# Housing market dynamics and macroprudential policies

Gabriel Bruneau
*Bank of Canada*

Ian Christensen
*Bank of Canada*

Césaire Meh
*Bank of Canada*

*Abstract.* In this paper, we analyze the implications of macroprudential and monetary policies for credit cycles, housing market stability and spillovers to consumption. We consider a countercyclical loan-to-value (LTV) policy that responds to a credit-to-income ratio, and we compare its effectiveness with a permanent tightening of the LTV ratio and a monetary policy rule that responds to credit. To this end, we construct a dynamic stochastic general equilibrium model with housing market, household debt and collateral constraints, and we estimate it with Canadian data using Bayesian methods. Our study suggests that a countercyclical LTV ratio is a useful policy to reduce spillovers from the housing market into consumption and to lean against housing market boom–bust cycles. It performs better than the permanent tightening of the LTV ratio—a policy that has been used in a number of countries—and the monetary policy rule, both in terms of the stabilization of household indebtedness and spillovers into consumption. Monetary policy that leans against the wind is the least desirable due to its large adverse consequences on the real economy.

*Résumé. Dynamiques du marché de l'habitation et politiques macroprudentielles.* Dans ce texte, les auteurs analysent les implications des politiques macroprudentielles et monétaires pour les cycles de crédit, la stabilité du marché de l'habitation, et les effets de retombée sur la consommation. On considère une politique contre-cyclique prêt/valeur (P/V) qui répond à un ratio crédit/revenu, et on compare son efficacité avec une contraction permanente du ratio P/V et une politique monétaire qui répond au crédit. À cette fin, on construit un modèle d'équilibre général dynamique stochastique et qui prend en compte le marché de l'habitation, la dette des ménages et les contraintes collatérales, et on e ce modèle à l'aide de méthodes bayésiennes en utilisant des données

Corresponding author: Gabriel Bruneau, gbruneau@bankofcanada.ca

The authors would like to thank Amélie Clément, Stefano Gnocchi, Brian Peterson, Jörn Tenhofen and two referees for very useful suggestions. They would also like to thank Jason Allen, Randall Morck and conference and seminar participants at the CEA, AEA, Swiss National Bank, Banco de Mexico, Central Bank of Chile and IFSC Dublin for comments and suggestions. Very constructive suggestions from the editor significantly improved the paper. Andrew Usher, Hongyu Xiao, Omar Abdelrahman and William Leung provided excellent research assistance. The views expressed in this paper are those of the authors. No responsibility for them should be attributed to the Bank of Canada.

Canadian Journal of Economics / *Revue canadienne d'économique* 2018 51(3)
August 2018. Printed in Canada / *Août 2018. Imprimé au Canada*

ISSN: 0008–4085 / 18 / pp. 864–900 / 

canadiennes. L'étude suggère qu'un ratio P/V contre-cyclique est une politique utile pour réduire les effets de retombée du marché de l'habitation sur la consommation, et pour contrer les cycles d'expansion et de contraction dans le marché de l'habitation. C'est une politique plus efficace qu'une contraction permanente de P/V – une politique qui a été utilisée dans de nombreux pays – et que la règle de politique monétaire, à la fois pour la stabilisation de l'endettement des ménages et les effets de retombée sur la consommation. La politique monétaire qui va à contre-courant de la tendance du marché est la moins désirable à cause des conséquences néfastes importantes sur l'économie réelle.

JEL classification: E31, E42, H23

## 1. Introduction

Understanding the dynamics between house prices and the accumulation of household debt is particularly important for policymakers designing and implementing public policy and regulation, as it has been established that housing busts preceded by large household debt increases tend to result in deeper recessions (IMF 2012). For instance, the recession resulting from the collapse of the US housing market after the financial crisis of 2008–2009 was more severe and prolonged relative to an average one, as households and financial institutions engaged in a long deleveraging process.

The regulatory LTV ratio on mortgages imposes a cap on the size of a mortgage loan relative to the value of a property at origination. It is therefore a policy measure that limits the leverage created by mortgage loans. There is growing evidence that high levels of a fixed LTV ratio or leverage contribute to the procyclicality of the housing market and exacerbate housing market boom–bust cycles, potentially leading to an increase in housing market vulnerabilities (Iacoviello and Neri 2010, Lamont and Stein 1999, Almeida et al. 2006, Calza et al. 2013). In recent years, a number of jurisdictions have lowered the regulatory LTV ratio limit to address financial stability concerns related to household indebtedness. However, the literature suggests that a lower LTV limit will reduce, but not eliminate, the significant amplifying role of the borrowing constraint for shocks that occur in housing markets.

Countercyclical LTV ratios are one potential regulatory tool to reduce the likelihood and impact of housing market boom–bust cycles. We provide a quantitative analysis of the effectiveness and trade-offs of this policy, in comparison with a monetary policy that leans against the wind, to address household indebtedness concerns. Specifically, we ask the following questions: Should LTV regulation be fixed or countercyclical (i.e., lowering the cap during upswings in housing activity and raising the cap during downswings)? If it should be countercyclical, to what extent? Should a monetary policy that "leans against the wind" be used instead?

The proposed analysis is relevant for countries like Canada, which have experienced a significant increase in house prices and household debt (see

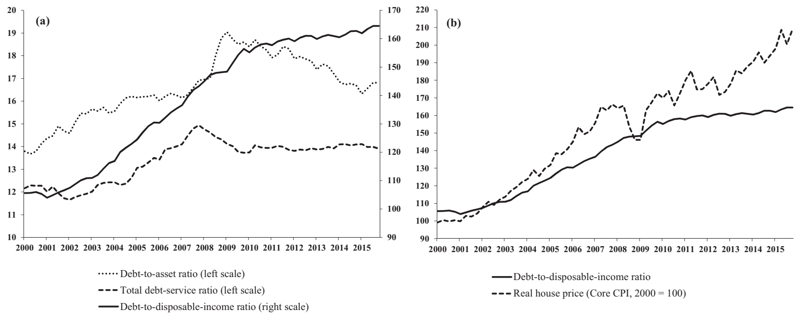


**FIGURE 1** Debt-to-disposable-income ratio and real house prices, from 2000 to 2015

figure 1). In recent years, household asset growth has outpaced the growth in household debt, pushing down the aggregate household debt-to-asset ratio. That said, since Canadian borrowers' most important asset is their house, their overall net worth remains sensitive to house price movements.

This paper develops a macroeconomic model with a housing stock and household debt that provides a quantitative assessment of the questions raised above. To do so, we extend the model of Iacoviello and Neri (2010) on three important dimensions. First, we introduce multi-period fixed-rate mortgage loans. In Canada, the majority of mortgage loan contracts have a length of five years and a fixed interest rate. This feature is potentially crucial to replicate business cycle facts, in particular, those related to debt dynamics (Gelain et al. 2017). Second, we assume that borrowers face a credit constraint tied to the current value of their housing investment, not their housing stock. The effectiveness of macroprudential policies, either countercyclical LTV or a monetary policy that leans against the wind, will be reduced as they apply only to new loans, and not on the entire stock of debt, as in models with a one-period loan and variable rate (Iacoviello and Neri 2010). This is an important feature of real-world LTV policies. Third, we introduce a shock on the house-price expectations of agents, which drives a wedge between the actual value of housing and its value under rational expectation (Alpanda and Zubairy 2017). These three extensions allow us to study the effect of macroprudential policies in a context where agents can have (over-)optimistic expectations about their future housing wealth and react by accumulating more debt under fixed long-term contracts. Following these steps, we operationalize the countercyclical LTV ratio caps, making it endogenous to macroeconomic developments, by reacting to the ratio of mortgage debt to income.

We report three main findings. First, a countercyclical LTV ratio is a useful policy to reduce the housing market spillovers on consumption and to prevent boom–bust cycles in the housing market. Second, a countercyclical LTV ratio that responds to the ratio of mortgage debt to income is more effective at reducing the volatility of household indebtedness than a monetary policy rule responding to debt or a permanent tightening of the LTV. Third, a monetary policy that leans against the wind is the least desirable because of its large adverse consequences on the real economy.

Our research is related to papers that consider the effects of changes in regulatory LTV in a dynamic stochastic general equilibrium (DSGE) framework similar to Iacoviello and Neri (2010). As in Lambertini et al. (2013), who study the potential gains of monetary and macroprudential policies that lean against house price and credit cycles, our model incorporates the notion of countercyclicality in LTV regulation. We also include multi-period mortgage loans, as in Gelain et al. (2014) and Alpanda and Zubairy (2017). However, they do not consider a countercyclical LTV. It is crucial to study the effectiveness of a countercyclical LTV ratio in a model that includes debt amortization since these policies typically apply to new loans. Finally, we draw from the literature that studies policy responses to housing market boom–bust cycles driven by departures from rational expectations (Burnside et al. 2016, Gelain et al. 2013).

The paper is organized as follows. Section 2 presents the theoretical model. Section 3 describes the calibration, estimation and data and discusses the estimation results and the overall performance of the model in describing business cycle characteristics. Section 4 introduces the macroprudential policies, while section 5 describes housing market dynamics and discusses the effectiveness of macroprudential policies. Finally, section 6 concludes.

## 2. Model

We start from a standard New Keynesian set-up, extended to incorporate household heterogeneity, irreversible housing investment and credit frictions, similar to Iacoviello (2005) and Iacoviello and Neri (2010). However, we depart from the usual set-up in three main ways, to better reflect the realities of the Canadian housing market. First, similar to Gelain et al. (2014), Alpanda et al. (2014) and Alpanda and Zubairy (2017), we allow for multi-period mortgage loans with fixed interest rates. This is a representation closer to the Canadian context, where most mortgage loan contracts have a length of five years and a fixed interest rate. Second, we assume that borrowers face a credit constraint tied to the current value of their housing investment, not their housing stock. This allows us to differentiate between the flow, to which the LTV ratio applies, and the stock of debt. It reflects the fact that mortgages are usually not callable. Third, we assume that agents experience an “expectation” shock on their rational expectations of housing prices (Alpanda and Zubairy 2017), as deviation from the *fundamental* value of housing is often identified as one of the main drivers in housing demand, leading to self-fulfilling expectations.

The rest of the model is standard. The economic agents are: (i) two types of heterogeneous households, namely patient and impatient households; (ii) two sectors of production in the economy, namely the non-housing goods sector, which produces consumption and capital goods, and the housing sector; (iii) financial intermediaries that convert patient households’ deposits into mortgage loans to impatient households and (iv) an authority that conducts monetary policy according to a Taylor-type rule (Taylor 1993) and macroprudential policy. The model also includes various nominal and real rigidities such as price and wage stickiness, indexation of prices and wages to past inflation, habit formation in consumption and housing services, adjustment costs in investment and costs of capital utilization.[1]

## 2.1. Households

The economy is populated by a unit measure of both types of infinitely lived patient ($i=P$) and impatient ($i=I$) households. Credit flows are generated by assuming ex-ante heterogeneity in agents' subjective discount factors, as the impatient agents discount the future at a faster rate than patient agents ($\beta_P > \beta_I$). Hence, in equilibrium, patient agents are net lenders while impatient agents are net borrowers. Households supply labour $n_{i,t}$ and derive utility from consumption $c_{i,t}$ and housing services $h_{i,t}$. The expected lifetime utility is given by

$$E_0 \sum_{t=0}^{\infty} \beta_i^t \epsilon_t^\beta \Bigg[ (1-\epsilon_t^h) \ln(c_{i,t} - \phi_i^c c_{i,t-1}) + \epsilon_t^h \ln(h_{i,t} - \phi_i^h h_{i,t-1}) - \frac{\epsilon_t^n}{1+\eta_i} n_{i,t}^{1+\eta_i} \Bigg], \tag{1}$$

where $n_{i,t} = ((n_{i,t}^c)^{\frac{\theta_i^n+1}{\theta_i^n}} + (n_{i,t}^h)^{\frac{\theta_i^n+1}{\theta_i^n}})^{\frac{\theta_i^n}{\theta_i^n+1}}$ is a CES aggregate of hours worked in both the non-housing goods sector, $n_{i,t}^c$, and the housing sector, $n_{i,t}^h$ (Horvath 2000, Iacoviello and Neri 2010). The parameters $\phi_i^c$ and $\phi_i^h$ govern the importance of habit formation in consumption and housing, respectively. While habit formation in consumption is a standard assumption, habit in housing services is not. Habit in housing services may capture transaction costs—either fixed or nonlinear with kinks—and may prevent households from adjusting their housing stock rapidly to the desired level. It could also involve emotional costs, as people become attached to their houses, environment and neighbours with time (see Kraft et al. 2015 for an in-depth discussion).

The intertemporal utility is affected by three stationary AR(1) exogenous processes. $\epsilon_t^\beta$ represents an exogenous process on discount rates that affects the intertemporal substitution of households (Smets and Wouters 2007, Justiniano et al. 2010) and therefore generates a time-varying natural rate of interest (Laubach and Williams 2016, Lubik and Matthes 2015). $\epsilon_t^h$ and $\epsilon_t^n$ are exogenous processes on the preference for services provided by the housing stock (i.e., housing demand shock) and labour supplies, respectively.

