy rule coefficients are similar to the estimated values for Canada reported in other studies (Lam and Tkacz, 2004; Ortega and Rebei, 2006; Cote, Kuszczak, Lam, Liu, and St-Amant, 2004; Dib, 2008; Dib, Mendicino, and Zhang, 2008).

[11]Strictly speaking this applies only to mortgages issued by deposit-taking institutions

We set the Calvo price stickiness for domestic goods θ^d to imply an average duration of price stickiness of about three quarters. Such estimates for average price stickiness are in line with previous DSGE models' estimates – even with more elaborate systems of nominal stickiness (for example Adolfson, Laseen, Linde, and Villani (2007) and Smets and Wouters (2003)). Wages are relatively flexible, with the probability of not be able to adjust,θ^w, set to 0.667 implying wages are unchanged for three quarters on average.

The price stickiness for imports θ^m is about the same as for domestically produced goods. However, price stickiness for exports θ^x is much lower, the average export price being sticky for only about 1.25 quarters on average. The long run elasticity of import demand σ is much lower (about 0.3) than that of export demand σ^f (about 1.5) which generates a much faster response of exports than imports to a change in the real exchange rate.

Fixed capital and housing capital adjustment costs are set to 1.6 and 1.2 respectively. The elasticity of the country risk premium with respect to the ratio of foreign debt-to-output, ϕ, is set to 0.005.

At present we set the standard deviations of all of the shocks to one percent and the persistence parameters of the shock processes to 0.9.

4 The impact of changes in the LTV ratio

4.1 LTV levels and procyclicality

In the aftermath of the financial crisis there has been much emphasis on identifying the channels through which financing arrangements may lead to procyclicality. In the context of our model we interpret procyclicality as the amplification of the responses of different variables after a shock. We now consider the role played by the LTV ratio in this amplification. Christensen, Corrigan, Mendicino, and Nishiyama (2009) show the presence of borrowing constraints plays an important amplifying role for shocks that occur in the Canadian housing market. Increases in demand for housing or the efficiency which with housing can be produced have direct effects on the price of housing. The evidence presented in Christensen, Corrigan, Mendicino, and Nishiyama (2009) shows that this amplification is related to the presence of borrowing constrained households, but does not consider the impact of a change in the severity of the borrowing constraint. Iacoviello and Neri (2009) estimate their model over two subsamples characterized by different levels of the LTV and find that the post 1989 period, a period when the LTV was higher, is associated with larger collateral effects on consumption.

We consider two aggregate shocks that lead to housing market booms and the accumulation of mortgage debt: a rise in the assessment of collateral value (valuation shock of χ_t shock), and a productivity shock in the intermediate goods production sector. This first shock is a temporary increase in the perceived value of housing that results in a short-term surge in mortgage credit.

Figure 1 plots the responses of selected model variables after a collateral value shock for 2 levels of the loan-to-value ratio: 0.8 (solid blue) and 0.95 (dashed green). Under the higher LTV an increase in collateral value by one percentage point deviation from steady-state allows access to a greater amount of debt. As a result, the initial response of mortgage debt is much stronger, increasing 13 per cent above steady-state levels in the first period as compared to 5 per cent for the 0.8 LTV. GDP (output), the house price, and residential investment also react more strongly in the periods following the shock. The weak reaction of inflation and the interest rate reflect the fact that the movements in output, house price, and residential investment are short-lived.

Figure 2 plots the responses to a productivity shock in the intermediate goods sector (TFP shock). The main impact of the higher LTV ratio is a stronger immediate response of output in the first quarter and debt accumulation in first few quarters after the shock. The other variables are virtually unchanged. The relatively small impact of a LTV is not surprising. Tomura (2009) shows that a higher level of the LTV amplifies the responses of key variables after a productivity shock, but this requires a framework where lenders have pessimistic expectations about house prices and borrowers are optimistic. Our model does not have this additional source of heterogeneity.

