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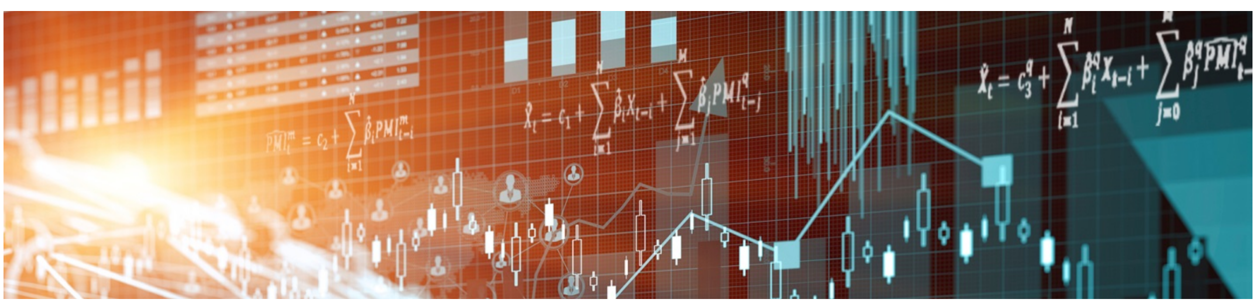

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Abstract

We perform an analysis to determine how well the introduction of a countercyclical loan-to-value (LTV) ratio can reduce household indebtedness and housing price fluctuations compared with a monetary policy rule augmented with house price inflation. To this end, we construct a New Keynesian model in which a fraction of households borrow against the value of their houses and we introduce news shocks on housing demand. We estimate the model with Canadian data using Bayesian methods. We find that the introduction of news shocks can generate a housing market boom-bust cycle, the bust following unrealized expectations on housing demand. Our study also suggests that a countercyclical LTV ratio is a useful policy to reduce the spillover from the housing market to consumption, and to lean against news-driven boom-bust cycles in housing price and credit generated by expectations of future macroeconomic developments.

JEL classification: E31, E42, H23
Bank classification: Business fluctuations and cycles; Financial stability; Housing; Monetary policy framework; Transmission of monetary policy

Résumé

Nous procédons à une analyse visant à déterminer dans quelle mesure la mise en place d'un rapport prêt-valeur contracyclique peut réduire l'endettement des ménages et les variations des prix des logements comparativement à l'instauration d'une règle de politique monétaire tenant compte de la hausse des prix des logements. À cette fin, nous élaborons un modèle de type nouveau keynésien dans lequel une partie des ménages empruntent sur la valeur de leur propriété et nous appliquons des chocs anticipés, induits par de nouvelles informations, à la demande de logements. Nous estimons le modèle à l'aide de données canadiennes en recourant à des méthodes bayésiennes. Nous constatons que l'application de tels chocs peut générer un cycle d'expansion et de contraction du marché du logement, la contraction découlant d'attentes non remplies au regard de la demande de logements. Notre étude donne aussi à penser qu'un rapport prêt-valeur contracyclique constitue une mesure utile pour réduire les répercussions négatives du marché du logement sur la consommation et contrer les cycles d'expansion et de contraction des prix des logements et du crédit à l'habitation engendrés par les nouvelles informations et l'anticipation de l'évolution macroéconomique.

Classification JEL : E31, E42, H23
Classification de la Banque : Cycles et fluctuations économiques; Stabilité financière; Logement; Cadre de conduite de la politique monétaire; Transmission de la politique monétaire

Non-Technical Summary

We perform an analysis to determine how well the introduction of a countercyclical loan-to-value (LTV) ratio responding to credit-to-GDP or house price can reduce household indebtedness and housing price fluctuations compared with a monetary policy rule augmented with house price inflation.

The analysis is conducted in the context of a New Keynesian model in which a fraction of households borrow against the value of their houses and we introduce news shocks on housing demand and multi-period fixed-rate mortgage loans. News shocks can generate optimistic or pessimistic expectations, and cause fluctuations in housing investment. Optimistic expectations lead to excessive housing investment, thereby causing a boom in the housing market not based on fundamentals. Once the news shocks are found to be unrealized, buyers revert their actions and a bust in the housing market follows. Therefore, our model allows us to study the effect of macroprudential policies in a context where agents can have (over-)optimistic expectations about the future and react by contracting more debt under fixed long-term contracts.

We estimate the model with Canadian data using Bayesian methods. We then assess the (in)effectiveness of leaning using an expanded Taylor rule compared with the countercyclical LTV policies.

We find that the introduction of news shocks can generate a housing market boom-bust cycle, the bust following unrealized expectations on housing demand. Our study also suggests that a countercyclical LTV ratio is a useful policy to reduce the spillover from the housing market to consumption and to lean against news-driven boom-bust cycles in housing price and credit generated by expectations of future macroeconomic developments.

1 Introduction

The correlation between consumption expenditures and house price over the business cycles is well documented in macroeconomic studies. Indeed, time-series estimates for a variety of countries — including Canada — have shown that the two variables tend to move together. Understanding the dynamics between house price and the accumulation of household debt is particularly important for policy-makers in 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). As an example, the economic fallout resulting from the collapse of the U.S. housing market was more painful and prolonged relative to a standard recession, as households and financial institutions engaged in a long deleveraging process following the crisis. During the same expansionary period, Canada also experienced a significant increase in house price, residential mortgages and consumer credit.[1]

In this paper, we perform an analysis to determine how well the introduction of a countercyclical loan-to-value (LTV) ratio[2] can reduce household indebtedness and housing price fluctuations compared with a monetary policy rule augmented with house price inflation. To this end, we construct a New Keynesian model in which a fraction of households borrow against the value of their houses and we introduce news shocks on housing demand. We estimate the model with Canadian data using Bayesian methods. We find that the introduction of news shocks can generate a housing market boom-bust cycle, the bust following unrealized expectations on housing demand. Our study also suggests that a countercyclical LTV ratio is a useful policy to reduce the spillover from the housing market to consumption and to lean against news-driven

[1] House price doubled and ratios of house-price-to-income and house-price-to-rent increased sharply (IMF, 2013). Mortgage credit (including Home Equity Lines of Credit, or HELOCs) expanded by almost 9 percent per year on average between 2000 and 2008, while household debt as a share of disposable income rose from about 100 percent in 2000 to 165 percent in 2013. As a result, mortgage and consumer loans secured by real estate (mostly HELOCs) are estimated to account for 80 percent of household debt and to represent the single largest exposure for Canadian banks with about 35 percent of their assets.

[2] LTV ratio imposes a cap on the size of a mortgage loan relative to the value of a property, thereby requiring a minimum down payment.

boom-bust cycles in housing price and credit generated by expectations of future macroeconomic developments.

Our paper is related to the business cycle literature on the role of collateral constraints in the transmission of shocks. A non-exhaustive list includes the following studies. Iacoviello and Neri (2010) estimate a New Keynesian model and study the sources and consequences of fluctuations in the U.S. housing market. Their results suggest that slow technological progress in the housing sector explains the upward trend in real housing price over the last 40 years and that the housing market spillovers are non-negligible, concentrated on consumption rather than business investment, and have become more important over time. Monacelli (2009) incorporates a durable goods sector into a general equilibrium model with collateral constraint and examines the monetary policy reaction to sectoral fluctuations. Finally, Gelain, Lansing, and Mendicino (2013) find that the introduction of a simple moving-average forecast rule, a deviation from the rational expectations hypothesis, for a subset of agents can significantly magnify the volatility and persistence of house price and household debt relative to an otherwise similar model with fully rational expectations.

Our research is also related to papers that consider either or both the effects of monetary policy and changes in regulatory LTV in a dynamic stochastic general equilibrium (DSGE) framework similar to Iacoviello (2005) and Iacoviello and Neri (2010). A non-exhaustive list includes Christensen, Corrigan, Mendicino, and Nishiyama (2009), Kannan, Rabanal, and Scott (2012), Justiniano, Primiceri, and Tambalotti (2013), Lambertini, Mendicino, and Teresa Punzi (2013b), Gelain et al. (2013) and Gelain, Kolasa, and Brzoza-Brzezina (2014). Among them, Lambertini et al. (2013b) study the potential gains of monetary and macroprudential policies that lean against house price and credit cycles and find that, when the implementation of both interest-rate and LTV policies is allowed, heterogeneity in the welfare implications is key in determining the optimal use of policy instruments.

Our model shares many features with Iacoviello and Neri (2010). At the core of the model is the borrowers-lenders set-up developed by Kiyotaki and Moore (1997). There are two types of households differentiated by the degree to which they discount the future. In equilibrium, one type of household is a lender and the other type a borrower. Borrowers face a collateral constraint that limits their ability to borrow to a fraction of the value of their housing assets. Rising house values can therefore improve the debt capacity of borrowers, allowing them to increase consumption. Households buy and sell housing in a centralized market. The mechanisms used in the paper are consistent with the view that credit, via collateral channel, is a propagation mechanism that causes macroeconomic fluctuations.

We extend the model of Iacoviello and Neri (2010) and contribute to the literature in two important dimensions. First, we introduce multi-period fixed-rate mortgage loans. Considering that the median length of a mortgage contract in Canada is 5 years and the majority are at a fixed rate, this feature is potentially crucial to replicate business cycle facts and to study the (in)effectiveness of macroprudential policies, assuming one-period loans as in Iacoviello and Neri (2010) and subsequent papers are not appropriate.[3] Secondly, we introduce news shocks (Beaudry and Portier, 2004) on housing demand. The notion that optimistic expectations can cause housing market booms and busts is widely accepted by policy-makers. As shown in Shiller (2007), real housing price can significantly deviate from economic fundamentals, as during the 1998–2007 housing boom. However, recent research on the housing sector in a DSGE model typically ignores expectation errors as a potential source of fluctuations. Notable exceptions are Kanik and Xiao (2014) and Lambertini et al. (2013b). News shocks can generate optimistic or pessimistic expectations and cause fluctuations in housing investment. Optimistic expectations lead to excessive housing investment, thereby causing a boom in the housing market not based on fundamentals. Once the news shocks are found to be unrealized, buyers revert their actions and a bust in the housing market follows. Therefore, our model allows us to study the effect of macroprudential

[3]This feature is introduced exogenously. Future research will study why this framework arises endogenously within the mortgage market.

policies in a context where agents can have (over-)optimistic expectations about the future and react by contracting more debt under fixed long-term contracts.