A central authority within households makes labour decisions and monopolistically supplies differentiated labour $n_{i,e,t}^j$ in a continuum of labour

1 A detailed description of the model is available in section A of the technical appendix available in the online version of this article.

markets $e \in [0,1]$ for each sectors of production (Erceg et al. 2000, Schmitt-Grohe and Uribe 2007) to satisfy the labour demand:

$$n^j_{i,e,t} = \left( \frac{W^j_{i,e,t}}{W^j_{i,t}} \right)^{-\theta^{n^j}} n^{j,d}_{i,t}, \tag{2}$$

where $W^j_{i,e,t}$ and $W^j_{i,t}$ are the nominal wage in the labour market $e$ and the nominal wage index, respectively. Combining the resource constraint $n^j_{i,t} = \int_0^1 (n^j_{i,e,t}) de$ with equation (2) yields the aggregated labour supply expressed in real terms:

$$n^j_{i,t} = n^{j,d}_{i,t} \int_0^1 \left( \frac{w^j_{i,e,t}}{w^j_{i,t}} \right)^{-\theta^{n^j}} de. \tag{3}$$

We introduce wage stickiness by assuming that, in each period, the central authority within household $i$ cannot set the nominal wage optimally for a share $\xi^{w^j} \in (0,1)$ of labour markets chosen randomly (Erceg et al. 2000, Schmitt-Grohe and Uribe 2007) but resets it according to the indexation rule $W^j_{i,e,t} = W^j_{i,e,t-1} (\pi^c)^{\iota^{w^c}} (\pi^c_{t-1})^{1-\iota^{w^c}}$, where $\pi^c_{t-1}$ is past gross inflation and $\pi^c$ its steady state. The remaining fraction of labour markets set $W^j_{i,e,t}$ optimally to equate the average of the expected future marginal revenue to the average of the marginal cost of supplying labour.

Households accumulate housing stock according to the law of motion:

$$h_{i,t} = \left(1 - \delta^h\right) h_{i,t-1} + i^h_{i,t}, \tag{4}$$

where $i^h_{i,t}$ is the investment in housing stock. An aggregate housing investment is irreversible,[2] while the housing investment at the household level is reversible (i.e., it can be traded with the other type of households) at the real equilibrium house price.

Finally, to allow the observed real house price $q^h_t$ to deviate from its rational expectation value, we let agents' expectations regarding future house prices be modified by an expectation shock $\epsilon^{q^h}_t$, which follows a stationary AR(1) process. Unlike a positive housing preference shock, which would increase agents' marginal utility of housing (i.e., rents), a positive expectation shock increases the expected capital gains from future house price increases in a persistent manner and thus creates a gap between the observed house price and its underlying rational expectation value (Alpanda and Zubairy 2017). The housing price influences the borrowing capacity of agents via the

2 It is the only type of goods produced by the housing sector; it therefore cannot be converted, as a consumption good can be converted to a capital good, once it is built.

constraint (see section 2.1.2). Expectation shocks can generate optimism or pessimism, causing important fluctuations in housing investment. Optimistic expectations lead to excessive housing investment, causing a boom in the housing market. Once an expectation reversal happens, buyers reverse their actions and a bust in the housing market follows.

### 2.1.1. Patient households

Patient households accumulate housing and capital stock, own all the land stock $l_t$,[3] supply loans to impatient households via long-term deposit at financial intermediaries and, since they own the financial intermediaries and firms in both sectors, receive dividends and profits. The budget constraint of the patient household is given by

$$
\begin{aligned}
c_{P,t} + q_t^h i_{P,t}^h + \sum_{j\in\{c,h\}} q_t^{kj} i_t^{kj} + q_t^l l_t + b_{P,t} + d_t = & \sum_{j\in\{c,\,h\}} r_t^{kj} u_t^{kj} k_{t-1}^j \\
& + (q_t^l + r_t^l) l_{t-1} + \sum_{j\in\{c,\,h\}} n_{P,t}^{j,d} \int_0^1 w_{P,e,t}^j \left(\frac{w_{P,e,t}^j}{w_{P,t}^j}\right)^{-\theta^{n^j}} de \\
& + \frac{R_{t-1} b_{P,t-1}}{\pi_t^c} + \sum_{j\in\{c,\,h,\,b\}} f_t^j + \frac{1}{\phi^d}\sum_{s=1}^{\phi^d} \frac{d_{t-s}}{\prod_{v=-s}^{0}\pi_{t+v}^c} \\
& + \sum_{s=1}^{\phi^d}\left(R_{t-s}^d - 1\right)\left(\frac{\phi^d - s + 1}{\phi^d}\right)\frac{d_{t-s}}{\prod_{v=-s}^{0}\pi_{t+v}^c},
\end{aligned}
\tag{5}
$$

where $b_{P,t}$ is the short-term bond and $f_t^j$ for $j \in \{c, h, b\}$ are the profits from the firms in non-housing and housing sectors and financial intermediaries, respectively. They are also subject to the law of motion for the housing stock (4) and the law of motion for capital in sector $j$:

$$
k_t^j = \left(1 - \delta_t^{kj}\right) k_{t-1}^j + z_t^{ik} i_t^{kj}\left[1 - \frac{\phi^{kj}}{2}\left(\frac{i_t^{kj}}{i_{t-1}^{kj}} - 1\right)^2\right], \tag{6}
$$

where $i_t^{kj}$ is the capital investment level in sector $j$. Patient households face an adjustment cost while investing in capital. The technology transforming final goods into capital goods is subject to a stationary AR(1) exogenous process denoted $z_t^{ik}$ (Justiniano et al. 2010), thereby inducing a time-varying real price of investment $q_t^{kj}$. Patient households can also control the intensity $u_t^{kj}$ at which they use the capital stock, where an increased intensity of utilization entails a cost in the form of a faster rate of depreciation (Schmitt-Grohe and Uribe 2012):

$$
\delta_t^{kj} = \delta_0^{kj} + \delta_1^{kj}\left(u_t^{kj} - 1\right) + \frac{\delta_2^{kj}}{2}\left(u_t^{kj} - 1\right)^2. \tag{7}
$$

3 The stock of land is exogenous, fixed and used in housing production. See section 2.2.2.

Patient households' savings take the form of $\phi^d$-period long-term deposit $d_t$ at the financial intermediaries with fixed interest rate $R_t^d$. Each period, the lenders receive a share $\frac{1}{\phi^d}$ of the principal as a reimbursement of the deposit and a fixed return on investment $(R_t^d - 1)$ on the principal not reimbursed at the last period.

Most of the optimality conditions are standard. For deposit, the optimality condition is given by

$$\epsilon_t^\beta \lambda_{P,t}^c = \sum_{s=1}^{\phi^d} \beta_P^s E_t \left[ \epsilon_{t+s}^\beta \frac{\lambda_{P,t+s}^c}{\prod_{v=1}^{s} \pi_{t+v}^c} \left( \frac{1}{\phi^d} + \left( R_t^d - 1 \right) \left( \frac{\phi^d - s + 1}{\phi^d} \right) \right) \right], \tag{8}$$

where $\lambda_{P,t}^c$ is the Lagrange multiplier on budget constraint (5). The patient household equates the cost of sacrificing one unit of consumption goods to the benefit of making deposits, which generates a flow of revenues for $\phi^d$ periods. Finally, the expectation shock on house prices $\epsilon_t^{q^h}$ impacts patient households via the optimality condition on housing:

$$\begin{aligned} \epsilon_t^\beta \lambda_{P,t}^c q_t^h - \beta_P (1-\delta^h) E_t[\epsilon_{t+1}^\beta \lambda_{P,t+1}^c \epsilon_t^{q^h} q_{t+1}^h] = & \frac{\epsilon_t^\beta \epsilon_t^h}{h_{P,t} - \phi_P^h h_{P,t-1}} \\ & - \beta_P \phi_P^h E_t \left[ \frac{\epsilon_{t+1}^\beta \epsilon_{t+1}^h}{h_{P,t+1} - \phi_P^h h_{P,t}} \right]. \end{aligned} \tag{9}$$

### 2.1.2. Impatient households

Impatient households maximize their stream of expected future utility subject to the following budget constraint:

$$\begin{aligned} & c_{I,t} + q_t^h i_{I,t}^h + \frac{1}{\phi^a} \sum_{s=1}^{\phi^m} \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \left( \frac{\phi^a - \phi^m}{\phi^a} \right) \frac{m_{t-\phi^m}}{\prod_{v=-\phi^m}^{0} \pi_{t+v}^c} \\ & + \sum_{s=1}^{\phi^m} \left( R_{t-s}^m - 1 \right) \left( \frac{\phi^a - s + 1}{\phi^a} \right) \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} \\ & = \sum_{j \in \{c,h\}} n_{I,t}^{j,d} \int_0^1 w_{I,e,t}^j \left( \frac{w_{I,e,t}^j}{w_{I,t}^j} \right)^{-\theta^{n^j}} de + m_t, \end{aligned} \tag{10}$$

the law of motion for housing stock (4) and a borrowing constraint. $m_t$ denotes mortgage loans and $R_t^m$ is the fixed interest rate. As documented by Campbell (2013), in many countries including Canada, the majority of mortgage loans are long-term with a fixed rate. For the purpose of this paper, only one type of mortgage is available, with fixed linear principal payments, a term of length $\phi^m$ and an amortization of length $\phi^a$, so that in each period borrowers have to pay interest on the outstanding debt and repay the amount of principal due.

Private borrowing is subject to an endogenous limit. Impatient households cannot borrow more than a share $\omega$ (Kiyotaki and Moore 1997, Iacoviello 2005, Monacelli 2009, Iacoviello and Neri 2010) of the current value of their housing investment and the full amount of the residual mortgage value over the term $\phi^m$:

$$m_t \leq \omega \chi_t q_t^h i_{I,t}^h + \left(\frac{\phi^a - \phi^m}{\phi^a}\right) \frac{m_{t-\phi^m}}{\prod_{v=-\phi^m}^{0} \pi_{t+v}^c}, \tag{11}$$

where $\chi_t$ represents time-varying credit availability (potentially reflecting changing unmodelled lending behaviour from financial institutions) and follows a stationary AR(1) exogenous process. The model reflects the fact that mortgage debt is re-optimized only for the new investment in housing and the share of contracts that reach their end and must be refinanced.[4] This type of long-term loan has just begun to be studied in the literature (Gelain et al. 2014, Alpanda et al. 2014, Alpanda and Zubairy 2017) and has important implications for, among others, the transmission of monetary policy shocks and the effectiveness of macroprudential policy. First, financial intermediaries cannot demand faster debt repayment when the household leverage (i.e., the observed LTV) ratio exceeds the fixed LTV cap. Therefore, the stock of debt is not equal to the flows of debt, and mortgage loans can only be reimbursed fully with negative housing investment (i.e., selling housing stock) once they reach the maturity of $\phi^m$ periods. This implies that the transmission effects of any shock to the housing market are greatly reduced, as this only applies to new loans. Second, a fixed interest rate can be viewed as insurance against future short-term interest rate increases, thereby reducing the transmission of monetary policy. An interest rate tightening only affects mortgage loans at origination or a refinancing, not existing loans. Third, the stock of debt being highly persistent implies an asymmetric reaction following the implementation of a countercyclical LTV ratio, depending on the stage of the business or credit cycle.

The optimality conditions for housing investment and mortgage borrowing are

$$\begin{aligned}
&\epsilon_t^\beta \lambda_{I,t}^c q_t^h - \beta_I \left(1-\delta^h\right) E_t \left[\epsilon_{t+1}^\beta \lambda_{I,t+1}^c \epsilon_t^{q^h} q_{t+1}^h\right] \\
&= \frac{\epsilon_t^\beta \epsilon_t^h}{h_{I,t} - \phi_I^h h_{I,t-1}} - \beta_I \phi_I^h E_t \left[\frac{\epsilon_{t+1}^\beta \epsilon_{t+1}^h}{h_{I,t+1} - \phi_I^h h_{I,t}}\right] \\
&+ \epsilon_t^\beta \lambda_{I,t}^c \lambda_t^b \omega \chi_t q_t^h - \beta_I \left(1-\delta^h\right) E_t \left[\epsilon_{t+1}^\beta \lambda_{I,t+1}^c \lambda_{t+1}^b \omega \chi_{t+1} \epsilon_t^{q^h} q_{t+1}^h\right]
\end{aligned} \tag{12}$$

and

$$\begin{aligned}
&\epsilon_t^\beta \lambda_{I,t}^c \left(1-\lambda_t^b\right) = \beta_I^{\phi^m} E_t \left[\epsilon_{t+\phi^m}^\beta \frac{\lambda_{I,t+\phi^m}^c}{\prod_{v=1}^{\phi^m} \pi_{t+v}^c} \left(\frac{\phi^a - \phi^m}{\phi^a}\right) \left(1 - \lambda_{t+\phi^m}^b\right)\right] \\
&+ \sum_{s=1}^{\phi^m} \beta_I^s E_t \left[\epsilon_{t+s}^\beta \frac{\lambda_{I,t+s}^c}{\prod_{v=1}^{s} \pi_{t+v}^c} \left(\frac{1}{\phi^a} + (R_t^m - 1)\left(\frac{\phi^a - s + 1}{\phi^a}\right)\right)\right],
\end{aligned} \tag{13}$$

4 The model abstracts from home equity lines of credit (HELOCs).

where $\lambda_{I,t}^{c}$ and $\lambda_{t}^{b}$ are the Lagrange multipliers on budget constraint (10) and borrowing constraint (11), respectively. In equation (12), the marginal cost of purchasing a unit of housing today is dampened by the shadow gain from relaxing the borrowing constraint associated with an increase in the level of housing stock. Since the borrowing constraint is on the flow and not on the stock of housing, the marginal gain for $t+1$ is also dampened by the borrowing constraint, because today's housing purchases increase the housing stock level in $t+1$, thereby reducing the need to invest in housing in following periods. The expectation shock on house prices, $\epsilon_{t}^{q^h}$, affects the expectations of impatient households. Finally, in equation (13), the marginal gain of relaxing the borrowing constraint in the current period is equal to the discounted principal payment and interest cost on a mortgage.