Overall, the impulse responses show that a permanent change of a regulatory LTV from 0.95 to 0.8 could achieve significant reductions in the procyclicality of mortgage debt, even before considering countercyclical LTVs. For the shocks considered here, the initial response of mortgage debt under the 0.8 LTV is no more than half the response under the LTV of 0.95. The spillover effects to consumption are also lower in the economy with the lower LTV ratio for all 3 shocks. In contrast, the lower LTV ratio economy only shows a dampening of house prices and residential investment after the valuation shock. For the technology shock the housing market variables are not significantly affected by the setting of the LTV.

4.2 Countercyclical Loan-to-value ratios

We now compare the model responses under a constant LTV ratio ($m = 0.8$) to those when the regulatory authorities change the LTV ratio in response to changes in the level of debt relative to its steady-state value. The strength of this regulatory response is determined by the parameter ϕ_b, which we set to -0.5 for the purposes of illustration. Thus, if the debt is 1 per cent above its steady-state level the LTV will be decreased by 0.5 per cent. For the remainder of the paper we focus primarily on the collateral value shock.

Figure 3 shows the model responses to a collateral shock under acyclical and countercyclical LTV policy. The blue solid line captures the responses when the LTV does not vary and is set to 0.8. The green dashed line shows the responses under the countercyclical LTV policy with a steady-state value at 0.8. Under a constant-LTV policy, the unanticipated rise in the valuation of collateral leads impatient agents to increase their borrowing. This access to more debt increases output with a peak effect 1 quarter after the shock. The increase in output is driven by a consumption increase along with an increase in residential investment. This increased demand for final goods drives up marginal cost and thus inflation only modestly. The central bank raises policy interest rates very slightly in response to this shock, with a small effect on the interest cost of carrying this debt. In addition, with sticky wages and an expected decrease in aggregate demand, wages start to fall immediately. The decrease in wages offsets the initial increase in marginal cost. To repay their debts, borrowers keep hours worked above steady-state levels despite the fall in wages and they reduce their holdings of real estate.

The countercyclical LTV policy results in a reduction of the mortgage loan-to-value ratio in response to the collateral valuation shock. Mortgage debt rises by about 1.5 per cent compared to roughly 5 per cent under the constant-LTV policy. Changing the LTV also has an impact on other macroeconomic variables. The rise in consumption and housing market variables is dampened considerably, thus the output increase is much lower than under the constant-LTV policy case. The lower inflation and output responses lead to a lower peak reaction of policy interest rates, though they are above steady-state for longer. Wages start to fall immediately, as in the constant-LTV policy case, but as a slower rate. Hours worked remains above steady-state levels despite the fall in wages and impatient households reduce their holdings of real estate.

Overall, the model's impulse responses suggest that a time-varying LTV rule with a relatively modest reaction to the deviation of the level of credit from its steady state can reduce the amplitude of fluctuations in mortgage debt considerably.

5 Can monetary policy achieve the same objective?

We now examine the impact on the dynamic response of key variables when the monetary authority responds to the same variable as the regulatory authority – in this case mortgage debt. Figure 4 shows the model responses when there is no countercyclical LTV, but instead monetary policy responds to credit. Also plotted is the case when there is both a countercyclical LTV and monetary policy responds to credit. We plot the responses using the interest-rate rule augmented with a response to credit with coefficient ρ_b set to 0.2. We conduct this experiment to highlight the potential trade-offs for monetary policy of attempting to achieve the same outcomes as would be attained by the regulator.

As in the constant-LTV policy case shown in Figure 1 where there was no systematic reaction from the monetary authority to the rise in debt, we observe a small but positive increase in interest rate. However, consumption, output and inflation all fall sharply (housing investment shows a mild decline) instead of rising as they do in the baseline responses of Figure 1, reflecting the strength of the expectations channel. In this case, agents know that the central bank will raise interest rates in response to higher mortgage debt and this reduces their desire to accumulate debt when the shock occurs. The magnitude of these responses suggests that attaining the same dampening of mortgage debt as under a countercyclical LTV would likely come at some cost to price-stability and output.

Figure 4 also plots the responses when both the regulator and the monetary authority react to credit. For this exercise we simply use the two policy rules already used in the previous experiments. When the regulator and the monetary authority both act to restrain the increase in credit, both the LTV ratio and the policy interest rate respond less than when each is operating on its own. The impact on output, inflation and housing variables still has the same qualitative features as the case where monetary policy acts on its own, but the magnitude of the responses is diminished considerably. This suggests that, in the presence of an LTV rule, the monetary authority does not have to be as aggressive in adjusting interest rates in response to credit. However these responses also suggest that lower output and inflation volatility could be obtained by leaving the bulk of the response to credit to the regulatory authority.