We estimate the model with Canadian data using Bayesian methods. We make three important contributions. First, we construct a new set of sectoral (disaggregated) data for consumption and the housing sector that allows us to better identify sectoral volatility and sector-specific dynamics. Second, we calibrated the share of patient and impatient households to reflect characteristics of wealth and income distribution data (Gelain et al., 2013). By using a calibration that underestimates the share of impatient households, recent research underestimates the mortgage-debt-to-GDP ratio, and thus results in the underestimation of the amplifier effects of macroprudential policy changes on the broader economy. Finally, in addition to the parameter priors, we also use the model priors, which better capture the dynamics of the model as a whole than the parameter priors alone.

Based on our model specifications, we find strong evidence suggesting important spillover effects between the housing market (and housing wealth creation) and the rest of the economy, and this link is mainly driven by demand and credit factors. We also find that the introduction of news shocks can generate a housing market boom-bust cycle, the bust following unrealized expectations on housing demand. In the news-driven business cycle literature, it is usually hard to generate the right co-movement among aggregate variables (Beaudry and Portier, 2004; Jaimovich and Rebelo, 2009). In our paper, two features of the model generate the co-movement: (i) the heterogeneity of households, bringing reallocation of housing stock between households, and (ii) the credit channel, by relaxing the collateral constraint of the borrowers, allowing them to borrow and consume more.

Finally, with the estimated model able to generate news-driven business cycles, we show that a countercyclical LTV ratio is a useful policy to reduce the spillover from the housing market to consumption and to lean against news-driven boom-bust cycles in housing price and credit generated by expectations of future macroeconomic developments.

The remainder of the paper is organized as follows. Section 2 presents the theoretical model. Section 3 describes the calibration, discusses estimation issues and our econometric strategy, and introduces the data employed. Section 4 discusses the estimation results and the overall performance of the model to describe business cycle characteristics, while Section 5 discusses the news-driven business cycles and reports the effect of the introduction of a countercyclical LTV ratio. Section 6 concludes.

2 A Model of Irreversible Housing Investment

We start from a standard New Keynesian set-up,[4] extended to incorporate household heterogeneity, irreversible housing investment and credit frictions, as in Iacoviello (2005) and Iacoviello and Neri (2010). Our economic environment features heterogeneity among economic agents. We consider an economy populated by two types of households, designated as borrowers and lenders. Credit flows are generated by assuming ex ante heterogeneity in agents' subjective discount factors. Impatient agents (borrowers) differ from patient agents (lenders) in that they discount the future at a faster rate. Hence, in equilibrium, patient agents are net lenders while impatient agents are net borrowers. To prevent borrowing from growing at the desired limit instantaneously, we assume that borrowers face a credit constraint tied to the current value of their collateral. We depart from the usual set-up of one-period loans by allowing for multi-period loans with fixed interest rates (Gelain et al., 2014; Alpanda, Cateau, and Meh, 2014; Alpanda and Zubairy, 2014), which is a representation closer to the Canadian context where the most common mortgage loan contract has a length of 5 years and a fixed interest rate.

There are two sectors of production in the economy: consumption and housing. Each variety of consumption goods is produced by a single firm in a monopolistic competitive environment and its price is set in a staggered fashion *à la* Calvo (1983). A

[4]We consider as *standard New Keynesian set-up* models incorporating households and firms having rational expectations, with a variety of market failures, among them imperfect competition.

representative firm produces houses in a perfectly competitive environment. Households supply differentiated labour in a monopolistic competitive environment, their wages being set in a staggered fashion *à la* Calvo (1983). They buy goods, deriving their utility from consumption goods and services provided by their housing stock. Credit flows are generated via perfectly competitive financial intermediaries, which accept deposits from patient households to lend to impatient households.[5] Finally, a central bank conducts monetary policy according to a Taylor-type rule.

2.1 Households

Households $i \in \{P, I\}$, patient and impatient respectively, derive in period t utility from consumption goods $c_{i,t}$ and from services provided by their housing stock $h_{i,t}$. They supply labour and derive a disutility from hours worked in the consumption sector $n_{i,t}^c$, and in the housing sector $n_{i,t}^h$. They maximize their expected lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta_i^t \epsilon_t^b U\left(c_{i,t}, h_{i,t}, n_{i,t}^c, n_{i,t}^h\right), \tag{1}$$

where $\beta_i \in (0,1)$ is the subjective discount factor and ϵ_t^b represents an exogenous process on discount rates that affects the intertemporal substitution of households (Smets and Wouters, 2007; Justiniano, Primiceri, and Tambalotti, 2010). The functional form of U is

$$U(\bullet) = \frac{(x_{i,t})^{1-\sigma_i^x}}{1-\sigma_i^x} - \frac{\epsilon_t^n}{1+\eta_i}\left(\left(n_{i,t}^c\right)^{\frac{\theta_i^n+1}{\theta_i^n}} + \left(n_{i,t}^h\right)^{\frac{\theta_i^n+1}{\theta_i^n}}\right)^{\frac{\theta_i^n(1+\eta_i)}{\theta_i^n+1}},$$

where σ_i^x is the constant elasticity of substitution (CES), ϵ_t^n is an exogenous process on labour supplies, and θ_i^n and η_i are, respectively, the intratemporal elasticity of substitution between sectoral labour supplies and the inverse of Frish elasticity of substitution. This specification of disutility of labour follows Horvath (2000) and allows for imperfect labour mobility across sectors by making the agents less responsive

[5] The presence of financial intermediaries is not crucial to our model, as we could have allowed the patient households to lend directly to impatient households. However, first, it simplifies the exposition of the model as the aggregation of deposits and loans is done at the financial intermediary level, and not by the households, and second, it will be useful to have that feature for future extension of the model.

to sectoral wage differentials.[6] The final good $x_{i,t}$ is defined as a CES composite of consumption goods $c_{i,t}$ and housing stock $h_{i,t}$:

$$x_{i,t} = \left[\left(1 - \epsilon_t^h\right)^{\frac{1}{\theta_i^x}} c_{i,t}^{\frac{\theta_i^x - 1}{\theta_i^x}} + \left(\epsilon_t^h\right)^{\frac{1}{\theta_i^x}} h_{i,t}^{\frac{\theta_i^x - 1}{\theta_i^x}} \right]^{\frac{\theta_i^x}{\theta_i^x - 1}}, \tag{2}$$

where ϵ_t^h is an exogenous process on the preference for services provided by the housing stock (housing demand shock). Housing demand shock includes both unanticipated (surprise) and anticipated (news) components, while all the other shocks in the model include unanticipated shocks only. We focus exclusively on studying news shocks on demand exogenous processes, as the effects of news shocks on supply exogenous processes have been covered extensively in Lambertini et al. (2013b). More details are provided in Section 2.5. The parameter θ_i^x is the intratemporal elasticity of substitution between consumption goods and the services provided by the housing stock.[7] This formulation of utility is slightly different than the standard utility in this literature, as we differ from the log-log specification of Iacoviello (2005) and Iacoviello and Neri (2010). Our specification allows us to better match Canadian data moments and is favoured by specification tests. Households accumulate housing stock according to the law of motion

$$h_{i,t} = \left(1 - \delta^h\right) h_{i,t-1} + i_{i,t}^h, \tag{3}$$

where $i_{i,t}^h$ is the investment in housing stock and δ^h its fixed depreciation rate. Aggregate housing investment is irreversible, while the housing investment at the household level is reversible at the real equilibrium house price. The irreversibility at the aggregate level is introduced via a specific production sector for housing goods, in which the production cannot be negative.[8] Therefore the housing stock can decrease at a

[6] $\theta_i^n \in [0, \infty)$, and when $\theta_i^n \to \infty$, hours worked in each sector tends to be a perfect substitute as agents devote all of their time to the sector paying the highest wage and all sectors pay the same hourly wage at the margin. Another way to include imperfect mobility between sectors would be the introduction of labour adjustment cost at the firm level.

[7] $\theta_i^x \in [0, \infty)$, and when $\theta_i^x \to \infty$, both goods tend to be perfect substitutes, whereas they tend to be perfect complements when $\theta_i^x \to 0$.

[8] Hours worked in the housing sector cannot be negative by the equilibrium conditions.

maximum rate of δ^h.[9]

Labour Labour decisions are made by a central authority within the households, which supplies, in a monopolistic competitive environment, differentiated labour $n^j_{i,e,t}$ in a continuum of labour markets $e \in [0,1]$ in sector $j \in \{c,h\}$ (Erceg, Henderson, and Levin, 2000; Schmitt-Grohe and Uribe, 2007).[10] Both sectors are, in terms of notation, the same. The central authority supplies labour to satisfy the demand given by

$$n^j_{i,e,t} = \left(\frac{W^j_{i,e,t}}{W^j_{i,t}} \right)^{-\theta^{n^j}} n^{j,d}_{i,t}, \tag{4}$$

where $W^j_{i,e,t}$ denotes the nominal wage charged by the central authority in the labour market e in sector j for agents of type i, $W^j_{i,t}$ is the nominal wage index, $n^{j,d}_{i,t}$ is a measure of aggregate labour demand by firms and θ^{n^j} is the wage-elasticity of demand.[11] In each labour market, the central authority takes $W^j_{i,t}$ and $n^{j,d}_{i,t}$ as given. In addition, the total number of hours allocated to the different labour markets must satisfy the resource constraint in each sector

$$n^j_{i,t} = \int_0^1 \left(n^j_{i,e,t} \right) de. \tag{5}$$

Combining this restriction with equation (4) yields the aggregated labour supply, expressed in real terms, in each sector j:

$$n^j_{i,t} = n^{j,d}_{i,t} \int_0^1 \left(\frac{w^j_{i,e,t}}{w^j_{i,t}} \right)^{-\theta^{n^j}} de. \tag{6}$$

[9]The Canadian data show that the value of house demolished (i.e. disinvestment in housing stock) over the total stock of house is extremely small.