## 2.2. Firms

### 2.2.1. Non-housing sector

*Final-goods producers*

Perfectly competitive firms purchase differentiated intermediate goods $m \in [0,1]$ to assemble final goods $y_{t}^{c}$ according to the technology:

$$y_{t}^{c} = \left[ \int_{0}^{1} \left( y_{m,t}^{c} \right)^{\frac{\theta^{c}-1}{\theta^{c}}} dm \right]^{\frac{\theta^{c}}{\theta^{c}-1}}. \tag{14}$$

Cost minimization and the zero profit condition imply that the price of the final goods, $P_{t}^{c}$, is a CES aggregate of the prices of the intermediate goods $P_{m,t}^{c}$:

$$P_{t}^{c} = \left[ \int_{0}^{1} \left( P_{m,t}^{c} \right)^{1-\theta^{c}} dm \right]^{\frac{1}{1-\theta^{c}}}, \tag{15}$$

and the demand function for the intermediate goods $m$ is

$$y_{m,t}^{c} = \left( \frac{P_{m,t}^{c}}{P_{t}^{c}} \right)^{-\theta^{c}} y_{t}^{c}. \tag{16}$$

*Intermediate-goods producers*

A monopolist produces the non-housing intermediate goods $m$ according to the production function:

$$y_{m,t}^{c} = z_{t}^{c} \left( k_{m,t}^{c} \right)^{\gamma^{c}} \left( \left( n_{P,m,t}^{c,d} \right)^{\alpha} \left( n_{I,m,t}^{c,d} \right)^{1-\alpha} \right)^{1-\gamma^{c}}, \tag{17}$$

where $k_{m,t}^{c}$ is the capital stock rented and $n_{i,m,t}^{c,d}$ are the number of hours of work demanded for both types of workers. $z_{t}^{c}$ represents a sector-wide total factor productivity process and follows a stationary AR(1) process. Finally, $\alpha$ is the patient households' share of labour income, which implicitly defines the weight of both types of households in the economy.

As in Calvo (1983) and Yun (1996), in every period, a fraction $\xi^{p^c}$ of intermediate firms cannot choose its price optimally but resets it according to the indexation rule $P^c_{m,t} = P^c_{m,t-1}(\pi^c)^{\iota^{p^c}} (\pi^c_{t-1})^{1-\iota^{p^c}}$, where $\pi^c_t$ is the gross inflation and $\pi^c$ is its steady-state. Other firms choose their price $P^c_{m,t}$ optimally by maximizing the present discounted value of future profits.

### 2.2.2. Housing sector

A representative firm produces houses in a perfectly competitive environment according to the technology:

$$y^h_t = z^h_t \left(u^{k^h}_t k^h_{t-1}\right)^{\gamma^h} l^{\gamma^l}_{t-1} \left(\left(n^{h,d}_{P,t}\right)^{\alpha} \left(n^{h,d}_{I,t}\right)^{1-\alpha}\right)^{1-\gamma^h-\gamma^l}, \tag{18}$$

where $u^{k^h}_t k^h_{t-1}$ is the capital stock rented, $n^{h,d}_{P,t}$ and $n^{h,d}_{I,t}$ are the number of hours of work demanded for both types of workers and $l_{t-1}$ is the land stock rented. $z^h_t$ is the sector-wide total factor productivity, which follows a stationary AR(1) process. $\alpha$ is the same as in (17) and $\gamma^l$ is the land share of income. The fixed stock of land creates a decreasing return to scale in the housing sector, similar to a convex adjustment cost (Iacoviello and Neri 2010).[5]

## 2.3. Financial intermediaries

Perfectly competitive financial intermediaries accept deposit $d_t$ from patient households at rate $R^d_t$ and lend $m_t$ to impatient households at rate $R^m_t$. The spread between rates on deposits and loans reflects a time-varying intermediation cost. Given that Canada is a small open economy, Canadian banks' funding costs are influenced by foreign markets, making it difficult to endogenously model the Canadian interest rate spread in a closed economy model like the one in this paper. Therefore, modelling it as a stationary AR(1) exogenous process is a simplification that keeps the transmission channel to the real economy.

Deposits are the only source of funding for the financial intermediaries to finance fixed-rate, long-term loans. We impose long-term deposits with the same term length as the mortgage loans and a fixed interest rate. We do so for simplicity to avoid keeping track of deposits and loans with different maturities, thereby avoiding solvency and funding risks.

Financial intermediaries maximize the expected present value of their real dividends, subject to their balance sheets,

5 The availability of land has been identified in the literature (Davis and Heathcote 2005, Kiyotaki et al. 2010) as one of the drivers of the housing price increase over the last two decades in major Canadian city areas, especially in Vancouver and Toronto.

$$
\begin{aligned}
& d_t + \frac{1}{\phi^a} \sum_{s=1}^{\phi^m} \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \sum_{s=1}^{\phi^m} \left(R_{t-s}^m - 1\right) \left(\frac{\phi^a - s + 1}{\phi^a}\right) \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} \\
& + \left(\frac{\phi^a - \phi^m}{\phi^a}\right) \frac{m_{t-\phi^m}}{\prod_{v=-\phi^m}^{0} \pi_{t+v}^c} = \\
& m_t + \frac{1}{\phi^d} \sum_{s=1}^{\phi^d} \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \sum_{s=1}^{\phi^d} \left(R_{t-s}^d - 1\right) \left(\frac{\phi^d - s + 1}{\phi^d}\right) \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} \\
& + f_t^b + \epsilon_t^{R^m} m_t,
\end{aligned}
\tag{19}
$$

which yields the solution for

$$
R_t^d = \frac{1 - \frac{1}{\phi^d} \sum_{s=1}^{\phi^d} \beta_P^s E_t \left[ \frac{\epsilon_{t+s}^\beta}{\epsilon_t^\beta} \frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c \prod_{v=1}^{s} \pi_{t+v}^c} \right]}{\sum_{s=1}^{\phi^m} \frac{\phi^m - s + 1}{\phi^m} \beta_P^s E_t \left[ \frac{\epsilon_{t+s}^\beta}{\epsilon_t^\beta} \frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c \prod_{v=1}^{s} \pi_{t+v}^c} \right]} + 1 \tag{20}
$$

and

$$
R_t^m = \frac{\left(1 + \epsilon_t^{R^m}\right) - \frac{1}{\phi^a} \sum_{s=1}^{\phi^m} \beta_P^s E_t \left[ \frac{\epsilon_{t+s}^\beta}{\epsilon_t^\beta} \frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c \prod_{v=1}^{s} \pi_{t+v}^c} \right] - \Upsilon}{\sum_{s=1}^{\phi^m} \frac{\phi^a - s + 1}{\phi^a} \beta_P^s E_t \left[ \frac{\epsilon_{t+s}^\beta}{\epsilon_t^\beta} \frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c \prod_{v=1}^{s} \pi_{t+v}^c} \right]} + 1, \tag{21}
$$

where

$$
\Upsilon = \left(\frac{\phi^a - \phi^m}{\phi^a}\right) \beta_P^{\phi^m} E_t \left[ \frac{\epsilon_{t+\phi^m}^\beta}{\epsilon_t^\beta} \frac{\lambda_{P,t+\phi^m}^c}{\lambda_{P,t}^c \prod_{v=1}^{\phi^m} \pi_{t+v}^c} \right]. \tag{22}
$$

Both $R_t^d$ and $R_t^m$ are a weighted sum of expected monetary policy rates and do not include other components that we usually retrieve in long-term rates, such as the inflation risk premium and real term premium.

## 2.4. Monetary and macroprudential policies

The central bank follows a Taylor-type interest rate rule with interest smoothing:

$$
\begin{aligned}
& R_t = \rho_r R_{t-1} \\
& + (1 - \rho_r) \left( R + \rho_{\pi^c} \left( \left( \prod_{v=1}^{4} \pi_{t,t+v}^c \right)^{\frac{1}{4}} - \pi_t^{c,targ} \right) + \rho_y (Y_t - Y) \right) + \epsilon_t^R.
\end{aligned}
\tag{23}
$$

Thus, the nominal interest rate is adjusted in response to deviations of annual inflation from its target, $\pi_t^{c,targ}$, and deviations of GDP from its steady-state value, $Y$. As in Smets and Wouters (2003), Adolfson et al. (2007) and Christensen et al. (2016), the inflation target of the central bank is assumed to be time-varying and is subject to a stationary AR(1) exogenous process, whereas $\epsilon_t^R$ is an i.i.d. monetary policy shock. The time-varying inflation targeting is useful to model monetary policy in Canada for two reasons. First, the inflation-targeting regime was introduced in 1991, therefore it is in place for only three quarters of our sample. Second, the inflation-targeting regime defines a band between 1% and 3%, and the Bank of Canada does not always react with the same strength to reach the target of 2% when the inflation rate is within that band.

There is also a macroprudential authority that controls the regulatory LTV ratio to be applied to new loans, which follows the rule

$$\omega_t = \omega - \phi^\omega \left(\nu_t - \nu\right), \tag{24}$$

where $\nu$ is the instrument chosen by the authorities and $\phi^\omega \geq 0$ measures the response of the LTV ratio to the instrument. For the estimation of the model, we assume $\phi^\omega = 0$ (i.e., a fixed LTV), as is currently the case in Canada.

### 2.5. Exogenous processes

All the exogenous processes in the model introduced earlier follow a linear process:

$$\ln \Theta_t = (1 - \rho_\Theta) \ln \Theta + \rho_\Theta \ln \Theta_{t-1} + \varepsilon_t^\Theta, \quad \varepsilon_t^\Theta \sim^{i.i.d.} N\left(0, \sigma_\Theta^2\right), \tag{25}$$

where $\Theta_t = \{\chi_t, \epsilon_t^\beta, \epsilon_t^h, \epsilon_t^{q^h}, \epsilon_t^n, \pi_t^{c,targ}, \epsilon_t^R, \epsilon_t^{R^m}, z_t^c, z_t^h$ and $z_t^{ik}\}$ are the exogenous processes, $\Theta$ the steady states and $\rho_\Theta$ the persistence parameters with $0 < \rho_\Theta < 1$.

## 3. Empirical strategy and results

In this section, we briefly discuss the solution and estimation methodology, data, calibrated parameters, Bayesian inference, second moments and historical variance decomposition, leaving analysis of the housing market dynamics and discussion on policies for the following sections.

### 3.1. Solution and estimation

In order to compute the likelihood for a given set of parameters, we solve a log-linear approximation of the equilibrium conditions in the neighbourhood of the non-stochastic steady-state (Blanchard and Kahn 1980, Klein 2000, Sims 2002). The solution, which takes the form of a linear state-space model, is used to compute the likelihood function. We evaluate this function using the Kalman filter, maximize it using numerical methods and then use Bayesian methods to characterize the posterior distribution of the non-calibrated parameters (DeJong et al. 2000, Lubik and Schorfheide 2006, An and Schorfheide 2007).[6]

6 We use the particle swarm algorithm to obtain the maximum a posteriori. We then use an adaptive random-walk Metropolis posterior simulator, with 500,000 draws, 100,000 burn-in draws and a target acceptance ratio of 0.234.

### 3.2. Data

We estimate the model using Canadian quarterly data covering the 1983Q3 to 2014Q4 period. The vector of observables includes 15 variables: real consumption, residential investment, non-residential investment and mortgage debt per capita; real house and capital prices; nominal short-term and five-year mortgage interest rates; the core CPI inflation rate; and hours worked per capita, real wage and capacity utilization rates in both the non-housing and housing sectors.[7] We apply the one-sided Hodrick–Prescott (HP) filter to isolate the cyclical component[8] with a tuning in 1991Q2 for the interest rates and the core CPI inflation rate to reflect the implementation of the inflation-targeting regime by the Bank of Canada.

### 3.3. Calibrated parameters

The calibrated parameters are shown in table 1. Since most of the calibration follows the literature, we focus in this section on the key elements. Based on the hypothesis on real interest rates, we set $\beta_P$ at 0.9916. For the impatient households, we set $\beta_I$ at 0.97, which is in range of other studies that have estimated or calibrated this parameter (Krusell and Smith 1998, Iacoviello 2005, Iacoviello and Neri 2010, Gelain et al. 2013) and translates into a desire for borrowing.

In the mortgage market, $\omega$ (i.e., the LTV ratio) is set at 0.91, which is its average value in Canada over the last few decades. $\epsilon_{ss}^{R^m}$ is set at 0.115 to match the average quarterly spread between the short-term and the five-year mortgage rates over the last 30 years. $\phi^m$ and $\phi^d$ are set to 20 to reflect the five-year mortgage term and $\phi^a$ is set at 100 as 25 years is the maximum length of amortization at the maximum LTV in Canada.

The patient household's labour share of income, $\alpha$, indirectly determines the physical capital wealth[9] and the distribution of real estate wealth. We are departing from the commonly used value in the literature, estimated at 0.79 by Iacoviello and Neri (2010) based on macroeconomic data and used by Lambertini et al. (2010) and Lambertini et al. (2013), by setting it at 0.25. This value represents characteristics of the top quartile of households in the model economy and helps define important ratios: (i) the percentage of total wealth owned by the patient households is 71, which is broadly in line with microeconomic financial data for that quartile,[10] and

7 A detailed description of the dataset is available in section B of the technical appendix.

8 The model solution takes the form of a backward-looking state-space system, and a non-causal two-sided HP filter would contradict this structure. The better option is to use the backward-looking one-sided HP filter (Stock and Watson 1999). $\lambda$ is set at its usual value of 1600 for quarterly data.