Finally, we plot model responses for the case of a technology shock (Figure 5). In this case there is a countercyclical LTV rule, but monetary policy uses the basic rule as in Figure 1 (not the credit augmented rule). This supply shock is of interest because it highlights the potential for conflict between the countercyclical LTV and monetary policy. Since mortgage debt increases after the rise in productivity the countercyclical LTV rule responds by lowering the LTV ratio for mortgages, reducing the debt accumulation, housing investment and consumption of borrowers. At the same time, the monetary authority lowers policy interest rates in an effort to boost aggregate demand and return inflation to its target. This scenarios suggests that they may be advantages to co-ordination between monetary authorities and the regulatory authorities that operate the LTV rule.

6 Conclusion and future work

Housing booms are often associated with subsequent widespread problems for the financial system. An emerging policy debate is concerned with how to reduce the amplitude or incidence of these boom busts. Central to this discussion is what tools are at the disposal of governments to mitigate these housing cycles and what is the likely impact of these tools on the housing markets and the rest of the economy.

In this paper we add a macroprudential instrument to a DSGE model with housing and debt backed by housing collateral. We assume that the objective is to reduce the expansion in household debt and thus mitigate rising household leverage and financial system vulnerabilities. We consider two types of shocks that could be behind a boom: a shock that increases the borrowing limit to constrained households and a productivity shock. We then examine the merits of responding to these shocks using the monetary policy instrument (short-term interest rates) against the alternative of a regulatory mortgage loan-to-value ratio.

We find that the financial shock leads to a large increase in mortgage borrowing, but small impacts on inflation. This shock might be considered a sectoral shock with relatively small spillovers to the wider economy. In the face of this financial shock, a shock that revalues collateral and increases the borrowing capacity of households, a countercyclical LTV is a more effective tool for stabilization than monetary policy. We find that a reduction in the regulatory LTV will dampen the increase in debt and the expansion in housing prices and residential investment brought about by this shock. When, instead, monetary policy responds to the credit boom, higher policy interest rates also reduce the magnitude of the expansion of the housing market and household debt, but do so at the cost of larger spillover effects to output and inflation. In this case, the countercyclical LTV is effective because it is well targeted at the source of the vulnerability.

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Appendix: Parameters' calibration and Results

Table 1: Calibrated parameters

Parameter	Description	Value
Preferences and borrowing constraint		
α	Patient wage share	0.6234
β_1	Patient discount factor	0.99
β_2	Impatient discount factor	0.95
b	External habit persistence in consumption	0.70
η_1	Patient inverse labour supply elasticity	1.0
η_2	Impatient inverse labour supply elasticity	1.0
j	Weight of housing in utility functions	0.6
m	Impatient borrowing constraint	0.8
Housing and Capital		
δ_k	Fixed capital depreciation rate	0.025
δ_H	Housing depreciation rate	0.011
ψ^k	Capital adjustment cost	1.6102
ψ^H	Housing adjustment cost	1.1723
μ	Capital share of income	0.23
ω	Import share in final goods production	0.3
Wage and prices		
θ_d	Intermediate good price stickiness	0.6
θ_m	Import price stickiness parameters	0.6
θ_x	Export price stickiness export	0.2067
θ_w	Wage stickiness	0.667
ϵ	Elasticity of demand for brands	21.0
Monetary policy rule		
ρ_R	Monetary policy: smoothing parameter	0.8
ρ_π	Monetary policy: weight of inflation	2.5
ρ_Y	Monetary policy: weight on GDP	0.0
Open economy		
σ	Import demand elasticity	0.3455
σ_f	Export demand elasticity	1.6418
ϕ	Risk premium - debt-to-GDP	0.005
ϕ_s	Risk premium - expected s	0.0006
Autoregressive processes		
ρ_{ϵ_b}	Preference's shock persistence	0.9
ρ_{ϵ_j}	Housing demand's shock persistence	0.9
ρ_{ϵ_s}	Risk premium's shock persistence	0.9
ρ_z	TFP's shock persistence	0.9
ρ_{A^H}	Housing investment's shock persistence	0.9
ρ_{A^k}	Capital investment's shock persistence	0.9
$\rho_{\epsilon_{IO}}$	Inflation objective's shock persistence	0.9
ρ_{ϵ_L}	Labour supply's shock persistence	0.9
$\rho_{\epsilon_{ex}}$	Export demand's shock persistence	0.9
ρ_{ϵ_m}	Import demand's shock persistence	0.9
ρ_{ϵ_p}	Price markup's shock persistence	0.9