[10]By assuming that all households will act as a representative household, this set-up avoids the need to assume separability of preferences and the existence of insurance for labour markets. This feature is already reflected in the notation since there are no subscripts for the continuum of households of each type i.

[11]The formal derivation of the labour demand by firms is presented in Section 2.2.

Patient Patient households ($i = P$) have a higher propensity to save (i.e. $\beta_P > \beta_I$). In equilibrium, they supply loans to impatient households ($i = I$) via their deposit d_t at financial intermediaries and accumulate housing and capital stock. Since lenders are the owners of the banks and firms in both sectors, they receive dividends f_t^c, f_t^h and f_t^{fi} from the consumption and housing sectors and from financial intermediaries, respectively. They maximize their expected lifetime utility (1) subject to their budget constraint in real terms

$$c_{P,t} + q_t^h i_{P,t}^h + \sum_{j\in\{c,h\}} q_t^{k^j} i_t^{k^j} + q_t^l l_t + b_{P,t} + d_t = \sum_{j\in\{c,h\}} r_t^{k^j} u_t^{k^j} k_{t-1}^j + \left(q_t^l + r_t^l\right) l_{t-1} + \quad (7)$$
$$\sum_{j\in\{c,h\}} n_{P,t}^{j,d} \int_0^1 w_{P,e,t}^j \left(\frac{w_{P,e,t}^j}{w_{P,t}^j}\right)^{-\theta^{n^j}} de + \frac{R_{t-1} b_{P,t-1}}{\pi_t^c} + \sum_{j\in\{c,h,fi\}} f_t^j +$$
$$\frac{1}{\phi^m} \sum_{s=1}^{\phi^m} \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \sum_{s=1}^{\phi^m} \left(R_{t-s}^d - 1\right) \left(\frac{\phi^m - s + 1}{\phi^m}\right) \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c},$$

the law of motion for capital in sector j

$$k_t^j = \left(1 - \delta_t^{k^j}\right) k_{t-1}^j + z_t^{i^k} i_t^{k^j} \left[1 - \frac{\phi^{k^j}}{2} \left(\frac{i_t^{k^j}}{i_{t-1}^{k^j}} - 1\right)^2\right], \quad (8)$$

and the law of motion for housing stock (3), where q_t^h is the real price of housing and $i_{P,t}^h$ is the investment in housing stock. Further, $j \in \{c, h\}$, k_t^j is the stock of capital specific to sector j, $i_t^{k^j}$ its investment level, $r_t^{k^j}$ its real rental rate, $u_t^{k^j}$ its variable capacity utilization rate and $\delta_t^{k^j}$ its variable depreciation rate. Lenders face an adjustment cost while investing in capital, parameterized by ϕ^{k^c} and ϕ^{k^h}. Moreover, the technology transforming investment goods into capital goods is subject to a transitory exogenous process denoted $z_t^{i^k}$ (Justiniano et al., 2010), and then induces a time-varying real price of investment $q_t^{k^j}$. Lenders own all the land stock l_t, which has a real price q_t^l and a real rental rate r_t^l. The stock of land is exogenous and fixed. π_t^c is the gross inflation rate in the consumption sector and R_t is the gross nominal interest rate on riskless one-period bonds $b_{P,t}$. Lenders' savings take the form of long-term deposits d_t at the financial intermediaries at the fixed interest rate R_t^d. As these deposits are the only source of funding for the financial intermediaries to finance the long-term loans, we have to impose long-term deposits on patient households to ensure zero profit conditions for the financial intermediaries. Finally, the deposit length is ϕ^m periods and, at each period, the lenders receive a share $\frac{1}{\phi^m}$ of the principal as a reimbursement of the deposit and a fixed return on investment $\left(R_t^d - 1\right)$ on the principal not reimbursed at the last period.

Lenders can control the intensity at which the capital stock is utilized. The effective amount of capital services supplied to firms in the consumption and housing sectors is given by $u_t^{k^c} k_{t-1}^c$ and $u_t^{k^h} k_{t-1}^h$, respectively. We assume that increasing the intensity of capital utilization entails a cost in the form of a faster rate of depreciation. Specifically, we assume that depreciation rate $\delta_t^{k^j}$ is an increasing and convex function of the rate of capacity utilization

$$\delta_t^{k^j} = \delta_0^{k^j} + \delta_1^{k^j}\left(u_t^{k^j} - 1\right) + \frac{\delta_2^{k^j}}{2}\left(u_t^{k^j} - 1\right)^2, \tag{9}$$

with $\delta_0^{k^j}, \delta_1^{k^j}, \delta_2^{k^j} > 0$, as in Schmitt-Grohe and Uribe (2012).[12]

Impatient The impatient households ($i = I$) do not accumulate physical capital nor hold any equity, and have access to multi-period fixed-rate mortgage loans with fixed (linear) principal payments, so that in each period borrowers have to pay interest on the outstanding debt and repay the amount of principal due. They maximize their expected lifetime utility (1) subject to a budget constraint

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

[12]See Appendix A for the Lagrangian and the complete set of first-order necessary conditions.

to the law of motion for housing stock (3), and a borrowing constraint. Private borrowing is subject to an endogenous limit. At any time t, borrowers agree to borrow no more than a share ω (Kiyotaki and Moore, 1997; Iacoviello, 2005; Monacelli, 2009; Iacoviello and Neri, 2010) of the current value of their housing stock:

$$M_t \geq -\omega \epsilon_t^{\chi} q_t^h h_{i,t}, \tag{11}$$

where ϵ_t^{χ} is an exogenous process on credit, and

$$M_t = \sum_{s=0}^{\phi^m - 1} \left(\frac{\phi^m - s}{\phi^m} \right) \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c}, \tag{12}$$

is the total mortgage debt.[13] The model reflects the fact that mortgage debt is reoptimized only for the share of contracts that reach their end and must be refinanced. This type of long-term loan has only just begun to be studied in the literature (Gelain et al., 2014; Alpanda et al., 2014; Alpanda and Zubairy, 2014).[14]

Wages We introduce wage stickiness by assuming that, in each period, the central authority within the households i cannot set the nominal wage optimally for a share $\xi^{w^j} \in (0,1)$ of labour markets chosen randomly. In the ξ^{w^j} labour markets that cannot set wages optimally, the wages are imperfectly indexed at rate ι^{w^j} to the steady-state inflation and at rate $1 - \iota^{w^j}$ to the $t-1$ inflation. The reoptimization probability is independent and identically distributed (i.i.d.) across labour markets and over time. In labour markets in which the wage rate is reoptimized in period t, the real wage is set to equate the expected future average marginal revenue to the average marginal cost of supplying labour, with $\frac{\theta^{n^j}}{\theta^{n^j}-1}$ being the markup of wages over the marginal cost of labour that would prevail in the absence of wage stickiness and trend inflation. $\tilde{w}_{i,t}^j$ denotes the real wage prevailing in the $\left(1 - \xi^{w^j}\right)$ labour markets in which the central authority can set wages optimally in sector j in period t. Because the labour demand curve faced by the union is identical across all labour markets, and because

[13] We use the convention that $m < 0$ is a debt.

[14] See Appendix A for the Lagrangian and the complete set of first-order necessary conditions.

the cost of supplying labour is the same for all markets, one can assume that wage rate $\tilde{w}^j_{i,t}$ is identical for all industries within a given sector (but not necessarily across sectors).[15]

2.2 Firms

2.2.1 Consumption Sector

Final-Goods Producers Perfectly competitive final-consumption-goods producers purchase differentiated intermediate goods $m \in [0, 1]$ to assemble final goods y^c_t via the Dixit-Stiglitz aggregator

$$y^c_t = \left[\int_0^1 \left(y^c_{m,t} \right)^{\frac{\theta^c - 1}{\theta^c}} dm \right]^{\frac{\theta^c}{\theta^c - 1}}, \tag{13}$$

where parameter θ^c denotes the intratemporal elasticity of substitution across varieties of intermediate differentiated goods[16] and $y^c_{m,t}$ is the demand for goods of variety m. When maximizing their profits, final-goods producers take as given the prices of intermediate goods and the aggregate price index.[17] The demand for goods of variety m is then given by

$$y^c_{m,t} = \left(\frac{P^c_{m,t}}{P^c_t} \right)^{-\theta^c} y^c_t, \tag{14}$$

where $P^c_{m,t}$ denotes the price of the intermediate consumption good m and P^c_t is the nominal price index defined as

$$P^c_t = \left[\int_0^1 \left(P^c_{m,t} \right)^{1-\theta^c} dm \right]^{\frac{1}{1-\theta^c}}. \tag{15}$$

[15]Part of the optimization problem (i.e. the Lagrangian) that is relevant for this purpose along with the first-order necessary condition can be found in Appendix A.

[16]When $\theta^c \to 0$, intermediate goods are perfect complements, whereas they are perfect substitutes when $\theta^c \to \infty$.

[17]The optimization problem can be found in Appendix A.