9 Patient households own all the physical capital wealth.

10 See the *Survey of Financial Security* from Statistics Canada.

**TABLE 1**
Calibrated parameters

| Parameter | Value | Parameter | Value | Parameter | Value |
|---|---|---|---|---|---|
| Households | | | | | |
| *All* | | *Patient* | | *Impatient* | |
| $\delta^h$ | 0.0171 | $\beta_P$ | 0.9916 | $\beta_I$ | 0.97 |
| | | $\phi_P^h$ | 0.75 | $\phi_I^h$ | 0.75 |
| | | $\phi^d$ | 20.0 | $\phi^m$ | 20.0 |
| | | $\delta_0^{k^c}$ | 0.025 | $\phi^a$ | 100.0 |
| | | $\delta_1^{k^c}$ | 0.0335 | | |
| | | $\delta_0^{k^h}$ | 0.03 | | |
| | | $\delta_1^{k^h}$ | 0.0385 | | |
| Production | | | | | |
| *All* | | *Non-housing sector* | | *Housing sector* | |
| $\alpha$ | 0.25 | $\gamma^c$ | 0.25 | $\gamma^h$ | 0.10 |
| | | $\theta^c$ | 7.67 | $\gamma^l$ | 0.35 |
| | | $\theta^{n^c}$ | 7.67 | $\theta^{n^h}$ | 6.00 |
| Policy and steady-state | | | | | |
| $\omega$ | 0.91 | $\epsilon^b$ | 1.0 | $\epsilon^\pi$ | 1.005 |
| $\pi^c$ | 1.005 | $\epsilon^\chi$ | 1.0 | $\epsilon^{R^m}$ | 0.115 |
| $l$ | 1.0 | $\epsilon^h$ | 0.165 | $z^c$ | 1.0 |
| $u^{k^c}$ | 1.0 | $\epsilon^{q^h}$ | 1.0 | $z^h$ | 1.0 |
| $u^{k^h}$ | 1.0 | $\epsilon^n$ | 5.0 | $z^{i^k}$ | 1.0 |

(ii) when combined with the LTV ratio, mortgage debt as a share of GDP is 76%.

Finally, the capital share of income in the consumption sector, $\gamma^c$, is set at 0.25. In the housing sector, we set the capital and land share of income $\gamma^h$ and $\gamma^l$ at 0.10 and 0.35, respectively. These factor shares, along with a weight on housing services in the utility function $\epsilon_{ss}^h$ of 0.165, a habit formation parameter in housing services of 0.75 for both types of households and depreciation rates, imply steady-state ratios of consumption, non-housing investment and housing investment to real GDP of approximately 75%, 15% and 9%, respectively. This is in line with the data of our sample. Moreover, these calibration choices imply ratios of business capital and housing wealth (together with $\alpha$) to annual GDP of around 1.5 and 1.4, respectively.[11]

## 3.4. Prior distributions

The prior distributions are displayed in the first columns of tables 2, 3 and 4. Most of the prior densities on parameters are relatively standard and follow the literature. The prior distribution of all the persistence parameters is a beta,

11 A table providing more details on the steady-state ratios is available in section C of the technical appendix.

**TABLE 2**
Prior and posterior distributions of structural parameters

| Parameter | Prior distribution | | | Posterior distribution | | |
|---|---|---|---|---|---|---|
| | Distribution | Mean | Std. | Mode | 5% | 95% |
| Households – All | | | | | | |
| $\xi^{w^c}$ | Beta | 0.5 | 0.22 | 0.9670 | 0.9474 | 0.9749 |
| $\xi^{w^h}$ | Beta | 0.5 | 0.22 | 0.9489 | 0.9215 | 0.9614 |
| $\iota^{w^c}$ | Beta | 0.5 | 0.22 | 0.0837 | 0.0558 | 0.1646 |
| $\iota^{w^h}$ | Beta | 0.5 | 0.22 | 0.5678 | 0.2773 | 0.8516 |
| Households – Patient | | | | | | |
| $\phi^c_P$ | Beta | 0.5 | 0.22 | 0.4616 | 0.3645 | 0.6020 |
| $\eta_P$ | Gamma | 1.0 | 0.2 | 1.2690 | 0.9477 | 1.6752 |
| $\theta^n_P$ | Gamma | 10.0 | 3.0 | 8.3739 | 4.8377 | 13.3579 |
| $\phi^{k^c}$ | Gamma | 5.0 | 2.0 | 4.0795 | 2.5843 | 5.8508 |
| $\phi^{k^h}$ | Gamma | 5.0 | 2.0 | 4.2852 | 2.5598 | 8.6322 |
| $\delta_2^{k^c}$ | Beta | 0.125 | 0.025 | 0.0897 | 0.0654 | 0.1397 |
| $\delta_2^{k^h}$ | Beta | 0.125 | 0.025 | 0.1729 | 0.1430 | 0.2101 |
| Households – Impatient | | | | | | |
| $\phi^c_I$ | Beta | 0.5 | 0.22 | 0.3088 | 0.1365 | 0.4474 |
| $\eta_I$ | Gamma | 1.0 | 0.2 | 1.5686 | 1.2655 | 1.9994 |
| $\theta^n_I$ | Gamma | 10.0 | 3.0 | 6.5490 | 3.4218 | 12.0367 |
| Production – Non-housing sector | | | | | | |
| $\xi^{p^c}$ | Beta | 0.5 | 0.22 | 0.2694 | 0.1214 | 0.3804 |
| $\iota^{p^c}$ | Beta | 0.5 | 0.22 | 0.9267 | 0.5538 | 0.9728 |
| Monetary policy | | | | | | |
| $\rho_r$ | Beta | 0.8 | 0.1 | 0.7967 | 0.7312 | 0.8345 |
| $\rho_{\pi^c}$ | Gamma | 3.5 | 0.5 | 3.9485 | 2.9811 | 4.4260 |
| $\rho_y$ | Beta | 0.30 | 0.025 | 0.3271 | 0.2814 | 0.3668 |

with a mean of 0.8 and a standard deviation of 0.1, and the priors of all the standard deviations of shocks is an inverse gamma, with a mean of 0.1 and a standard deviation of 0.2. These priors are quite dispersed and were chosen to generate volatility in the endogenous variables that is broadly in line with the data. Their covariance matrix is assumed to be diagonal. Finally, the priors on monetary policy parameters reflect previous estimates done internally at the Bank of Canada. We assume a beta prior for $\rho_r$ and $\rho_y$ with means of 0.8 and 0.1 and standard deviations of 0.3 and 0.025, respectively, and a gamma prior with a mean of 3.5 and a standard deviation of 0.5 for $\rho_{\pi^c}$. These priors are in line with previous Canadian studies (Christensen et al. 2016, Dorich et al. 2013).

Moreover, we use a novel approach based on priors' densities on the model's properties (Andrle and Benes 2013) to add information to the estimation of the model. In contrast with parameter priors, model priors are those about the model's features and behaviour as a system, such as the covariance and

**TABLE 3**
Prior and posterior distributions of exogenous processes

| Parameter | Prior distribution | | | Posterior distribution | | |
|---|---|---|---|---|---|---|
| | Distribution | Mean | Std. | Mode | 5% | 95% |
| Persistence parameters $\rho_{\Theta}$ | | | | | | |
| $\rho_{\chi}$ | Beta | 0.8 | 0.1 | 0.9796 | 0.7216 | 0.9859 |
| $\rho_{\epsilon^{\beta}}$ | Beta | 0.8 | 0.1 | 0.8923 | 0.7924 | 0.9323 |
| $\rho_{\epsilon^{h}}$ | Beta | 0.8 | 0.1 | 0.9648 | 0.4608 | 0.9756 |
| $\rho_{\epsilon^{q^h}}$ | Beta | 0.8 | 0.1 | 0.7771 | 0.6725 | 0.8299 |
| $\rho_{\epsilon^{n}}$ | Beta | 0.8 | 0.1 | 0.8850 | 0.8203 | 0.9094 |
| $\rho_{\pi^{c,targ}}$ | Beta | 0.8 | 0.1 | 0.9088 | 0.8842 | 0.9293 |
| $\rho_{\epsilon^{R^m}}$ | Beta | 0.8 | 0.1 | 0.9718 | 0.9186 | 0.9860 |
| $\rho_{z^{c}}$ | Beta | 0.8 | 0.1 | 0.7944 | 0.5255 | 0.8557 |
| $\rho_{z^{h}}$ | Beta | 0.8 | 0.1 | 0.7458 | 0.6610 | 0.9639 |
| $\rho_{z^{i^k}}$ | Beta | 0.8 | 0.1 | 0.5992 | 0.5218 | 0.7107 |
| Standard deviation of shocks $\sigma_{\Theta}$ | | | | | | |
| $\sigma_{\chi}$ | Inv. gamma | 0.1 | 0.2 | 0.0312 | 0.0161 | 0.0367 |
| $\sigma_{\epsilon^{\beta}}$ | Inv. gamma | 0.1 | 0.2 | 0.0191 | 0.0163 | 0.0227 |
| $\sigma_{\epsilon^{h}}$ | Inv. gamma | 0.1 | 0.2 | 0.0231 | 0.0157 | 0.0339 |
| $\sigma_{\epsilon^{q^h}}$ | Inv. gamma | 0.1 | 0.2 | 0.0080 | 0.0061 | 0.0104 |
| $\sigma_{\epsilon^{n}}$ | Inv. gamma | 0.1 | 0.2 | 0.0881 | 0.0702 | 0.1700 |
| $\sigma_{\pi^{c,targ}}$ | Inv. gamma | 0.1 | 0.2 | 0.0030 | 0.0026 | 0.0036 |
| $\sigma_{\epsilon^{R}}$ | Inv. gamma | 0.1 | 0.2 | 0.0029 | 0.0025 | 0.0034 |
| $\sigma_{\epsilon^{R^m}}$ | Inv. gamma | 0.1 | 0.2 | 0.0440 | 0.0321 | 0.0631 |
| $\sigma_{z^{c}}$ | Inv. gamma | 0.1 | 0.2 | 0.0038 | 0.0032 | 0.0047 |
| $\sigma_{z^{h}}$ | Inv. gamma | 0.1 | 0.2 | 0.0154 | 0.0139 | 0.0174 |
| $\sigma_{z^{i^k}}$ | Inv. gamma | 0.1 | 0.2 | 0.0557 | 0.0361 | 0.0848 |
| Standard deviation of measurement errors | | | | | | |
| $\sigma_{n^{c}}$ | Inv. gamma | 0.1 | 0.2 | 0.0078 | 0.0069 | 0.0090 |
| $\sigma_{w^{c}}$ | Inv. gamma | 0.1 | 0.2 | 0.0124 | 0.0112 | 0.0140 |
| $\sigma_{u^{k^c}}$ | Inv. gamma | 0.1 | 0.2 | 0.0245 | 0.0222 | 0.0276 |
| $\sigma_{n^{h}}$ | Inv. gamma | 0.1 | 0.2 | 0.0050 | 0.0043 | 0.0063 |
| $\sigma_{w^{h}}$ | Inv. gamma | 0.1 | 0.2 | 0.0134 | 0.0111 | 0.0159 |
| $\sigma_{u^{k^h}}$ | Inv. gamma | 0.1 | 0.2 | 0.0304 | 0.0267 | 0.0341 |

correlation. While being consistent and reasonable at the parameter level, parameter priors can result in unreasonable aggregate model properties, different from the researcher's beliefs, due to the nonlinear mapping of parameters into the model's properties. In contrast, a prior about system properties creates direct stochastic restrictions on the combinations of parameters.

Given our focus on housing market-related business cycles, spillovers from housing wealth on consumption and the notion of boom–bust, we have determined that correlation is the most relevant model prior. More specifically, we use the current to third-order cross-correlation between consumption, residential investment, non-residential investment, house price and mortgage debt, and we apply a normal prior with mean being the cross-correlation computed on the filtered data used in the estimation and with standard deviation being set at 0.1.

**TABLE 4**
Model priors

| Correlation | Prior distribution | | Posterior distribution | |
|---|---|---|---|---|
| | Distribution | Mean | Std. | Mode |
| $corr(c_t, y_t^h)$ | Normal | 0.2773 | 0.1 | 0.2630 |
| $corr(c_t, y_{t-1}^h)$ | Normal | 0.3443 | 0.1 | 0.2098 |
| $corr(c_t, y_{t-2}^h)$ | Normal | 0.3742 | 0.1 | 0.1724 |
| $corr(c_t, y_{t-3}^h)$ | Normal | 0.3966 | 0.1 | 0.1489 |
| $corr(c_{t-1}, y_t^h)$ | Normal | 0.1793 | 0.1 | 0.2198 |
| $corr(c_{t-2}, y_t^h)$ | Normal | 0.0509 | 0.1 | 0.1913 |
| $corr(c_{t-3}, y_t^h)$ | Normal | −0.0567 | 0.1 | 0.1717 |
| $corr(c_t, q_t^h)$ | Normal | 0.2991 | 0.1 | 0.1559 |
| $corr(c_t, q_{t-1}^h)$ | Normal | 0.4159 | 0.1 | 0.1262 |
| $corr(c_t, q_{t-2}^h)$ | Normal | 0.4626 | 0.1 | 0.1053 |
| $corr(c_t, q_{t-3}^h)$ | Normal | 0.4563 | 0.1 | 0.0927 |
| $corr(c_{t-1}, q_t^h)$ | Normal | 0.1649 | 0.1 | 0.1109 |
| $corr(c_{t-2}, q_t^h)$ | Normal | 0.0421 | 0.1 | 0.0847 |
| $corr(c_{t-3}, q_t^h)$ | Normal | −0.0308 | 0.1 | 0.0696 |
| $corr(c_t, i_t^k)$ | Normal | 0.5012 | 0.1 | 0.4031 |
| $corr(c_t, i_{t-1}^k)$ | Normal | 0.5084 | 0.1 | 0.4083 |
| $corr(c_t, i_{t-2}^k)$ | Normal | 0.4858 | 0.1 | 0.4055 |
| $corr(c_t, i_{t-3}^k)$ | Normal | 0.4728 | 0.1 | 0.4005 |
| $corr(c_{t-1}, i_t^k)$ | Normal | 0.4438 | 0.1 | 0.3790 |
| $corr(c_{t-2}, i_t^k)$ | Normal | 0.3169 | 0.1 | 0.3461 |
| $corr(c_{t-3}, i_t^k)$ | Normal | 0.1533 | 0.1 | 0.3101 |
| $corr(c_t, M_t)$ | Normal | 0.1389 | 0.1 | 0.1303 |
| $corr(c_t, M_{t-1})$ | Normal | 0.1365 | 0.1 | 0.1399 |
| $corr(c_t, M_{t-2})$ | Normal | 0.1266 | 0.1 | 0.1474 |
| $corr(c_t, M_{t-3})$ | Normal | 0.1071 | 0.1 | 0.1529 |
| $corr(c_{t-1}, M_t)$ | Normal | 0.1355 | 0.1 | 0.1211 |
| $corr(c_{t-2}, M_t)$ | Normal | 0.1258 | 0.1 | 0.1134 |
| $corr(c_{t-3}, M_t)$ | Normal | 0.1073 | 0.1 | 0.1070 |

### 3.5. Summary of estimation results

The estimated posterior distributions of the non-calibrated parameters are summarized in the second columns of tables 2 and 3.[12] In general terms, the information contained in the likelihood significantly updates the assumed priors for all the parameters, given the marked differences in the statistics describing these two distributions.