Figure 1: Impact of alternative LTV ratios on collateral shock propagation effects

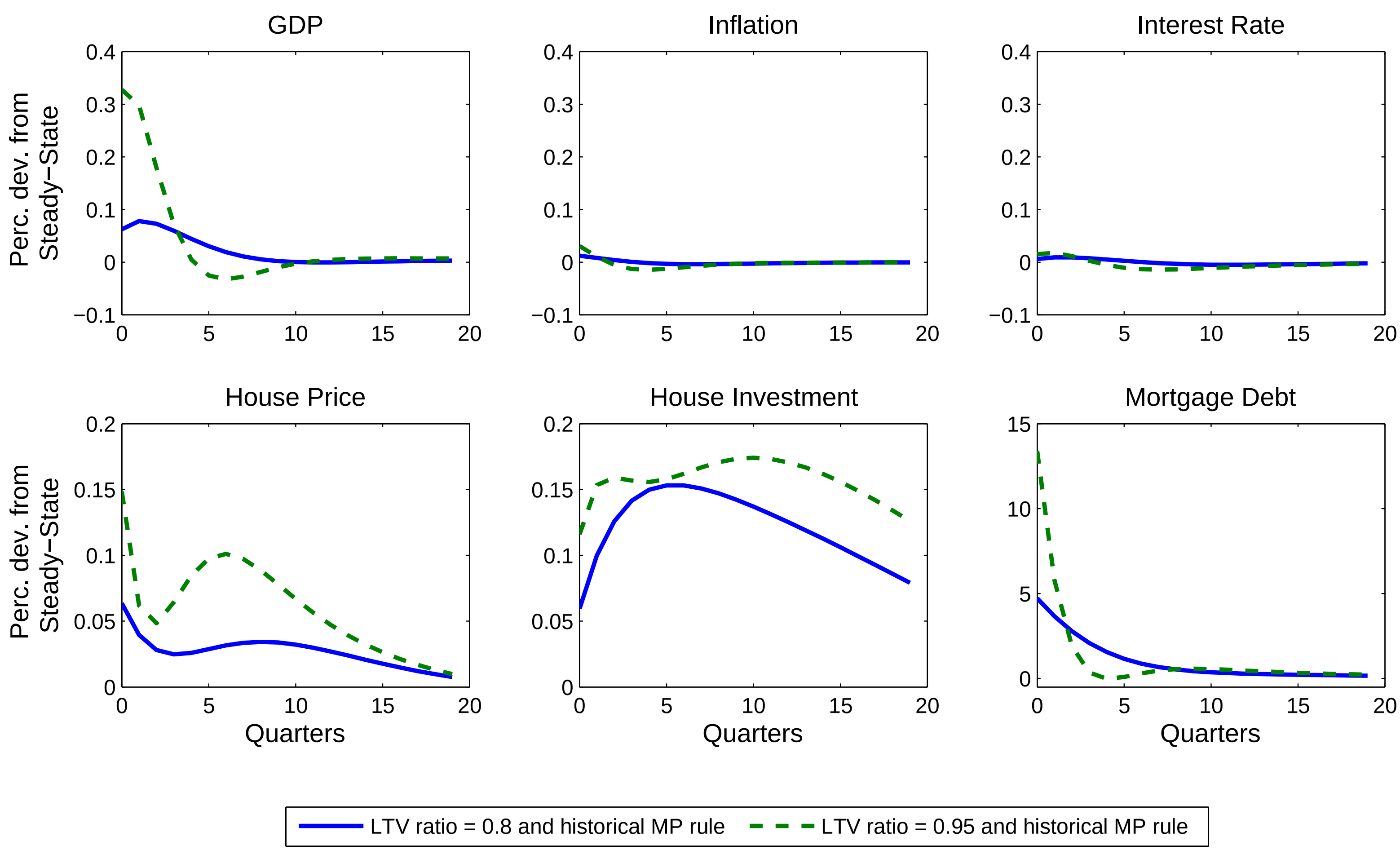

Figure 2: Impact of alternative LTV ratios on productivity shock propagation effects