Intermediate-Goods Producers Each variety of intermediate goods in the consumption sector is produced by a single firm m evolving in a monopolistic competitive environment. The production function for each of these firms $m \in [0,1]$ is

$$y^c_{m,t} = z^c_t \left(k^c_{m,t}\right)^{\gamma^c} \left(\left(n^{c,d}_{P,m,t}\right)^{\alpha^c} \left(n^{c,d}_{I,m,t}\right)^{1-\alpha^c}\right)^{1-\gamma^c}, \tag{16}$$

where $y^c_{m,t}$ is its total production, $n^{c,d}_{P,m,t}$ and $n^{c,d}_{I,m,t}$ are the number of hours of work demanded by the firm for both types of workers, z^c_t is the sector-wide total factor productivity and $k^c_{m,t}$ is the capital stock rented by the firm. Also, γ^c is the capital share of income and α^c is the lenders' share of labour income. We assume that the firm must satisfy the aggregated demand for good m (14) at posted price.[18]

Firms are able to reoptimize their prices as in Calvo (1983) and Yun (1996). Specifically, each firm faces a price rigidity with a non-zero probability ξ^{p^c} of being unable to adjust its nominal price in a given period. These firms are able to imperfectly index their price at rate ι^{p^c} to the steady-state inflation and at rate $1-\iota^{p^c}$ to the $t-1$ inflation. The reoptimization probability is i.i.d. across firms and over time. Firms maximize the expected present value of their real dividends. Therefore, in setting their price in period t, firms take into account the fact that they may have to wait some time until they are able to reoptimize their price. In particular, the probability of not reoptimizing between dates t and $t+s$ is $\left(\xi^{p^c}\right)^s$. Since all reoptimizing firms face the same problem, they will all choose $\tilde{p}^c_t$ as the real optimal price. Optimizing firms set nominal prices so that average future expected marginal revenues equate average future expected marginal costs.[19]

Given that the opportunity to reoptimize prices arrives probabilistically for each firm in each period, the aggregate price index (15) can be written in real terms in this

[18] The optimization problem along with the first-order necessary condition for wages and rental rate can be found in Appendix A.

[19] Part of the optimization problem (i.e. the Lagrangian) that is relevant for this purpose along with the first-order necessary condition can be found in Appendix A.

recursive form:

$$1 = \left(1 - \xi^{p^c}\right) \left(\tilde{p}_t^c\right)^{1-\theta^c} + \xi^{p^c} \left(\frac{\left(\pi^c\right)^{\iota^{p^c}} \left(\pi_{t-1}^c\right)^{1-\iota^{p^c}}}{\pi_t^c} \right)^{1-\theta^c}. \tag{17}$$

2.2.2 Housing Sector

A representative firm produces houses in a perfectly competitive environment. Its production function is

$$y_t^h = z_t^h \left(u_t^{k^h} k_{t-1}^h\right)^{\gamma^h} l_{t-1}^{\gamma^l} \left(\left(n_{P,t}^{h,d}\right)^{\alpha^h} \left(n_{I,t}^{h,d}\right)^{1-\alpha^h} \right)^{1-\gamma^h-\gamma^l}, \tag{18}$$

where y_t^h is the total production for the housing sector, $n_{i,t}^{h,d}$ are the number of hours of work demanded by the firm for both types of workers, z_t^h is the sector-wide total factor productivity, $u_t^{k^h} k_{t-1}^h$ is the capital stock rented, and l_{t-1} is the land stock rented.[20] Also, γ^h is the capital share of income, α^h is the lenders' share of labour income and γ^l is the land share of income.[21] The fixed stock of land creates decreasing return to scale in the housing sector, as the availability of land has been identified in the literature to be one of the drivers of the housing price increase over the last two decades in the major Canadian city areas, mainly Vancouver and Toronto.

2.2.3 Labour Input

The labour input used by the firms in a given sector, denoted by $n_{i,t}^{j,d}$, is assumed to be a composite made of a continuum of differentiated labour services $n_{i,e,t}^{j,d}$. In the case of the consumption sector, we first need to integrate labour demand over all

[20] Since we assume a representative firm, to simplify the notation, we have already included the fact that the firm rents all the available capital in the sector, represented by $u_t^{k^h} k_{t-1}^h$, and all the available land, represented by l_{t-1}.

[21] In the calibration, we will assume that $\alpha^h = \alpha^c = \alpha$. The optimization problem along with the first-order necessary condition for wages and rental rate can be found in Appendix A.

intermediate firms $m \in [0,1]$, which yields

$$n_{i,e,t}^{c,d} = \int_0^1 \left(n_{i,e,m,t}^{c,d} \right) dm. \tag{19}$$

The aggregated labour demand for agents of type i in sector j is given by

$$n_{i,t}^{j,d} = \left[\int_0^1 \left(n_{i,e,t}^{j,d} \right)^{\frac{\theta^{n^j}-1}{\theta^{n^j}}} de \right]^{\frac{\theta^{n^j}}{\theta^{n^j}-1}}, \tag{20}$$

where $n_{i,e,t}^{j,d}$ is the demand for labour input of type e. When minimizing the cost, firms take as given the wage of labour input and the aggregate wage index. The optimal demand is

$$n_{i,e,t}^{j} = \left(\frac{W_{i,e,t}^{j}}{W_{i,t}^{j}} \right)^{-\theta^{n^j}} n_{i,t}^{j,d}, \tag{21}$$

where the nominal wage index is given by

$$W_{i,t}^{j} = \left[\int_0^1 \left(W_{i,e,t}^{j} \right)^{1-\theta^{n^j}} de \right]^{\frac{1}{1-\theta^{n^j}}}. \tag{22}$$

Given that the opportunity to reoptimize wages arrives probabilistically for each household in each period, the aggregate wage index (22) can be written in real terms in this recursive form:

$$\left(w_{i,t}^{j} \right)^{1-\theta^{n^j}} = \left(1 - \xi^{w^j} \right) \left(\tilde{w}_{i,t}^{j} \right)^{1-\theta^{n^j}} + \xi^{w^j} \left(\frac{w_{i,t-1}^{j} \left(\pi^c \right)^{\iota^{w^j}} \left(\pi_{t-1}^{c} \right)^{1-\iota^{w^j}}}{\pi_t^c} \right)^{1-\theta^{n^j}}. \tag{23}$$

2.3 Financial Intermediaries

We assume that households use financial intermediaries because they cannot borrow and lend with each other directly. As mentioned before, the presence of financial intermediaries is not crucial to our model, as we could have allowed the patient households to lend directly to impatient households. However, it simplifies the exposition of the model as the aggregation of deposits and loans is done at the financial intermediary level, and not by the households.[22] Financial intermediaries accept deposit d_t from lenders at the cost R_t^d and lend to borrowers m_t at rate R_t^m. The spread between rates on loans and deposits reflects a time-varying intermediation cost and it is assumed to be a deadweight loss to the economy. As Canada is a small open economy, trying to model the Canadian interest rate spread in a closed-economy model would have been difficult, as a major source of spread is the bank's funding cost on foreign markets. Therefore, modelling it as an exogenous process simplifies the process while keeping the transmission channel to the real economy. Financial intermediaries are assumed to be perfectly competitive and maximize the expected present value of their real dividends[23] subject to their balance sheets (in real terms)

$$\begin{aligned} d_t + \frac{1}{\phi^m} \sum_{s=1}^{\phi^m} \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \sum_{s=1}^{\phi^m} \left(R_{t-s}^m - 1\right) \left(\frac{\phi^m - s + 1}{\phi^m}\right) \frac{m_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} = \\ m_t + \frac{1}{\phi^m} \sum_{s=1}^{\phi^m} \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \sum_{s=1}^{\phi^m} \left(R_{t-s}^d - 1\right) \left(\frac{\phi^m - s + 1}{\phi^m}\right) \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + f_t^{fi} + \epsilon_t^{R^m} m_t. \end{aligned} \tag{24}$$

As documented by Campbell (2013), in many countries (including Canada), the vast majority of housing loans are long-term fixed-rate mortgages. We then incorporate this type of contract with one type of mortgage being available, with principal being reimbursed linearly over ϕ^m periods. It is obviously a simple modelling, abstracting from many mortgage characteristics, among them amortization, prepayment, availability of mortgage with variable rate, home equity line of credit, etc.[24] The deposit is also of the same form.[25]

[22] It will also be useful to have that feature for future extension of the model.

[23] See the objective function in the Appendix.

[24] Also, we impose this type of loan exogenously to all households, while it is chosen endogenously by 70 percent of the households, among different type of contracts.

[25] This hypothesis is not central to our results, but ensures zero profit over the terms of mortgage as monetary and spread shocks do not have any impact on the cost of funding. We tried one-period variable-rate deposit and it yielded similar results, but created profits or loss over the cycle and then

Taking the first-order necessary conditions for d_t and m_t yields the solution for R_t^m

$$R_t^m = \frac{\left(1+\epsilon_t^{R^m}\right) - \frac{1}{\phi^m}\sum_{s=0}^{\phi^m}\beta_P^s E_t\left[\frac{\epsilon_{t+s}^b}{\epsilon_t^b}\frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c}\frac{1}{\prod_{v=1}^s \pi_{t+v}^c}\right]}{\sum_{s=0}^{\phi^m}\frac{\phi^m - s+1}{\phi^m}\beta_P^s E_t\left[\frac{\epsilon_{t+s}^b}{\epsilon_t^b}\frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c}\frac{1}{\prod_{v=1}^s \pi_{t+v}^c}\right]}.$$

2.4 Monetary Policy

The central bank implements a Taylor-type (Taylor, 1993) monetary policy rule with interest smoothing:

$$R_t = \rho_r R_{t-1} + (1-\rho_r)\left(R + \rho_{\pi^c}\left(\frac{\prod_{v=1}^4 \pi_{t+v}^c}{4} - \epsilon_t^{\pi^c}\right) + \rho_y\left(Y_t - Y\right)\right). \tag{25}$$

The monetary authority adjusts the nominal gross interest rate R_t from its steady-state value in response to deviations of inflation π_t^c from its target, deviations of the GDP (Y_t) from its steady-state value, and the i.i.d. monetary policy innovation ε_t^R with variance $\sigma_{\varepsilon^R}^2$. ρ_r, ρ_{π^c} and ρ_y are the persistence parameter, and the inflation and output response parameters, respectively. The central bank's target, $\epsilon_t^{\pi^c}$, is assumed to be an exogenous time-varying process subject to shocks, as in Smets and Wouters (2003) and Adolfson, Laseen, Linde, and Villani (2007). The inflation targeting has been implemented since 1991 in Canada, therefore this model specification can help capture the response of R_t to movements in π_t^c in the first third of our sample.