Overall, the posterior estimates of the structural coefficients imply a substantial degree of wage stickiness and indexation to inflation, habit formation

12 Including measurement errors on hours worked per capita, real wage and capacity utilization rates in both the non-housing and housing sectors is the usual practice (Iacoviello and Neri 2010), and they are reported in table 3. Tables providing more details about the posterior distributions are available in section C of the technical appendix.

**TABLE 5**
Cross-correlations in data and model

| Variable | Non-res. investment | | Res. investment | | Mortgage debt | | House price | |
|---|---|---|---|---|---|---|---|---|
| | Data | Model | Data | Model | Data | Model | Data | Model |
| Consumption | 0.50 | 0.40 | 0.28 | 0.26 | 0.14 | 0.13 | 0.30 | 0.16 |
| Non-res. investment | | | 0.31 | 0.14 | 0.22 | 0.14 | 0.25 | 0.07 |
| Res. investment | | | | | 0.28 | 0.08 | 0.70 | 0.69 |
| Mortgage debt | | | | | | | 0.63 | 0.51 |

in consumption and adjustment costs in investment, which is mostly in line with previous studies (Altig et al. 2010, Del Negro and Schorfheide 2008, Smets and Wouters 2007). However, we find a lower level of price stickiness than that in the literature (Iacoviello and Neri 2010). The estimate of $\theta^{p^c}$ (0.27) implies that prices are re-optimized frequently, once every 1.3 quarters. Moreover, given the positive value of the indexation parameter ($\iota^{p^c} = 0.93$), prices also change every period at a rate mostly equal to the Bank of Canada target inflation rate, and therefore not optimally in response to a change in nominal costs. As for wages, we find that stickiness in the housing sector ($\theta^{w^h} = 0.95$) and the consumption sector ($\theta^{w^c} = 0.97$) are almost equal. While being re-optimized infrequently, once every 30–40 quarters, wages are indexed every period to compensate the last period inflation ($\iota^{w^c} = 0.08$) and the steady-state inflation ($\iota^{w^h} = 0.57$). The capital adjustment costs do not seem to differ across sectors.

The autoregressive parameters (table 3) show quite dispersed degrees of persistence, with parameters ranging from 0.6 to 0.98. However, with autoregressive parameters being in general higher than 0.75, the estimated exogenous processes are generally persistent. The technology processes in both sectors and the investment-specific process are the least persistent, while the preference processes show the highest level of persistence. Among the estimated standard errors, the investment-specific shock is the most volatile, followed by the interest rate spread shock. Finally, estimates of the parameters of the monetary policy rule are in line with previous evidence (Christensen et al. 2016, Dorich et al. 2013) and the parameters used at the Bank of Canada for economic projection, with a large weight on inflation ($\rho_{\pi^c} = 3.95$) and a fairly small weight on output gap ($\rho_y = 0.33$). In terms of the three monetary disturbances, the shock to the interest rate spread is the most volatile, and more persistent than the shock to inflation targeting. Standard error of the monetary policy shock is in line with previous studies based on Canadian data (Christensen et al. 2016, Dorich et al. 2013).

Table 5 presents data and asymptotic cross-correlations for a set of key model variables explaining important housing market dynamics, while the first- to third-order cross-correlations used as the estimated model's properties

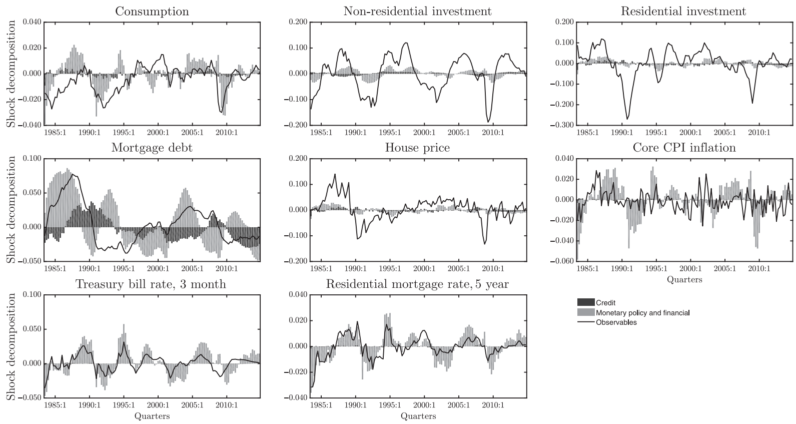


**FIGURE 2** Historical variance decomposition – Credit, monetary and financial shocks

are shown in table 4.[13] Both are evaluated using the posterior mode. Overall, the model seems to properly replicate the contemporaneous behaviour of the data. It matches both the sign and the level of the cross-correlations for most of the desired relationships being studied. However, it underestimates the cross-correlations of non-residential investment with both residential investment and house prices. Lastly, the correlation between residential investment and mortgage debt has the right sign but not the right magnitude. The structure of mortgage loan contracts used in the model, albeit a better representation of the Canadian context than the usual one-period mortgage with variable rate used in the literature, is too rigid and does not incorporate certain features, like HELOCs and mortgages with variables rates, likely to bridge the gap in terms of volatility between these two variables. The first- to third-order cross-correlations among variables are in general also well replicated by the estimated model. However, the model overestimates the first- to third-order cross-correlations of consumption with both residential investment and house prices, implying a stronger persistent relationship between these variables than found in the data.

Figures 2 and 3 present the historical variance decomposition for a set of selected observables over the sample 1983Q2 to 2014Q4.[14] We present results by grouping shocks into five classes: (i) credit shock ($\chi_t$), (ii) housing supply shock ($z_t^h$), (iii) housing demand shock ($\epsilon_t^h$), (iv) expected house price shock ($\epsilon_t^{q^h}$) and (v) monetary policy and financial shocks ($\pi_t^{c,targ}, \epsilon_t^R, \epsilon_t^{R^m}$) and, finally, (vi) other supply and demand shocks ($\epsilon_t^\beta, \epsilon_t^n, z_t^c, z_t^{ik}$).

13 A more detailed table on cross-correlations is available in section C of the technical appendix.

14 A forecast error variance decomposition is also available in section C of the technical appendix.

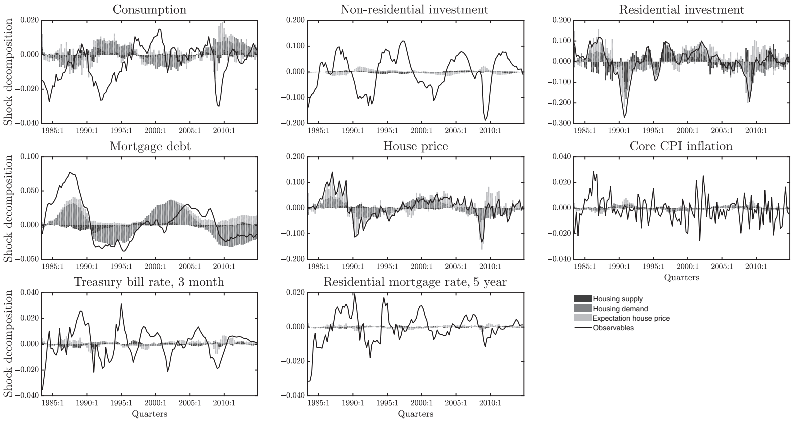


**FIGURE 3** Historical variance decomposition – Housing demand, supply and prices expectation shocks

Focusing first on the decomposition of the variance in housing investment and house prices, we find that their short-run variability is mostly explained by the housing demand shock, the expectation shock on house prices and the housing supply (TFP) shock. Indeed, these shocks seem to have driven the boom–bust cycle in the late 80s and early 90s and the decline in both the supply and demand of the housing market during the recession, in 2008. This result is in line with Kaplan et al. (2017), who show that the main driver of the housing booms and busts around the Great Recession in the US was a shift in beliefs. The role of the expectation shock on house prices is crucial, as rational expectations models with only a housing demand shock have difficulty producing large movements in housing values with patterns similar to data. It is therefore common for such models to use extremely large and persistent exogenous shocks to rational agents' preferences for housing to bridge the gap between the model and the data. However, as demonstrated by Gelain et al. (2015), large housing preference shocks are not a plausible explanation for housing boom–bust cycles, as they generate large movements in the imputed housing market rent, which are not observed in the data. Mortgage debt is also explained by this set of shocks and by the credit shock.

As expected, most of the fluctuations in non-residential investment in both production sectors are mainly driven by the other demand and supply shocks. However, a non-negligible share is also explained by monetary policy and financial shocks, which affect the intertemporal reallocation of lenders' resources over time and have a direct impact on investment decisions. Consumption is influenced by a wide range of shocks, but the housing demand shock and the expectation shock on house prices seem to have a non-negligible impact. Lastly, mortgage debt is influenced, as expected, by monetary policy, financial, housing demand and credit (LTV) shocks.

From figure 2 and 3, the procyclicality of macroeconomic aggregates is striking, with consumption, non-residential, residential investment, mortgage debt and house prices moving together, with various degrees of correlation, and the housing market variables being driven historically by the same set of shocks.

## 4. Discussion of policies to reduce mortgage debt

In this section, we describe three policies to reduce households indebtedness and housing market vulnerabilities: a permanent tightening of the LTV ratio,[15] a countercyclical LTV ratio and a modified Taylor-type monetary policy rule.

*Tightening of the regulatory fixed LTV ratio*

In the aftermath of the financial crisis, there has been a lot of emphasis on identifying the channels through which financing arrangements may lead to the procyclicality of the main macroeconomic aggregates following economic disturbances. A regulatory (fixed) LTV ratio for mortgage loans are widely-used policies to address concerns related to household indebtedness.

There is growing evidence to suggest that high LTV ratios play an important amplifying role for shocks that occur in housing markets. The leverage resulting from a high LTV ratio contributes to the procyclicality of the housing market and exacerbates boom–bust cycles in housing prices. For example, Lamont and Stein (1999) use US city-level data to show that the sensitivity of house prices to income shocks is higher in cities with more highly levered homeowners (i.e., a high LTV ratio). Almeida et al. (2006) show that cross-country differences in the maximum LTV ratio accepted for a mortgage can explain cross-country variations in the sensitivity of house prices and credit demand to income shocks. Calza et al. (2013) show that features of mortgage markets can also explain differences in the transmission of monetary policy across countries.

In the Canadian case, the amplifying role of a fixed LTV ratio has been shown by Christensen et al. (2016). Increases in demand for housing or the efficiency with which housing can be produced have direct effects on the price of housing. But Christensen et al. (2016) do not consider the impact of a change in the degree of restrictions to the borrowing constraint. Iacoviello and Neri (2010) estimate their model using two subsamples with different levels of LTVs and find that the post-1989 period, characterized by a higher LTV, is associated with larger collateral effects on consumption. This evidence suggests that features of the financial system amplify swings in the real economy, particularly the housing market, thereby exacerbating boom–bust cycles in asset prices and financial instability.

---

15 It is interesting to study the permanent reduction as this is the type of regulatory action taken by Canadian authorities in recent years, for example, the reduction of the maximum LTV ratio from 100% to 95% in October 2008.

Intuitively, one way to understand the link between asset price booms and household indebtedness is to start with the idea that an economy's borrowing capacity is a function of the value of its assets.[16] Optimistic expectations regarding future housing demand or housing prices induce a reallocation of assets within a portfolio and increase the demand for housing. If the supply of these assets were near fixed or subject to adjustment costs in the short term, an increase in demand would raise the asset price. This, in turn, would augment the economy's credit limit by increasing the value of collateral, even in the presence of a fixed LTV. Relaxing the credit limits that constrain domestic borrowing can then lead to an asset price boom through a self-reinforcing process: higher asset prices cause more borrowing and additional rounds of constraint relaxation via higher house prices, pushing prices even higher.