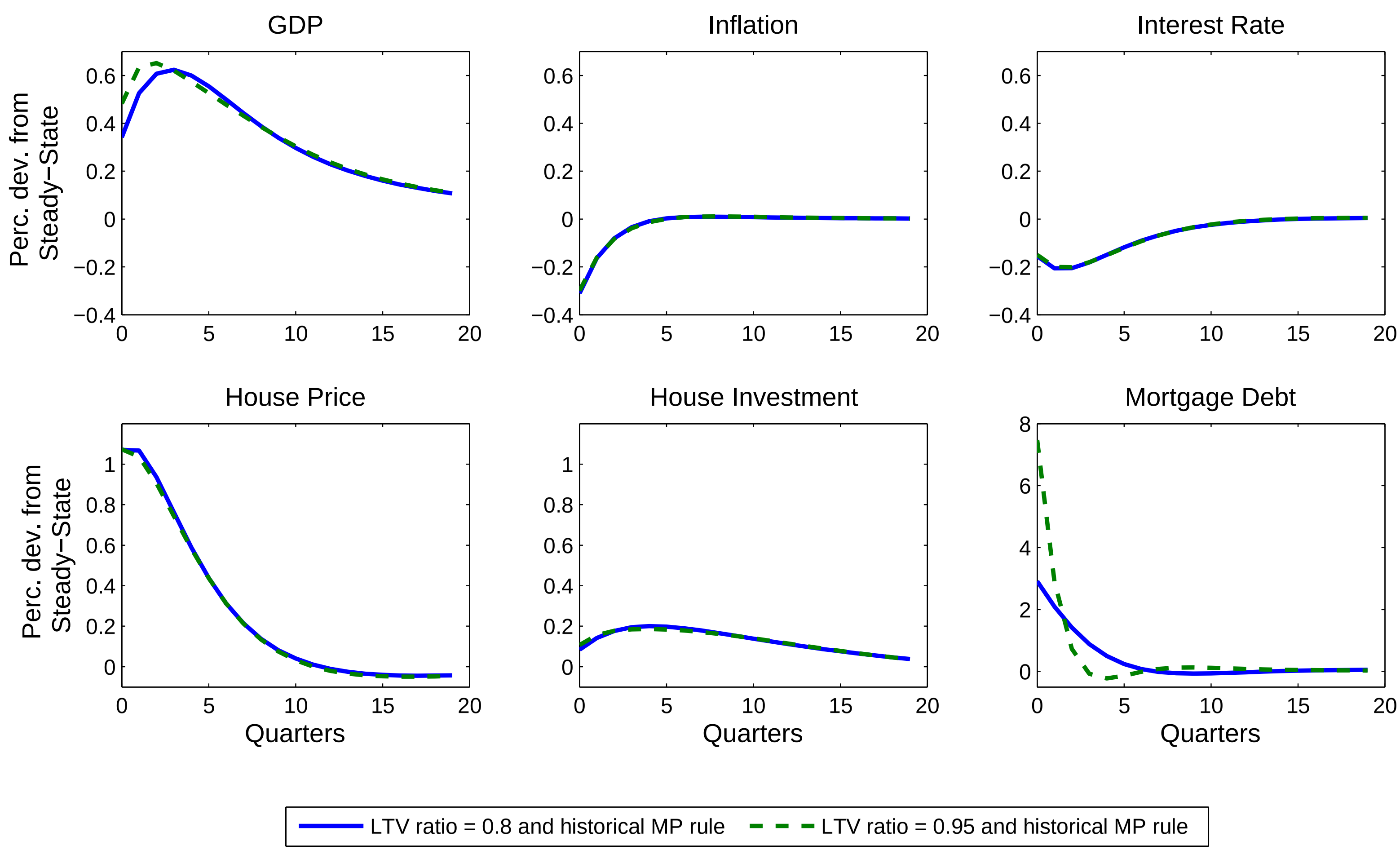

Figure 3: Collateral shock: Acyclical and Countercyclical LTV ratio