2.5 Exogenous Processes

All the exogenous processes in the model introduced earlier follow

$$\ln\Theta_t = (1-\rho_\Theta)\,\Theta + \rho_\Theta\Theta_{t-1} + \varepsilon_t^\Theta, \tag{26}$$

would potentially create entry-exit dynamics.

where $\Theta_t = \left\{ \epsilon_t^{\chi}, \epsilon_t^{b}, \epsilon_t^{h}, \epsilon_t^{n}, \epsilon_t^{\pi^c}, \epsilon_t^{R^m}, z_t^c, z_t^h, z_t^{i^k} \right\}$ are the exogenous processes, Θ are their respective steady-state values, and ρ_Θ their respective persistence parameters. The structural shocks in the model, $\varepsilon_t^\Theta = \left\{ \varepsilon_t^{\epsilon^\chi}, \varepsilon_t^{\epsilon^b}, \varepsilon_t^{\epsilon^h}, \varepsilon_t^{\epsilon^n}, \varepsilon_t^{\epsilon^{\pi^c}}, \varepsilon_t^{\epsilon^{R^m}}, \varepsilon_t^{z^c}, \varepsilon_t^{z^h}, \varepsilon_t^{z^{i^k}} \right\}$, along with the monetary policy innovation ε_t^R, are all zero-mean i.i.d. shocks with process-specific variance σ_Θ^2 and are uncorrelated contemporaneously and at all leads and lags, except for the housing demand shock, where it is the individual components (unanticipated and anticipated shocks) that independently have these characteristics.

Housing Demand Shocks We assume that economic agents have in period t an information set that goes beyond current and past realizations of ε^{ϵ^h}. The housing demand innovation $\varepsilon_{t-i}^{\epsilon^h}$, $\forall i$ is now composed of unanticipated and anticipated components:

$$\varepsilon_{t-i}^{\epsilon^h} = \sum_{j=0,4,8}^{s} \varepsilon_{t-i-j}^{\epsilon^h, j}.$$

In this formulation, agents observe the current and past values of the housing demand news shocks $\varepsilon^{\epsilon^h, j}$. The notation $\varepsilon_{t-i}^{\epsilon^h, j}$, $\forall i, j$ means that the anticipated disturbances (or news shocks) learned in $t-i$ will affect the economy in j periods ahead (i.e. we learn in $t-i$ a news shock that will happen in $t-i+j$). More specifically, the disturbance $\varepsilon_t^{\epsilon^h, 4}$ represents an innovation to ϵ_{t+4}^h, which is announced in period t but materializes only in period $t+4$. Note that $\varepsilon_t^{\epsilon^h, 4}$ does not appear in the expression for $\varepsilon_t^{\epsilon^h}$ given above. Rather, the above expression features $\varepsilon_{t-4}^{\epsilon^h, 4}$, the four-periods-ahead announcement made in period $t-4$. Similarly, $\varepsilon_t^{\epsilon^h, 8}$ would be observed in t and represent eight-periods-ahead announcements of future changes in the housing demand. In this set-up, $\varepsilon_t^{\epsilon^h, 0}$ can be viewed as the usual contemporaneous (i.e. unanticipated) disturbances to ϵ_t^h.

Since agents are forward-looking, they use the information contained in the realizations of news shocks in their current choices of consumption, investment in capital and housing and hours worked. It is precisely this forward-looking behaviour of economics agents that allows us, via our econometric method, to identify the volatilities of housing demand news shocks, even if we cannot observe them directly.

2.6 Market Clearing

Consumption Sector The aggregation in the production sectors and labour markets follows similar processes introduced in the New Keynesian literature. Integrating both sides of the intermediate goods production technology (16) yields

$$\int_0^1 \left(y_{m,t}^c\right) dm = \int_0^1 z_t^c \left(k_{m,t}^c\right)^{\gamma^c} \left(\left(n_{P,m,t}^{c,d}\right)^{\alpha^c} \left(n_{I,m,t}^{c,d}\right)^{1-\alpha^c}\right)^{1-\gamma^c} dm \tag{27}$$

$$= z_t^c \left(u_t^{k^c} k_{t-1}^c\right)^{\gamma^c} \left(\left(n_{P,t}^{c,d}\right)^{\alpha^c} \left(n_{I,t}^{c,d}\right)^{1-\alpha^c}\right)^{1-\gamma^c}.$$

Substituting $y_{m,t}^c$ in (27) and using demand function (14), we get

$$\left[\int_0^1 \left(\frac{P_{m,t}^c}{P_t^c}\right)^{-\theta^c} dm\right] y_t^c = s_t^y y_t^c = z_t^c \left(u_t^{k^c} k_{t-1}^c\right)^{\gamma^c} \left(\left(n_{P,t}^{c,d}\right)^{\alpha^c} \left(n_{I,t}^{c,d}\right)^{1-\alpha^c}\right)^{1-\gamma^c}, \tag{28}$$

where s_t^y captures the inefficiencies associated with price dispersion arising from the price rigidity. Schmitt-Grohe and Uribe (2007) show that these price dispersion indexes can be defined as

$$s_t^y = (1-\xi^c) \left(\tilde{p}_t^c\right)^{-\theta^c} + \xi^c \left(\frac{(\pi^c)^{\iota^{p^c}} \left(\pi_{t-1}^c\right)^{1-\iota^{p^c}}}{\pi_t^c}\right)^{-\theta^c} s_{t-1}^y. \tag{29}$$

The market clearing condition for the consumption sector is therefore

$$y_t^c = c_t + q_t^{k^c} i_t^{k^c} \left(1 + \frac{\phi^{k^c}}{2} \left(\frac{i_t^{k^c}}{i_{t-1}^{k^c}} - 1\right)^2\right) + q_t^{k^h} i_t^{k^h} \left(1 + \frac{\phi^{k^h}}{2} \left(\frac{i_t^{k^h}}{i_{t-1}^{k^h}} - 1\right)^2\right) + \epsilon_t^{R^m} m_t, \tag{30}$$

where $c_t = c_{P,t} + c_{I,t}$. Finally, the real profits are

$$f_t^c = y_t^c - w_{P,t}^c n_{P,t}^{c,d} - w_{I,t}^c n_{I,t}^{c,d} - r_t^{k^c} u_t^{k^c} k_{t-1}^c. \tag{31}$$

Housing Sector The total production, as expressed by (18), must satisfy the aggregate demand for the sector

$$y_t^h = i_{P,t}^h + i_{I,t}^h, \tag{32}$$

the real profits are

$$f_t^h = q_t^h y_t^h - w_{P,t}^h n_{P,t}^{h,d} - w_{I,t}^h n_{I,t}^{h,d} - r_t^{k^h} u_t^{k^h} k_{t-1}^h - r_t^l l_{t-1}, \tag{33}$$

and the total housing stock is $h_t = h_{P,t} + h_{I,t}$.

Labour Input The nominal wage rigidity induces a loss in the number of hours worked supplied due to nominal wage dispersions. Schmitt-Grohe and Uribe (2007) show that these price dispersions can be expressed as

$$s_{i,t}^j = \left(1 - \xi^{w^j}\right) \left(\frac{\tilde{w}_{i,t}^j}{w_{i,t}^j}\right)^{-\theta^{n^j}} + \xi^{w^j} \left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t-1}^c\right)^{1-\iota^{w^j}}}{\pi_t^c}\right)^{-\theta^{n^j}} \left(\frac{w_{i,t-1}^j}{w_{i,t}^j}\right)^{-\theta^{n^j}} s_{i,t-1}^j, \tag{34}$$

and the labour supply-demand relation is given by $n_{i,t}^j = n_{i,t}^{j,d} s_{i,t}^j$.

Aggregate Economy The real GDP is therefore given by

$$y_t = y_t^c + q_t^h y_t^h. \tag{35}$$

3 Empirical Strategy

In order to evaluate the performance of the model, we use a combination of calibrated and estimated parameters. Our choice to calibrate some of the parameters was mainly based on the lack of data for some of the model variables, particularly those describing the production functions and the wealth and income distributions. This section first describes our calibration approach, then presents the details regarding the estimation procedure, and concludes with a presentation of the data.

3.1 Calibration

The model is calibrated on a quarterly basis. Table 1 summarizes our calibration, while Table 2 displays the steady states of the model and observed values of corresponding data. We calibrated this set of parameters because they are either difficult to estimate given the information contained in the model[26] or they are better identified using other information. For instance, some parameters are set to achieve target values for steady states while others are set to commonly used values in the literature.