*Countercyclical LTV ratio*
Given the spillover effects observed in the presence of a fixed LTV ratio, we can therefore think of a countercyclical LTV ratio as a way to moderate credit booms and household indebtedness. The countercyclical LTV ratio is a sectoral policy that aims to reduce housing market vulnerabilities. Recent research on macroprudential policies has proposed Taylor-type rules for LTV ratios that react inversely to variables such as the growth rates of GDP, credit, the credit-to-GDP ratio or house prices (Prakash et al. 2012, Lambertini et al. 2013). The choice of the instrument $\nu$ (equation 24) should reflect its ability to mitigate the buildup of housing market vulnerabilities coming from financially vulnerable households, while at the same time avoiding penalizing financially stable households. We therefore assume that the instrument $\nu$ is the mortgage debt-to-income ratio $\frac{m^{tot}}{inc_I}$, where $m^{tot}$ is the total amount of mortgages held by impatient households and $inc_I$ is their labour income.[17]

*Monetary policy augmented with household debt*
Alternatively, the monetary policy-makers might take emerging housing market 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. We therefore compare the results of these regulatory LTV policies with the performance

16 Taking the form of the borrowing constraint in this paper. However, this is also related to the notion of financial accelerator (Bernanke et al. 1999).

17 The rule with the instrument in deviation from its last period value ($\omega_t = \omega - \phi^{\omega}(\nu_t - \nu_{t-1})$) yields the same dynamics as the rule with the instrument in deviation from its steady-state value, but its impact is obviously more short lived since the deviation from the steady-state value is usually more persistent than the deviation from its last period value. Adding persistence to the LTV (e.g., $\omega_t = \rho^{\omega}\omega_{t-1} + (1-\rho^{\omega})(\omega - \phi^{\omega}(\nu_t - \nu_{t-1}))$ yields the same results as the rule with the instrument in deviation from its steady-state value.

of a modified Taylor-type monetary policy rule, augmented with a credit aggregate[18]

$$R_t = \rho_r R_{t-1} + (1-\rho_r) * \left( R + \rho_{\pi^c} \left( \frac{\prod_{v=1}^{4} \pi_{t+v}^{c}}{4} - \epsilon_t^{\pi^c} \right) + \rho_y (Y_t - Y) \right.$$
$$\left. + \rho_{m^{tot}} (m_t^{tot} - m_{t-1}^{tot}) \right).$$

## 5. Results

In this section, we use the model estimated above to study the effectiveness of the macroprudential policies introduced in the previous section and assess the potential spillover effects of these macroprudential policies on the macroeconomy. Before presenting the main results on macroprudential policies, we first examine the responses of macroeconomic variables and mortgage debt to key shocks using the estimated model with a fixed regulatory LTV ratio. This allows us to better understand the transmission of shocks, which is important for policy analysis. We then proceed, in the second sub-section, with an assessment of macroprudential and monetary policy effectiveness in reducing household debt.

### 5.1. Housing market dynamics in the benchmark model

We first describe the responses of macroeconomic variables by focusing on housing market dynamics. We identify in the historical variance decomposition the four shocks that have played a dominant role in the housing market boom–bust cycle in the late 80s and early 90s (see section 3.5). These are the shocks on credit, housing demand, housing supply (TFP) and expectations of house prices.[19]

First, figure 4 plots the impulse responses (in a solid black line) to a one-standard-deviation shock to housing demand when the LTV ratio is set at 0.91. Given the increase in housing demand, both housing investment and house prices increase. Since borrowers' collateral is linked to house prices, impatient households are able to borrow more out of their new investment in housing. The wealth effect allows them to increase their consumption. However, this increase in consumption is short lived, since a stronger housing demand raises the returns on housing investment, and therefore triggers a

18 The monetary policy rule is augmented with the instrument in deviation from its last period value $(m_t^{tot} - m_{t-1}^{tot})$, as the rule augmented with the instrument in deviation from its steady-state value $(m_t^{tot} - m^{tot})$ yields solution indeterminacy. The persistence of the monetary policy $(\rho_r R_{t-1})$ already captures the impact of the accumulated deviation of debt from its steady-state.

19 All impulse responses are presented in percentage deviation from steady states. Impulse responses for other shocks are available in section C of the technical appendix.

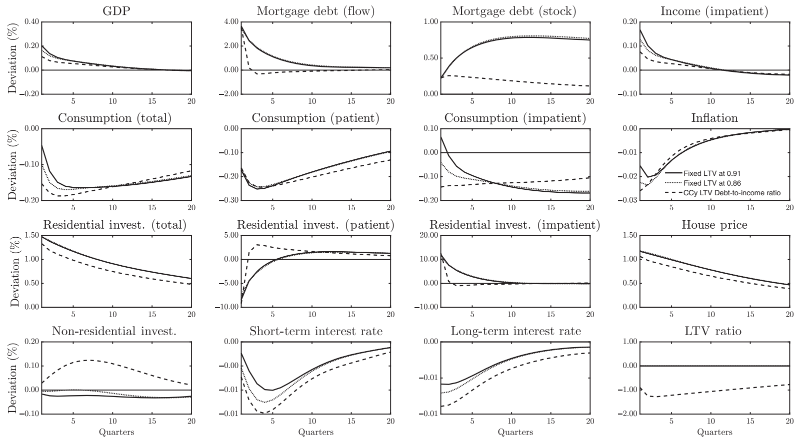


**FIGURE 4** Dynamics with macroprudential policies – Housing demand shock

reallocation of expenses between consumption and housing, which dominates the wealth effect on consumption.

The increase in house prices is transmitted to the real economy, causing output increases. However, since the rise in output is concentrated in the housing sector, via the increased housing investment from impatient households, and the production of non-housing goods decreases, inflation[20] and the policy rate fall. On impact, the lower interest rate further increases house prices, which reinforces the effects of the housing demand shock.

Second, figure 5 displays the impulse responses to a one-standard-deviation shock to housing price expectations. This shock differs from the housing demand shock as it does not directly affect the utility of agents. Another way to think about the expectation shock would be as an unrealized news shock on future housing quality (see Alpanda and Zubairy 2017, similar to the unrealized capital quality shocks in Gertler and Karadi 2011). This shock affects the contemporaneous choices of agents via the asset pricing equations (9) and (12). The agents receiving news today regarding future housing quality incorporate this news into their expectations of future house prices ex ante. While the news never happens ex post, its impact on current choices is propagated in the real economy and financial decisions.

The expectation shock on housing prices generates the co-movement between house prices, total consumption, residential investment and inflation observed in the data, especially during periods of housing booms. When the expectation of future higher house prices arises, it is optimal for agents to start increasing their housing stock to take advantage of the capital gain. The marginal gain is higher for impatient than patient households, as the

20 The inflation rate focuses on non-housing consumption goods as the numeraire, and abstract from imputed rent, which rises following an increase in housing demand.

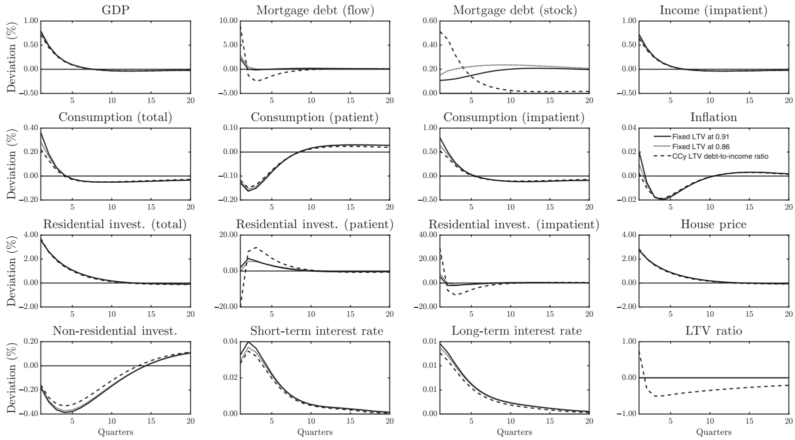


**FIGURE 5** Dynamics with macroprudential policies – House price expectation shock

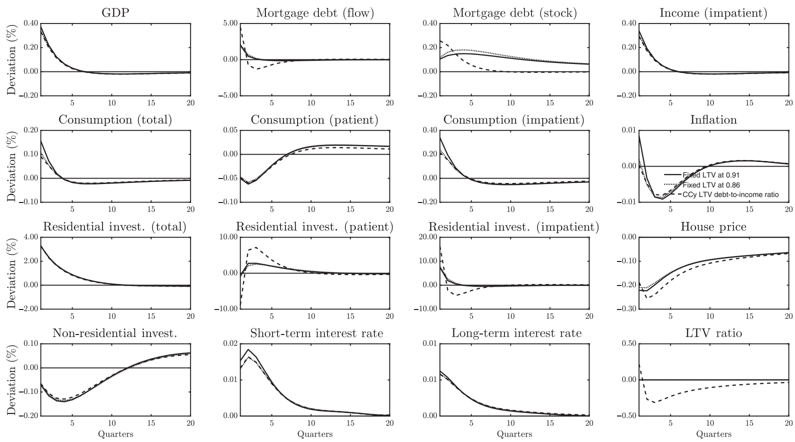


**FIGURE 6** Dynamics with macroprudential policies – TFP (housing sector) shock

house price expectation shock increases the marginal utility of the housing stock for both types of households, but also relaxes the borrowing constraint of impatient households via the increased value of new housing investment, allowing them to borrow and consume more. However, the types of households react differently to this wealth effect. As permanent income agents, patient households reallocate their portfolio of assets and increase their housing investment. However, impatient households channel their wealth effect via an immediate increase in consumption. Optimistic expectations lead to excessive housing investment, thereby causing a boom in the housing market not based on fundamentals.

Third, figure 6 presents the impulse responses to a positive TFP shock (one-standard-deviation) in the housing sector. This directly increases the

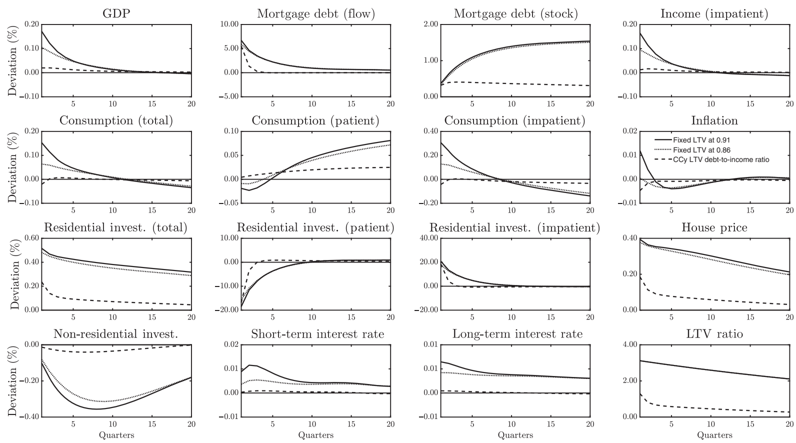


**FIGURE 7** Dynamics with macroprudential policies – Credit shock

supply of housing and leads to a fall in house prices. Lower house prices lead impatient households to increase their demand for housing investment, which raises their borrowing capacity and, ultimately, increases their consumption. Patient households also increase their housing investment, but to a lesser extent, and decrease their consumption, rising their deposits, which are then lent to impatient households. Hence, new mortgage debt increases. In net, aggregate consumption and GDP increase. With aggregate consumption increasing and business investment falling, inflation first increases then quickly falls.

Lastly, figure 7 plots impulse responses to a one-standard-deviation shock to credit. A positive shock relaxes the borrowing constraint of impatient households, thereby decreasing their shadow cost of borrowing and allowing them to borrow and consume more. However, to finance this borrowing, patient households reduce their consumption and housing investment and increase their deposits, which receive a higher interest rate due to the response to inflation of the Taylor-type rule. Overall, consumption and residential and non-residential investment increase.

The overall debt dynamics presented in figures 4 to 7 are consistent with Gelain et al. (2017). First, when household debt is amortized gradually and new loans are constrained by the current value of collateral, house prices always react more rapidly than mortgage debt, as the latter is highly persistent. Therefore, the credit cycles last longer than the business and asset price cycles. Second, monetary policy influences debt dynamics in two ways. First, since mortgage loans are extended in nominal terms, inflation affects the real value of debt. As a consequence, the strength of the monetary policy reaction to inflation and the time-varying inflation target are important determinants of fluctuations in the real debt burden of borrowers and the real value of lenders' assets. Second, monetary policy also affects the demand for new loans since the interest rate charged by financial intermediaries represents the integral of all expected short-term interest rates over a five-year period, which is mostly influenced by the expected inflation.

## 5.2. Economic effects of macroprudential policies

We now discuss the role of tighter fixed regulatory LTV ratios and countercyclical LTV ratios in mitigating household debt and the effects of shocks.

### 5.2.1. Effects of permanently lowering the regulatory LTV ratio

For this policy analysis, we consider two cases. The first one examines the transition dynamics of lowering the regulatory LTV by 5 percentage points from 0.91 to 0.86, while the second case studies the impact of such a policy after shocks that increase mortgage debt.

*Transition dynamics from lowering the regulatory LTV ratio*

Figure 8 plots the simulation of a transition following a permanent tightening of the regulatory LTV ratio. This involves macroeconomic adjustments in the short run, as well as long-run effects due to a change in steady-state values.[21] The change in the regulatory LTV ratio has a direct effect on the borrowing constraint of impatient households, particularly on the desired level of housing investment. The shadow cost on new loans increases, since the desired level of housing investment is higher than the available volume of loans.

Housing prices fall, as the effective housing demand from impatient households is reduced due to the lower level of mortgage financing available. Moreover, falling house prices reduce collateral values, reinforcing the impact of the initial tightening of the LTV ratio. Given the substitutability of housing and consumption, and the decline in their income due to the overall decrease in output, impatient households also decrease their consumption demand.