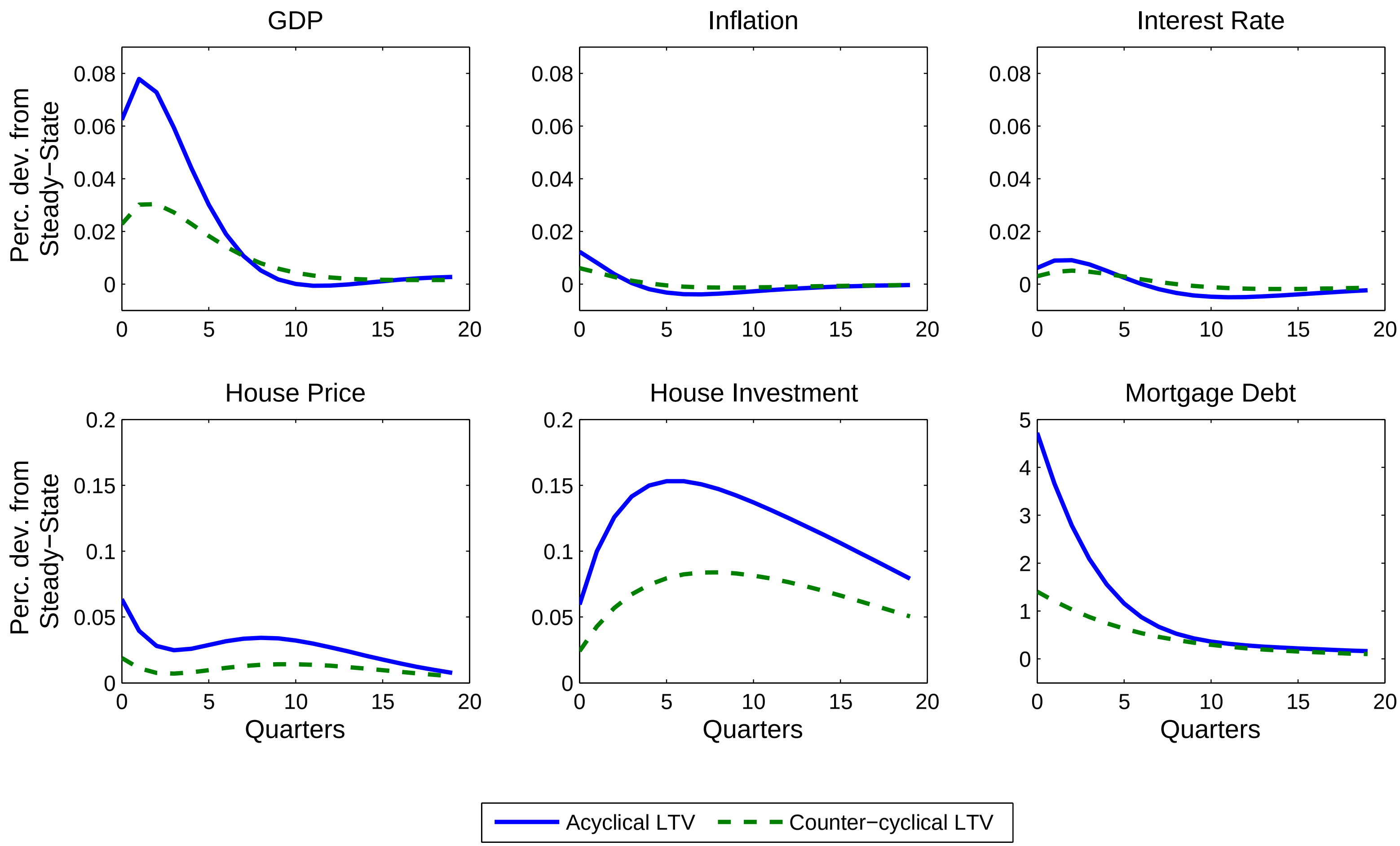

Figure 4: Collateral shock: Acyclical and Countercyclical LTV ratio with Credit in MP rule