We set the steady state annual inflation rate at 2 percent, this value being the target of the inflation-control policy implemented by the Bank of Canada. The steady states of nominal and real interest rates reflect the lender's degree of time preference, β_P, and the steady-state gross inflation rate. We use an annual real rate of return of 2.77 percent (the average over our sample), which yields a β_P of 0.9925. As for the calibration of the borrower's time discount factor, based on the sample mean of R_t^m, we choose a value of 0.9844, which is in range of other studies that 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. We are departing here from a common strategy used in previous studies estimating models of housing dynamics that assumes zero steady-state inflation. Given that, up to the first order, the steady state represents the unconditional mean of the variables, our approach has the advantage of centring the model closer to the unconditional mean in the data. The inflation expectations of 2 percent being well anchored in Canada by economic agents, our approach then has the desirable property to disentangle the expectations on components of nominal interest rates, which are the real interest rate

[26] For identification testing, we compute the Fisher information matrix. It is a property of the model itself, and is independent of any data. It represents the maximum amount of information we can find in the data assuming the data are really generated by the model data-generating process (DGP) for a given parametrization. In that sense, it is a local identification test. We compute two approaches: a time-domain and a frequency-domain, and use a singular value decomposition to learn more about which parameters (or combinations of them) are identified the best or the worst. In our case, the intratemporal elasticity of substitution between sectoral labour supplies, the depreciation rates, the intratemporal elasticity of substitution across different varieties of intermediate goods and the wage-elasticities of demand has been revealed to be not or weakly identifiable.

and inflation rate.

The share of patient households (α) in the model is 0.25, representing the top quartile of households in the model economy. Parameter α determines the labour share of income and, indirectly, the physical capital wealth[27] and the distribution of real estate wealth. By targeting the top quartile of households and setting α at 0.25, we are able to target some important ratios: (i) the patient households own 72 percent of total wealth, which is broadly in line with financial data for that quartile;[28] (ii) the patient households earn 75 percent of total labour income, which is in line with income data;[29] and (iii) mortgage debt as a share of GDP is 0.89 (in the top of the distribution in our sample). We are departing here 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, Mendicino, and Punzi (2010) and Lambertini et al. (2013b). We conduct local identification tests and find that it is not possible to identify this parameter in the absence of wealth data.[30]

Following Iacoviello and Neri (2010), the quarterly depreciation rates for housing and capital in both the consumption and housing sectors are set at 0.01, 0.025 and 0.03, respectively, implying annual depreciation rates of 4.06 percent, 10.38 percent and 12.55 percent, respectively. Likewise, the prices and wages markups θ^c and θ^{n^j} are set at 7.67, which yields steady-state markups of 15 percent for intermediate goods producers and households. All those values are common in the literature.

The capital share of income in the consumption sector, γ^c, is set at 0.25. In the housing sector, we set the capital and land share of income γ^h and γ^l at 0.10 and 0.35, respectively. These factor shares, along with a weight of housing service in the utility function ϵ^h_{ss} at 0.75, the intertemporal elasticities $\sigma^x_P = \sigma^x_I = 1.2$, following Dorich, Johnston, Mendes, Murchison, and Zhang (2013), the intratemporal elasticities $\theta^x_P =$

[27] Patient households own all the physical capital wealth.

[28] See the *Survey of Financial Security* from Statistics Canada.

[29] See the *World Top Income Database* available on Emmanuel Saez's website.

[30] Estimation of the model with α as an estimated parameter yields a bi-modal posterior distribution of α, with modes around 0.25 and 0.75. Without wealth data based on micro-studies and surveys, it is not possible to discriminate between those values.

$\theta_I^x = 0.4$ and the depreciation rates, imply steady-state ratios of consumption, non-housing investment and housing investment to real GDP of approximately 74, 15 and 8 percent, respectively, which are in line with the data in our sample. Moreover, these calibration choices imply ratios of business capital and housing wealth (together with α) to annual GDP of around 1.6 and 2.0, respectively. While the former is in line with data, the latter is 50 percent higher than the mean over our sample. The model is not disaggregated enough to allow the ratio of housing-investment-to-GDP and of housing-stock-to-GDP to match the data at the same time. We then focus on the flow and leave the stock unmatched. Finally, along with the estimated parameters, the land share of income implies that the value of residential land is around 80 percent of GDP, a value close to the empirical data. The parameters η_P and η_I are set at 2.5 and 1.5, respectively, and the steady-state ϵ_{ss}^n is set so the steady-state labour supply by borrowers is 20 percent higher than by the lenders. The intratemporal elasticity of substitution between sectoral labour supplies is set at 10 for both households, yielding a share of total hours worked of 0.92 in the consumption sector, a value close to the data.

Finally, the LTV ratio is set at 0.91, which is the average value in Canada over the last few decades, while ϵ_{ss}^{Rm} is set at 0.066 to match the average quarterly spread between the risk-free and the 5-year mortgage rates over the last 30 years.

3.2 Bayesian Approach

The noncalibrated parameters are estimated by using a Bayesian approach (see DeJong, Ingram, and Whiteman (2000); Lubik and Schorfheide (2006); An and Schorfheide (2007)). In order to compute the likelihood for a given set of parameters, we solve a log-linear approximation of the equilibrium conditions in the neighborhood of the non-stochastic steady-state (Blanchard and Kahn, 1980; Klein, 2000; Sims, 2002).[31] The solution takes the form of a state-space model that is used to compute the likelihood

[31] We use a modified version of the Klein (2000) algorithm available in the IRIS Toolbox (http://iristoolbox.codeplex.com/).

function, and, given the linear solution and the assumption of normally distributed shocks, the Kalman filter is used to evaluate the likelihood.

Given the likelihood function, we characterize the posterior distribution in two steps. First, we transform the data into a form suitable for computing the likelihood function, we use the parameter and the model prior distributions to incorporate additional information into the estimation, and we maximize the posterior using numerical methods.[32] Finally, we use a metropolis posterior simulator to evaluate the behaviour of the posterior distribution and to draw model parameters from the posterior distribution.[33]

Parameter's Prior Distributions The advantage of using priors is to take our *a priori* beliefs into account in estimating the parameters of the model. The choice of priors is described in the second, third and fourth columns of Table 3 and Table 4 for the noncalibrated parameters, and Table 5 for the measurement errors. The prior distributions are guided by the constraints in these parameters and are either consistent with previous studies (Levin, Onatski, Williams, and Williams, 2006; Del Negro, Schorfheide, Smets, and Wouters, 2007; Justiniano et al., 2010; Iacoviello and Neri, 2010; Schmitt-Grohe and Uribe, 2012) or fairly diffuse and relatively uninformative.

To reflect their strict positivity, we set a Gamma prior on the investment adjustment costs (ϕ^{k^c} and ϕ^{k^h}) around 5 with a standard error of 2. We select a Beta prior for the Calvo price and wage parameters (ξ^{p^c}, ξ^{w^c} and ξ^{w^h}) and the inflation indexation parameters (ι^{p^c}, ι^{w^c} and ι^{w^h}), as they belong to the interval $[0, 1)$, and due to a lack of consensus on their values in the literature (Christiano, Eichenbaum, and Evans, 2005; Smets and Wouters, 2007), we set the prior mean at 0.5, with a standard deviation of 0.22.

For all the persistence parameters governing the exogenous processes, we use a Beta prior with a mean equal to 0.80 and a standard deviation equal to 0.1.[34] For all

[32] We use the Active-set algorithm in KNITRO.

[33] We use the mode obtained in the first step as a starting point and an adaptive random-walk Metropolis posterior simulator with 500,000 draws with 100,000 burn-in draws and target acceptance ratio of 0.234.

[34] A Beta prior with a mean equal to 0.5 and a standard deviation equal to 0.22 yields the same

innovation and measurement error standard deviations, we use an inverse-Gamma prior with a mean equal to 0.1 and a standard deviation equal to 0.2. These priors are quite disperse 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.

For the monetary policy specification, we base our priors on a standard Taylor rule with interest rate smoothing that responds gradually to inflation and output gap. We use a Beta prior for ρ_r and ρ_y with means of 0.8 and 0.1 and standard deviations of 0.3 and 0.025, respectively, and a Gamma prior with mean of 3.5 and a standard deviation of 0.5 for ρ_{π^c}. These priors are in line with previous Canadian studies (Christensen et al., 2009; Dorich et al., 2013).

Model's Prior Distributions We also use additional information to estimate the model, by implementing a novel approach using model priors (Andrle and Benes, 2013). In contrast with parameter priors, model priors are those about the model's features and behaviour as a system, such as the covariance and 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. In our case, since we focus on housing-market-related business cycles, spillovers from housing wealth to consumption level and the notion of boom-bust, we select correlation to be the most relevant model priors to implement. More specifically, we use the first- to third-order cross-correlation between consumption, residential investment, non-residential investment, house price and mortgage debt, and we apply a normal prior with the mean being the sample first- to third-order cross-correlation computed on the filtered data used in the estimation (see next section on Data), and standard deviation set at 0.1. The choice of priors is described in Table 6.

estimation results on these parameters.

Data To estimate the model, we use Canadian quarterly data for the period 1983Q3 to 2014Q4. The vector of observables used for the estimation includes 15 variables: real consumption, residential investment, non-residential investment, and mortgage debt per capita; real house and capital prices; nominal short- and long-term interest rates; core CPI inflation rate; and finally hours worked per capita, real wage and capacity utilization rate in both consumption and housing sectors. In order to remove the trend and isolate the cyclical component, we apply the one-sided Hodrick-Prescott (HP) filter on most of data.[35] The interest rates are detrended by removing a linear time trend, and the core CPI inflation rate and the capacity utilization rates are demeaned. Figure 1 plots the time series. A detailed description of the series used in the estimation is provided in Appendix B. In addition, we include i.i.d. measurement errors for hours worked, wages and capacity utilization rate for both sectors.