The overall short-term impact of lowering the regulatory LTV ratio on the economy is to reduce GDP, which is followed by a decline in inflation, caused by a lower demand for labour and wages fall. The fall in inflation prompts the central bank to reduce the policy rate, which pushes patient households to increase their consumption expenditures, but not enough to offset the decline in impatient households' consumption. A few factors influence the level of consumption of patient households. The lower LTV ratio reduces the demand for deposits, which lowers the deposit rate and hence decreases the diversification of asset portfolios. Moreover, falling house prices imply a negative wealth effect and induce patient households to increase their purchases of housing. The decline in the policy rate also lowers long-term mortgage interest rates, which

21 We experiment with this policy change for two reasons. First, a permanent decrease of 5 percentage points is the usual policy change implemented in Canada over the last two decades. Second, the same policy change has been tested in Alpanda and Zubairy (2017), making the results easily comparable.

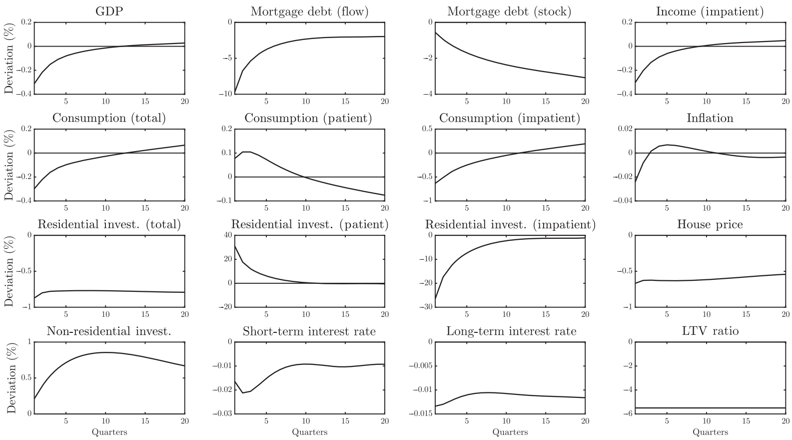


**FIGURE 8** Effects of a permanent LTV ratio reduction from 0.91 to 0.86

slightly moderates the fall in housing investment and in impatient households' consumption.

The new steady state is reached after all of the mortgage stock originated pre-tightening has been replaced by mortgages originated post-tightening. In the new steady state, total mortgage debt declines by slightly more than 7%, in part because house prices fall by about 0.6%. The relatively modest drop in house prices reflects, to some extent, the significant price elasticity of patient households' demand for housing, which compensates for the decline in borrowers' demand (as supply is subject to convex adjustment costs). Notably, impatient households' consumption of goods will be permanently higher by about 0.6% in the new steady state, as their debt service burden is lower, partly offsetting the decline in their consumption of housing services. However, patient households' consumption continues to decline during the transition and will be ultimately 0.9% lower in the new steady state. This result is driven mainly by the negative wealth effect caused by the decline in house prices and the reduction in mortgage lending. As a result, GDP is about 0.2% lower in the new steady state.

*Comparing the transmission of shocks when LTV is lowered*

The black dotted lines in figures 4 to 7 show the impulse responses to a housing demand shock, a house price expectation shock, a housing TFP shock and a credit shock when the regulatory LTV ratio is set at 0.86. As can be seen from these figures, the dynamics of the variables after the shocks are broadly similar with the model in which the fixed LTV is set at 0.91. For example, the dynamics of new mortgage, house prices and residential investment following a housing demand shock are all the same in the two model economies. However, the dynamics of consumption in the two economies differ slightly. Total consumption decreases in the first period by about twice the amount of the decrease when the LTV is higher. This is driven by a decrease in impatient household's consumption. In fact, when the LTV is set at 0.86, their consumption falls on impact after the shock, while it first increases when the LTV is at 0.91. The intuition is that impatient households have less borrowing available to satisfy the increased housing demand when LTV is tight and, as a result, they reduce their consumption by more to satisfy the higher housing demand. Both the house price expectation and the housing supply (TFP) shocks display the same patterns in two model economies. Lastly, the spillover into consumption is diminished when the LTV is lowered, as the credit shock applies to a lower LTV in the steady state.

#### 5.2.2. Effects of introducing a countercyclical LTV ratio

Figures 4 to 7 plot the impulse responses (in dashed lines) when a countercyclical LTV ratio, with $\phi^{\omega}=1$ and $\omega=0.91$ (i.e., steady-state), is present.[22] The figures show that a countercyclical LTV ratio is effective at mitigating the increase in household debt and house prices that results from a housing demand shock. However, by being effective at reducing credit, it also leads to a larger decline in consumption as impatient households have to cut consumption in the presence of tighter credit to satisfy their higher demand for housing. The effectiveness of the countercyclical LTV ratio is evident for the credit shocks as it dampens the effects of the shock on mortgages, consumption and GDP.

The house price expectations shock illustrates a key outcome of the countercyclical policy. This shock induces households to buy more housing in order to take advantage of the expected future house price growth, which increases house prices on impact. Household debt increases, but impatient households also increase labour supply, raising their income and leading to an initial decline in the debt-to-income ratio. The rise in impatient income is short lived and it soon falls relative to debt, leading to a lowering of the countercyclical LTV limit. Under the countercyclical LTV policy, the expectations shock leads to a larger initial increase in mortgage debt than occurs under a fixed LTV. However, when the countercyclical LTV is lowered, impatient households accumulate new debt more slowly and sell a portion of their housing stock to maintain their desired consumption level. The latter leads them to repay existing debt more quickly in the process. As a result, the impact of the expectations shock on mortgage debt is much less persistent than under a fixed LTV. The level of mortgage debt returns to steady state in roughly 10 quarters under the countercyclical policy, but persists well beyond five years under a fixed LTV.

### 5.3. Role of macroprudential and monetary policies for stabilization

So far we have examined the effects of macroprudential policies in the presence of a given shock. In reality, more than one shock can hit the economy simultaneously. We now illustrate the effectiveness of the macroprudential

22 The choice $\phi^{\omega}=1$ is based on the simulation results, available upon request, which show that this value is enough to bring stabilization.

**TABLE 6**
Stabilization effects of macroprudential policies

| Variable/policy | Fixed LTV at 0.91 | Fixed LTV at 0.86 | CCy LTV based on debt-to-income | Modified monetary policy |
|---|---|---|---|---|
| *Mean* | | | | |
| GDP | 0.8603 | 0.8583 | 0.8603 | 0.8607 |
| Consumption patient | 0.3059 | 0.3029 | 0.3056 | 0.3060 |
| Consumption impatient | 0.3418 | 0.3441 | 0.3417 | 0.3422 |
| Res. invest. patient | 0.0893 | 0.0876 | 0.1083 | 0.0875 |
| Res. invest. impatient | 0.0857 | 0.0836 | 0.1105 | 0.0822 |
| House price | 0.5018 | 0.4989 | 0.5017 | 0.5019 |
| Mortgage debt | 2.3490 | 2.1766 | 2.2366 | 2.3621 |
| Income impatient | 0.4147 | 0.4138 | 0.4147 | 0.4149 |
| Short-term interest | 1.0135 | 1.0135 | 1.0135 | 1.0135 |
| Inflation | 1.0050 | 1.0050 | 1.0050 | 1.0051 |
| *Standard deviation* | | | | |
| GDP | 0.0381 | 0.0378 | 0.0388 | 0.0481 |
| Consumption patient | 0.0155 | 0.0149 | 0.0111 | 0.0181 |
| Consumption impatient | 0.0207 | 0.0200 | 0.0188 | 0.0269 |
| Res. invest. patient | 0.0366 | 0.0321 | 0.0915 | 0.0303 |
| Res. invest. impatient | 0.0414 | 0.0376 | 0.1127 | 0.0301 |
| House price | 0.0333 | 0.0332 | 0.0306 | 0.0341 |
| Mortgage debt | 0.6824 | 0.6349 | 0.1288 | 0.7503 |
| Income impatient | 0.0183 | 0.0181 | 0.0186 | 0.0234 |
| Short-term interest | 0.0077 | 0.0077 | 0.0081 | 0.0083 |
| Inflation | 0.0111 | 0.0111 | 0.0111 | 0.0170 |

NOTES: Moments based on simulation. The model is simulated 1,000 times for 2,000 periods, with initial conditions being the steady state. We compute the moments based on the last 1,500 periods simulated. Finally, the acronym CCy means countercyclical.

policies in the presence of all the model's shocks by conducting counterfactual simulation experiments for the two policies analyzed so far. We also compare the effectiveness of such measures to that of monetary policy in addressing household indebtedness.

Table 6 presents the first and second moments of macroeconomic and households' variables for: (1) the benchmark case of a fixed regulatory LTV ratio of 0.91 (first column), (2) a tighter LTV ratio of 0.86 (the second column), (3) a countercyclical LTV ratio based on the debt-to-income ratio (third column) and (4) a monetary policy augmented with a reaction to debt growth (fourth column).

The table shows that the countercyclical LTV ratio can significantly reduce the standard deviation of mortgage debt as well as the variability of macroeconomic variables, inflation and house prices. For example, the standard deviation of household debt decreases by more than 80% relative to the benchmark case. Moreover, the effects of the countercyclical LTV ratio on the mean of economic variables and mortgage debt are small.

A tighter fixed regulatory LTV ratio has a much smaller impact on the standard deviation of debt and macroeconomic variables, but it has mostly a first-order effect on the level of the variables. For example, a tighter LTV reduces the mean of mortgage debt by about 7%.

Lastly, monetary policy augmented with household debt[23] increases the variability of household debt, GDP, consumption, inflation and prices. For instance, monetary policy that reacts to debt growth increases the standard deviation of mortgage debt by about 10%.

### 5.4. Effectiveness of macroprudential and monetary policies in addressing housing market boom–bust cycles

In this section, we discuss the extent to which macroprudential and monetary policies can mitigate the housing market boom–bust cycle experienced in Canada in the late 80s and early 90s. Recall that the boom–bust cycle of this period was largely driven by shocks to housing demand and house price expectations, as well as TFP shocks in the housing sector and credit shocks (see section 3.5).

Figures 9 and 10 present the counterfactual experiment of the housing boom–bust cycle that occurred in Canada from 1985 to 1992. They include three panels reflecting respectively: (1) a permanent tightening in LTV from 0.91 to 0.86 in the first column, (2) a countercyclical LTV ratio and (3) a monetary policy reacting to debt growth. Comparing these panels, we see several findings that emerge from these figures.

First, a countercyclical LTV ratio is effective at stabilizing mortgage debt and reduces the boom–bust cycle in GDP and consumption. Moreover, the boom–bust cycle in impatient households' consumption is mitigated considerably. Second, monetary policy is not only unable to mitigate the boom–bust cycles but it instead leads to a larger rise in debt and amplifies the bust in GDP and consumption. Monetary policy reacting to household debt leads to large volatility in inflation. This result is consistent with Svensson (2013) and others that show that monetary policy is a blunt tool to address financial vulnerabilities. Third, a lower (fixed) regulatory LTV ratio is more effective than monetary policy at reducing household debt, although it is less effective than the countercyclical LTV ratio.

Overall, these simulations suggest that tools targeted to the housing market, such as fixed LTV and countercyclical LTV ratios are more effective at reducing boom–bust cycles in household debt and macroeconomic variables, while monetary policy is a poor tool to address household sector vulnerabilities.

## 6. Conclusion

Housing busts, preceded by large increases in household debt, are often associated with deeper recessions and widespread problems for the financial system. Policy-makers are concerned with reducing the amplitude and incidence of these boom–bust cycles. Recent changes in global banking regulation have put

23 The choice of $\rho_{m^{tot}} = 0.8$ is based on simulation results, available upon request.

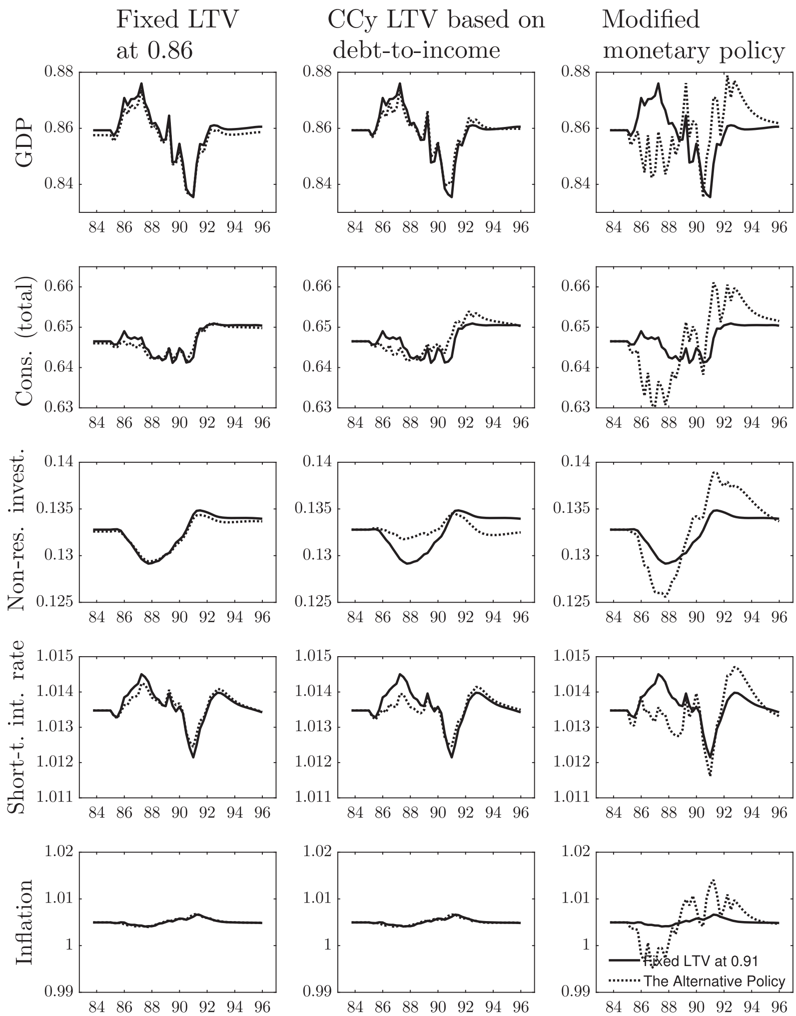


**FIGURE 9** Boom–bust cycles in the Canadian housing market

countercyclical regulatory policy in the toolkit of public authorities seeking to mitigate risks to the functioning of the financial system. A countercyclical regulatory LTV ratio is one potential tool to reduce the likelihood and impact of a housing boom–bust cycle.