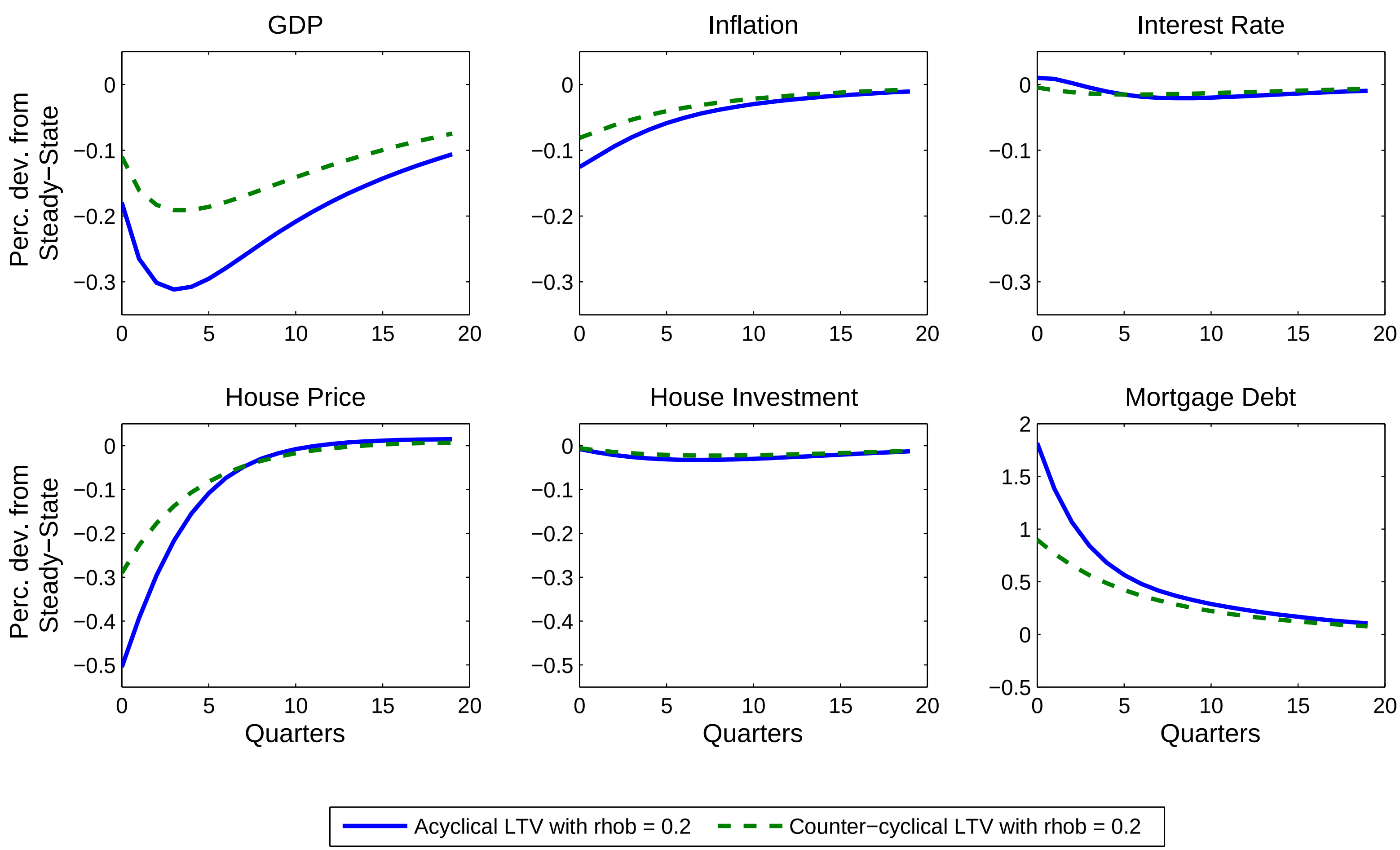

Figure 5: Productivity shock: Countercyclical LTV ratio