Our set of observables includes more variables than most previous DSGE estimations for housing market dynamic models. We consider series that are of general interest for policy analysis usually used in the literature, such as consumption, investments, wages, hours worked, inflation and interest rates. Our data set also includes variables that may *a priori* help us identify several features of the model. For instance, sectoral data, such as hours worked, wages and capacity utilization rates, will be useful in characterizing movements and correlation that are sector-specific and could be hidden in aggregated data. As an example, hours worked and real wages in the housing sector experience around two times the volatility of their counterparts in the consumption sector (see Figure 1). Since the consumption sector accounts for 75 percent of the model-consistent total GDP, using aggregated data would hide this sectoral volatility. We construct the sectoral data by linking the model definitions to their Standard Industry Classification (SIC) and North American Industry Classification System (NAICS) counterparts. The housing sector is approximated by the construction sec-

[35]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). We adjust for seasonality before any computation when necessary.

tor.[36] The construction sector also includes the non-residential construction, but since we focus on the cyclical component and not the level, we make the conjecture that the cycles in both non-residential and residential construction are approximatively similar. The consumption sector includes the rest of goods- and services-producing industries, excluding all government components. Finally, mortgage debt contains information on the reallocation of debt between agents and the preference on consumption and housing services.

Monetary Policy Since the Bank of Canada introduced its inflation-targeting regime in 1991, the Taylor-type monetary policy rule appropriately describes the behaviour of the short-term interest rate path from 1992 to 2014, but is less likely to reflect its behaviour from 1983 to 1991. Therefore, we estimate the model in two steps. First, we use a restricted sample covering 1992Q1 to 2014Q4 without the time-varying inflation target process to recover the parameters of the monetary policy rule. Second, in the full sample estimation covering 1983Q3 to 2014Q4, the parameters of the monetary policy rule are calibrated and time-varying inflation targeting is introduced. This two-step process allows us to both impose the same monetary policy rule over the full sample and avoid introducing a bias on estimated parameters by estimating the model on the sample when the assumed functional form of the monetary policy rule is likely to apply.

4 Empirical Results

In this section, we first describe the estimated posterior distribution, paying attention to the parameters describing the housing market dynamics. We then perform a posterior analysis to establish the extent to which the model can fit the data.

[36] Codes F in SIC and 23 in NAICS.

4.1 Posterior Distributions

The estimated posterior distributions of the noncalibrated parameters are summarized in Table 3 and Table 4, the measurement errors are presented in Table 5, while the model's properties are shown in Table 6. 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.

The capital adjustment costs seem to differ across sectors. These results could imply that the model requires partial capital mobility across sectors in order to better approximate the data. Cumulated with the imperfect mobility in the labour market, this means that the real frictions caused by imperfect mobility play a significant role in the suboptimal allocation of resources relative to the perfect mobility scenario.

With autoregressive parameters being, in general, higher than 0.85, the estimated exogenous processes are generally persistent, except for the technology process in the consumption sector and the investment-specific process, with parameters equal to 0.48 and 0.68, respectively. Labour supply is the most persistent process, with an autoregressive parameter equal to 0.9991. In terms of volatility, among the estimated standard error of the exogenous processes, the interest rate spread shock seems to be the most volatile, followed by the investment-specific shock. However, we will see in the next section that the latter shock is not a main driver of the forecast error variance decomposition, mainly because of its persistence.

Regarding parameters measuring nominal rigidities, the estimate of θ^{p^c} (0.62) implies that prices are reoptimized frequently, once every 2 quarters. However, given the positive value of the indexation parameter ($\iota^{p^c} = 0.96$), prices 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 ($\theta^{w^h} = 0.97$) and the consumption sector ($\theta^{w^c} = 0.98$) are almost equal. While being reoptimized infrequently, once every 30–40 quarters, wages are indexed every period to compensate the steady-state inflation ($\iota^{w^h} = 0.84$

and $\iota^{w^c} = 0.37$) and the past inflation.

Finally, with a large weight on inflation ($\rho_{\pi^c} = 4.23$) and a fairly small weight on output gap ($\rho_y = 0.30$), estimates of the parameters of the monetary policy rule are in line with previous evidence (Christensen et al., 2009; Dorich et al., 2013) and the parameters used at the Bank of Canada. In terms of the three monetary disturbances, the shock to interest rate spread is the most volatile, and more persistent than the shock to inflation targeting. The monetary policy shock standard error is perfectly in line with previous studies with Canadian data (Christensen et al., 2009; Dorich et al., 2013).

4.2 Second Moments

Table 7 presents first-, second- and fourth-order auto- and cross-correlations for a set of selected model variables for both the data moments and asymptotic (model-based) moments evaluated using the posterior mode. While the model underestimates the first- and fourth-order autocorrelations of mortgage debt and the fourth-order autocorrelation of residential and non-residential investment, it is able to replicate well all the other autocorrelations of the data, with the theoretical autocorrelation always being closed from its data counterpart. The model also matches both the sign and the level of the cross-correlations for most of the desired relationship being studied. The theoretical zeroth- to fourth-order cross-correlations of consumption with housing investment and house price are all in line, both in sign and level, with their data counterparts, which is an important feature to match to attain the desired volatility and co-movement in boom-bust scenarios. Lastly, the model-based correlation between consumption and mortgage debt is also of the expected sign, but is twice the level of correlation seen in the data. Overall, the model seems to properly replicate the behaviour of the observables.

4.3 Variance Decomposition

After establishing the extent to which the estimated model can replicate the business cycle observations, we proceed with the variance decomposition. In this section we discuss both the historical and forecast error variance decomposition.

Historical Figure 3 presents the historical variance decomposition for a set of selected observables for the period 1983Q2 to 2014Q4. We present results by grouping shocks into five classes: (i) monetary policy and financial, which includes $\varepsilon_t^{\epsilon^{\chi}}$, $\varepsilon_t^{\epsilon^{\pi^c}}$, $\varepsilon_t^{\epsilon^R}$ and $\varepsilon_t^{\epsilon^{R^m}}$; (ii) demand, which is $\varepsilon_t^{\epsilon^b}$; (iii) supply, which includes $\varepsilon_t^{\epsilon^n}$, $\varepsilon_t^{z^c}$, $\varepsilon_t^{z^h}$ and $\varepsilon_t^{z^{ik}}$; (iv) housing, which is all housing demand shocks (surprise and news); and finally (v) measurement errors.

Focusing on the decomposition of the housing investment and house price first, it is clear that their short-run variability is mostly accounted for by the housing demand shocks and the monetary policy and financial shocks. Indeed, both types of shocks seem to have driven the decline in both supply and demand sides in the two last recessions of 1991 and 2008, while the boom in the 1980s was driven by only the latter.

As expected, most of the fluctuations in non-residential investment in both production sectors are mainly driven by the supply-specific shocks. However, a non-negligible share is also explained by monetary policy and financial shocks, which affect the intertemporal reallocation of resources of lenders over time, and then have a direct impact on investment decision.

Forecast Error We now proceed with the forecast error variance decomposition. Table 8 presents the unconditional variance decomposition of the observables for all the shocks in the model, the last column being the sum of the contributions of all measurement errors.

In terms of explaining the consumption fluctuations, the labour supply, the credit, the housing demand (both news and surprise) and the inflation-targeting shocks appear to be the most significant. They explain respectively 54, 18, 10.3 and 9.8 percent of the consumption volatility. The labour supply shock directly affects the labour income of the agents and therefore all economic decisions made by households, while the inflation-targeting shock causes, for a given increase in price level, variation in the reaction of the monetary policy across periods. Finally, the credit shock affects the impatient households' capacity to borrow against their collateral, therefore affecting their consumption. The other drivers do not seem to play a significant role in explaining consumption fluctuations. These results are in contrast with other studies that identified technology shock in the consumption sector and monetary policy shock among the main drivers of consumption volatility.

The same analysis applies to non-residential investment and capital price, while replacing the credit shock with the investment-specific shock as the third driver. Since these variables are driven by decisions of patient households and are not affected directly by the credit shock (but only by spillovers from impatient households' reactions to credit shock), these results were expected. Finally, house price and residential investment forecast error variances are mostly driven by labour supply, housing demand and total factor productivity (TFP) in housing sector shocks, as expected.

4.4 Shock Responses

In the last section, we analyzed how well the estimated model can replicate the business cycle observations. It is also important to understand the dynamics in the model implied by the shocks. In this section, we focus on five of them that explain most of the volatility in the model. All results presented in this section are the model's responses to a one-standard-deviation shock.

Housing Demand Figure 4 plots impulse responses to the estimated housing demand shocks, both surprise and news. Overall, it raises on impact house price and returns on housing investment. Since borrowers' collateral is linked to house price, they can increase their level of borrowing and consumption. Given their higher marginal propensity to consume, the effects on total consumption are positive and entirely driven by borrowers, their consumption increase being high enough to compensate the decrease in lenders' consumption.

Housing demand shocks generate the co-movement between house price, total consumption, residential investment and hours worked (not shown) in both sectors of production observed in the data, especially during periods of housing booms. Shocks affect economic choices and, in particular, the housing investment and credit decisions of households. The occurrence of a positive housing demand shock prompts appreciation in housing price and fuels current housing demand. Consequently, housing investment rises quickly on impact, with a peak increase of more than 1.7 percent. House price follows the same curve, with a peak increase of 1.4 percent on impact. Mortgage debt increases significantly, by close to 15 percent, reflecting both the increase in housing investment and the increase in house price that affect the value of all the undepreciated housing stock. This increase in the collateral value boosts the consumption of borrowers and causes inflationary pressures, which has the effect of increasing interest rates, both short- and long-term. Moreover, due to limits to credit, borrowers increase their labour supply in order to raise funds for housing investments. However, coupled with a decrease in non-residential investment, wages rise. The increase in consumption and housing investment also makes GDP rise. Thus, housing demand shocks in this model generate procyclicality among relevant variables.

The story behind news shocks is similar, but the dynamics are different, since news shocks generate reactions only via the expectation channel. When news about higher future housing demand arrives, it is optimal for agents to immediately start increasing their housing stock to take advantage of the capital gain. The marginal gain is higher for impatient than patient households, as it increases the marginal utility of housing stock for both but also relaxes the borrowing constraint for the former, allowing them to borrow and consume more. Patient households sell their houses to impatient households. Optimistic expectations lead to excessive housing investment, thereby causing a boom in the housing market not based on fundamentals.