This paper presents a macroeconomic framework that can be used to study the impact of implementing a countercyclical LTV. The model emphasizes the role of multi-period mortgage loan contracts with fixed interest rates, exuberance in housing price expectations and persistence of household debt.

We find that countercyclical LTV ratio regulation has strong stabilization properties when policy responds directly to the source of housing market

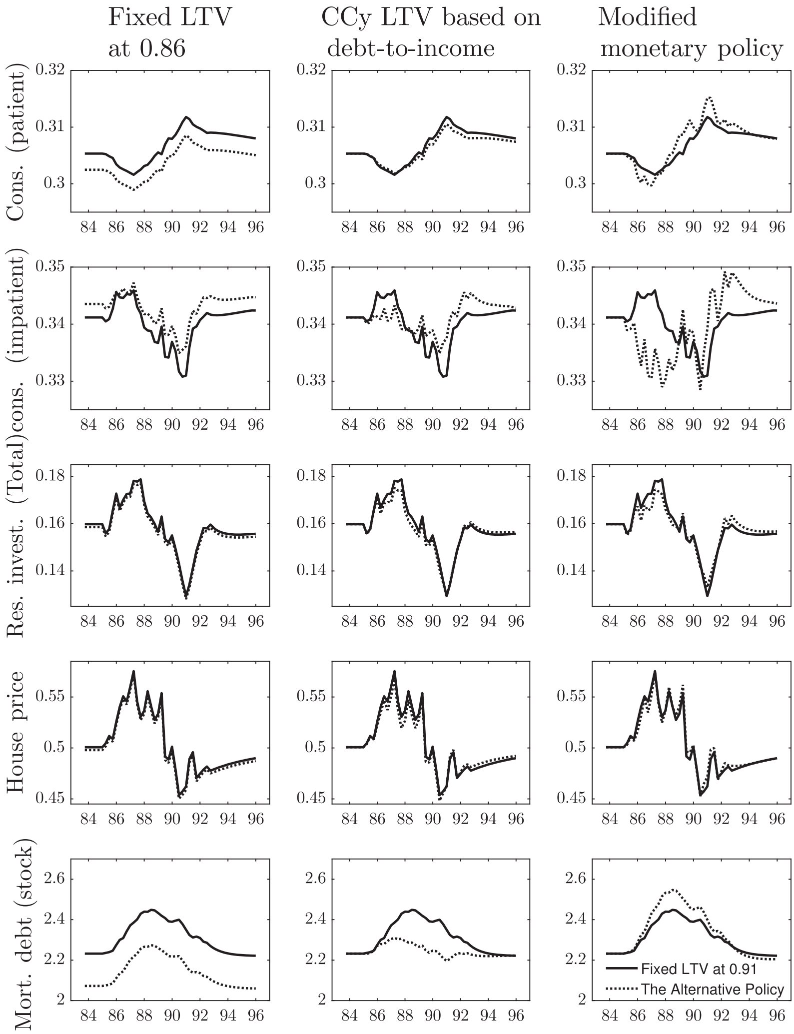


**FIGURE 10** Boom–bust cycles in the Canadian housing market (cont.)

vulnerabilities (i.e., the debt-to-income ratio) and when shocks to house price expectations are a significant source of economic fluctuations. It performs better than both the permanent tightening of the LTV ratio—a policy that has been used in a number of countries—and a monetary policy rule that reacts to debt growth, both in terms of the stabilization of household indebtedness and spillovers into consumption. Finally, monetary policy is the least desirable due to its large adverse consequences on the real economy. Therefore, the countercyclical LTV ratio should be considered by authorities seeking to reduce housing market volatility.

Our model can be extended in two important dimensions in future research. First, we plan to extend the model to account for endogenous mortgage default with systemic implications for the financial system. This would allow a clear examination of the welfare implications of macroprudential policies. The second extension is to introduce a limit on the ratio of mortgage payments to income in addition to the LTV constraint. Greenwald (2018) shows that a cap on payment-to-income ratios can be an effective macroprudential tool for limiting boom–bust cycles.

## References

Adolfson, M., S. Laseen, J. Linde, and M. Villani (2007) "Bayesian estimation of an open economy DSGE model with incomplete pass-through," *Journal of International Economics* 72(2), 481–511

Almeida, H., M. Campello, and C. Liu (2006) "The financial accelerator: Evidence from international housing markets," *Review of Finance* 10(3), 321–52

Alpanda, S., G. Cateau, and C. Meh (2014) "A policy model to analyze macroprudential regulations and monetary policy," Bank of Canada working paper no. 14-6

Alpanda, S., and S. Zubairy (2017) "Addressing household indebtedness: Monetary, fiscal or macroprudential policy?," *European Economic Review* 92(C), 47–73

Altig, D. E., L. J. Christiano, M. Eichenbaum, and J. Linde (2010) "Firm-specific capital, nominal rigidities and the business cycle," International Finance Discussion Papers, no. 990, Board of Governors of the Federal Reserve System (US)

An, S., and F. Schorfheide (2007) "Bayesian analysis of DSGE models," *Econometric Reviews* 26(2-4), 113–72

Andrle, M., and J. Benes (2013) "System priors: Formulating priors about DSGE models' properties," IMF working paper no. 13/257

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999) "The financial accelerator in a quantitative business cycle framework." In J. B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics*, Volume 1, Chapter 21, pp. 1341–93. Elsevier

Blanchard, O. J., and C. M. Kahn (1980) "The solution of linear difference models under rational expectations," *Econometrica* 48(5), 1305–11

Burnside, C., M. Eichenbaum, and S. Rebelo (2016) "Understanding booms and busts in housing markets," *Journal of Political Economy* 124(4), 1088–147

Calvo, G. A. (1983) "Staggered prices in a utility-maximizing framework," *Journal of Monetary Economics* 12(3), 383–98

Calza, A., T. Monacelli, and L. Stracca (2013) "Housing finance and monetary policy," *Journal of the European Economic Association* 11, 101–22

Campbell, J. Y. (2013) "Mortgage market design," *Review of Finance* 17(1), 1–33

Christensen, I., P. Corrigan, C. Mendicino, and S.-I. Nishiyama (2016) "Consumption, housing collateral and the Canadian business cycle," *Canadian Journal of Economics* 49(1), 207–36

Davis, M. A., and J. Heathcote (2005) "Housing and the business cycle," *International Economic Review* 46(3), 751–84

DeJong, D. N., B. F. Ingram, and C. H. Whiteman (2000) "A Bayesian approach to dynamic macroeconomics," *Journal of Econometrics* 98(2), 203–23

Del Negro, M., and F. Schorfheide (2008) "Forming priors for DSGE models (and how it affects the assessment of nominal rigidities)," *Journal of Monetary Economics* 55(7), 1191–208

Dorich, J., M. K. Johnston, R. R. Mendes, S. Murchison, and Y. Zhang (2013) "ToTEM II: An updated version of the Bank of Canada's quarterly projection model," Bank of Canada technical report no. 100

Erceg, C. J., D. W. Henderson, and A. T. Levin (2000) "Optimal monetary policy with staggered wage and price contracts," *Journal of Monetary Economics* 46(2), 281–313

Gelain, P., M. Kolasa, and M. Brzoza-Brzezina (2014) "Monetary and macroprudential policy with multi-period loans," 2014 Meeting Papers, 575, Society for Economic Dynamics

Gelain, P., K. J. Lansing, and C. Mendicino (2013) "House prices, credit growth, and excess volatility: Implications for monetary and macroprudential policy," *International Journal of Central Banking* 9(2), 219–76

Gelain, P., K. J. Lansing, and G. J. Natvik (2015) "Explaining the boom–bust cycle in the U.S. housing market: A reverse-engineering approach," FRBSF Working Paper Series, no. 2015-2

——— (2017) "Leaning against the credit cycle," FRBSF Working Paper Series, no. 2017-18

Gertler, M., and P. Karadi (2011) "A model of unconventional monetary policy," *Journal of Monetary Economics* 58(1), 17–34

Greenwald, D. (2018) "The mortgage credit channel of macroeconomic transmission," MIT Sloan working paper no. 5184–16

Horvath, M. (2000) "Sectoral shocks and aggregate fluctuations," *Journal of Monetary Economics* 45(1), 69–106

Iacoviello, M. (2005) "House prices, borrowing constraints, and monetary policy in the business cycle," *The American Economic Review* 95(3), 739–64

Iacoviello, M., and S. Neri (2010) "Housing market spillovers: Evidence from an estimated DSGE model," *American Economic Journal: Macroeconomics* 2(2), 125–64

IMF (2012) "Chapter 3: Dealing with household debt. World economic outlook, April 2012," IMF technical report

Justiniano, A., G. E. Primiceri, and A. Tambalotti (2010) "Investment shocks and business cycles," *Journal of Monetary Economics* 57(2), 132–45

Kaplan, G., K. Mitman, and G. L. Violante (2017) "The housing boom and bust: Model meets evidence," NBER working paper no. 23694

Kiyotaki, N., A. Michaelides, and K. Nikolov (2010) "Winners and losers in house markets," Central Bank of Cyprus working paper no. 2010-5

Kiyotaki, N., and J. Moore (1997) "Credit cycles," *Journal of Political Economy* 105(2), 211–48

Klein, P. (2000) "Using the generalized Schur form to solve a multivariate linear rational expectations model," *Journal of Economic Dynamics and Control* 24(10), 1405–23

Kraft, H., C. Munk, and S. Wagner (2015) "Housing habits and their implications for life-cycle consumption and investment," SAFE Working Paper Series, no. 85, Research Center, SAFE, Goethe University Frankfurt

Krusell, P., and A. A. Smith (1998) "Income and wealth heterogeneity in the macroeconomy," *Journal of Political Economy* 106(5), 867–96

Lambertini, L., C. Mendicino, and M. T. Punzi (2010) “Expectations-driven cycles in the housing market,” working paper no. w201004, Banco de Portugal, Economics and Research Department
——— (2013) “Leaning against boom–bust cycles in credit and housing prices,” *Journal of Economic Dynamics and Control* 37(8), 1500–22
Lamont, O., and J. C. Stein (1999) “Leverage and house-price dynamics in U.S. cities,” *The RAND Journal of Economics* 30(3), 498–514
Laubach, T., and J. C. Williams (2016) “Measuring the natural rate of interest redux,” Finance and Economics Discussion Series, no. 2016-11, Board of Governors of the Federal Reserve System (US)
Lubik, T., and F. Schorfheide (2006) “A bayesian look at the new open economy macroeconomics.” In *NBER Macroeconomics Annual 2005, Volume 20*, NBER Chapters, pp. 313–82. National Bureau of Economic Research
Lubik, T. A., and C. Matthes (2015) “Calculating the natural rate of interest: A comparison of two alternative approaches,” *Richmond Fed Economic Brief* (Oct), 1–6
Monacelli, T. (2009) “New Keynesian models, durable goods, and collateral constraints,” *Journal of Monetary Economics* 56(2), 242–54
Prakash, K., R. Pau, and A. M. Scott (2012) “Monetary and macroprudential policy rules in a model with house price booms,” The B.E *Journal of Macroeconomics* 12(1), 1–44
Schmitt-Grohé, S., and M. Uribe (2007) “Optimal inflation stabilization in a medium-scale macroeconomic model.” In F. S.Miskin and K. Schmidt-Hebbel, eds., *Monetary Policy under Inflation Targeting*, Volume 11 of *Central Banking, Analysis, and Economic Policies Book Series*, Chapter 5, pp. 125–86. Central Bank of Chile
——— (2012) “What’s news in business cycles,” *Econometrica* 80(6), 2733–64
Sims, C. A. (2002) “Solving linear rational expectations models,” *Computational Economics* 20(1-2), 1–20
Smets, F. R., and R. Wouters (2003) “An estimated dynamic stochastic general equilibrium model of the euro area,” *Journal of the European Economic Association* 1(5), 1123–75
——— (2007) “Shocks and frictions in US business cycles: A Bayesian DSGE approach,” *The American Economic Review* 97(3), 586–606
Stock, J. H., and M. W. Watson (1999) “Business cycle fluctuations in US macroeconomic time series.” In J. B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics*, Volume 1, Chapter 1, pp. 3–64. Elsevier
Svensson, L. (2013) “Leaning against the wind leads to higher (not lower) household debt-to-GDP ratio,” technical report, Stockholm University
Taylor, J. B. (1993) “Discretion versus policy rules in practice,” *Carnegie–Rochester Conference Series on Public Policy* 39(1), 195–214
Yun, T. (1996) “Nominal price rigidity, money supply endogeneity, and business cycles,” *Journal of Monetary Economics* 37(2-3), 345–70

## Supporting information

Additional supporting information can be found in the online version of this article.