Labour Supply Figure 5 presents the model's response to a shock in labour supply. This shock induces a greater disutility of hours worked to agents, causing an immediate decrease in hours worked in both sectors. This decrease leads to an increase in real wages in both sectors as the productivity increases slightly. The marginal cost of production is driven up and gradually transmitted to the inflation in the consumption sector, which drives interest rates up via the monetary policy response. The decrease in labour income and the increase in borrowing costs lead to a decrease in housing investment from the borrowers and a real house price decline, thereby reducing collateral values. Overall, all economic aggregates react negatively in response to negative income shock.

Monetary and Inflation Targeting Figure 6 plots the effects of monetary policy shocks. The temporary shock leads to a rise in the nominal and real short-term interest rates, and a fall in output, consumption and residential and non-residential investment. In line with the stylized facts on monetary policy shocks, real wages fall (not shown). The largest effect on consumption is about 1.5 times that on non-residential investment. Overall, these effects are consistent with the evidence found in the literature.

Finally, Figure 6 presents the model's response following a shock in inflation targeting. An increase in the inflation target means that, following an increase in inflation, the central bank will not increase the interest rate as much as in steady state. The effects of a persistent change in the inflation objective are strikingly different from the monetary policy shock in one aspect. First, there is a liquidity effect, as nominal interest rates start increasing immediately as a result of the increased inflation expectations. Inflation picks up immediately, driven by an increase in consumption and housing investment. Interest rates continue to increase in response to higher inflation, this time at a slower pace.

Interest Rate Spread Figure 7 plots the effects of interest rate spread shocks. The temporary shock leads to a rise in the nominal and real long-term interest rates, and a fall in output, consumption and residential and non-residential investment. In line with the stylized facts on monetary policy shocks, real wages fall (not shown). The real short-term interest rate declines to respond to negative outlook on inflation. Overall, these effects are consistent with the evidence found in the literature.

LTV Finally, Figure 8 plots impulse responses to the estimated LTV shocks, which are credit shocks. A positive shock on LTV relaxes the borrowing constraint of impatient households, allowing them to borrow and consume more. However, to finance this borrowing, patient households reduce their consumption and housing investment, inducing a house price decline, and constraining the borrowing constraint of impatient households. Overall, consumption and non-residential investment increase, but the effect on consumption is short-lived.

4.5 Robustness

As mentioned in Section 3.2, we estimate the model in two steps. While it is not the primary purpose of this procedure, this two-step estimation provides robustness analysis by estimating our model over a subsample. Overall, the results described for the full sample remain true when considering the subsample, with a notable exception of the persistence of the LTV exogenous process, which is less persistent by a factor of 2 than in its full sample counterpart. Because of similarity of results, we do not reproduce the robustness analysis in this paper, but all results are available upon request.

5 Housing Market News-Driven Boom-Bust Cycles and Loan-to-Value Ratio

Since we now have an estimated model able to replicate business cycle properties of the housing market in the Canadian economy, in this section, we first highlight key findings regarding the transmission mechanism of news shocks and describe the role of news shocks in housing market dynamics. Through simulation, we analyze the impacts of news shocks on selected variables over the business cycle and show that news shocks can generate boom-bust housing market cycles. Then we examine the effectiveness of implementing different countercyclical LTV ratios and compare it to the effectiveness of a simple Taylor-type monetary policy rule augmented with house price inflation.

5.1 News Shocks and Housing Market News-Driven Boom-Bust Cycles

Our paper contributes to the news-driven business cycle literature. It is well-known in the literature that rational-expectations DSGE models can hardly generate news-driven boom-bust cycles. In the real-business cycle literature, positive news about future TFP shocks create a strong wealth effect, inducing a decline in hours worked. Agents then produce less and invest less to finance their consumption increase. Therefore, positive news shocks create a recession. The economic outcome becomes even worse when the positive news shocks are unrealized. There is a stream of literature that studies which mechanisms could potentially generate news-driven business cycles (see, among others, Beaudry and Portier (2004) and Jaimovich and Rebelo (2009)).

In general, macroeconomic models of housing markets rely on mainly fundamental developments in the economy to explain fluctuations in house price and residential investment (notable exceptions are Kanik and Xiao (2014) and Lambertini et al. (2013b)). However, survey evidence shows that house price dynamics are greatly related to macroeconomic expectations, especially to optimism about future house price appreciations (Lambertini, Mendicino, and Punzi, 2013a). Also, real housing price can significantly deviate from economic fundamentals, as during the 1998–2007 housing boom episode (Shiller, 2007).

In this paper, we generate news-driven business cycles and co-movement among economic aggregates by relying on two features of the model: (i) the existence of heterogeneous agents; and (ii) the collateral channel. When news about higher future housing demand arrives, it is optimal for agents to start immediately increasing their housing stock to take advantage of the capital gain. The marginal gain is higher for impatient than patient households, as it increases the marginal utility of housing stock for both but also relaxes the borrowing constraint for the former, allowing them to borrow and consume more. Patient households sell their houses to impatient households. Optimistic expectations lead to excessive housing investment, thereby causing a boom in the housing market not based on fundamentals. Once the news shocks are found to be unrealized, buyers revert their actions and a bust in the housing market follows. Therefore, our model allows us to study the effect of macroprudential policy in a context where agents can have (over-)optimistic expectations about the future and react by contracting more debt under fixed long-term contracts.

Figure 9 presents the simulated impact of anticipated shocks on housing demand for key macroeconomic variables. Three simulations are presented in the figure. The **unanticipated shocks** case presents a scenario consisting of a series of four unanticipated shocks (i.e. $\varepsilon^{\epsilon^h,0}$) on housing demand. We assume an increasing value of $\varepsilon^{\epsilon^h,0}$ from $t+5$ to $t+8$: (i) $\varepsilon^{\epsilon^h,0}_{t+5} = 0.5\sigma_{\epsilon^h,0}$; (ii) $\varepsilon^{\epsilon^h,0}_{t+6} = 1.0\sigma_{\epsilon^h,0}$; (iii) $\varepsilon^{\epsilon^h,0}_{t+7} = 1.5\sigma_{\epsilon^h,0}$; and (iv) $\varepsilon^{\epsilon^h,0}_{t+8} = 2.0\sigma_{\epsilon^h,0}$. The **anticipated shocks** case presents a scenario consisting of a series of four anticipated shocks learned in t but unrealized (i.e. revised by an equivalent negative unanticipated shock in the period it was supposed to happen): (i) $\varepsilon^{\epsilon^h,4}_{t+1} = 0.5\sigma_{\epsilon^h,4}$ but revised with $\varepsilon^{\epsilon^h,0}_{t+5} = -0.5\sigma_{\epsilon^h,4}$; (ii) $\varepsilon^{\epsilon^h,4}_{t+2} = 1.0\sigma_{\epsilon^h,4}$ but revised with $\varepsilon^{\epsilon^h,0}_{t+6} = -1.0\sigma_{\epsilon^h,4}$; (iii) $\varepsilon^{\epsilon^h,4}_{t+3} = 1.5\sigma_{\epsilon^h,4}$ but revised with $\varepsilon^{\epsilon^h,0}_{t+7} = -1.5\sigma_{\epsilon^h,4}$; and (iv) $\varepsilon^{\epsilon^h,4}_{t+4} = 2.0\sigma_{\epsilon^h,4}$ but revised with $\varepsilon^{\epsilon^h,0}_{t+8} = -2.0\sigma_{\epsilon^h,4}$.

As expected, the unanticipated shocks plotted in Figure 9 start to have an impact in $t+5$, when the shock happens. Therefore, the impacts under this scenario are the same as the impulse response following a housing demand shock described in Section 4. We observe a positive co-movement between housing investment, house price and consumption, but also a monetary policy reaction following the slight increase in inflation and the deviation of GDP from its steady-state value. Finally, housing demand increases following the four positive shocks from $t+5$ to $t+8$.

The story is different for the anticipated shocks scenario. News shocks generate the co-movement between house price, consumption and residential investment, but also hours worked (not shown) in both sectors of production observed in the data, especially during periods of housing booms. News shocks affect economic choices and, in particular, the housing investment and credit decisions of households differently than unanticipated shocks. Expectations about the occurrence of positive housing demand shocks immediately generate beliefs of future appreciation in housing price and fuel current housing demand. All the agents start to learn about the positive news shocks at the same moment in $t + 1$. Consequently, housing investment rises quickly, with a peak increase of near 6 percent in $t + 5$. House price follows the same curve, with a peak increase of 4 percent in $t+5$. Mortgage debt increases significantly, by more than 20 percent, reflecting the increase in housing investment, but also the increase in house price that affects the value of all the undepreciated housing stock. This increase in the collateral value boosts the consumption of borrowers and fuels inflation, inducing a rise in interest rates. Overall, as news shocks spread, the value of housing collateral increases and the rise in house price is, thus, coupled with an expansion in household credit and consumption. Moreover, due to limits to credit, borrowers increase their labour supply in order to raise internal funds for housing investments. For the decrease in non-residential investment to be coupled with an increase in hours, wages rise. The increase in consumption and housing investment also causes GDP to rise. Thus, news shocks in this model generate procyclicality among relevant variables. However, in $t + 5$, agents learn about the housing demand and revise their views on the current state of the economy: positive housing demand shock does not occur. Housing investment and house price start to decline on impact, followed by mortgage debt. The collateral value then starts to drop and agents have to revise their consumption level. The same mechanism occurs every time when the positive housing demand news shock does not materialize. From $t+5$ to $t+9$, housing investment declines by 6 percent and house price by 4 percent. Moreover, from peak to trough, consumption level declines by nearly 15 percent, and the real GDP declines by close to 10 percent, generating a recession. All of this resulted from unrealized expectations.

Overall, the two case scenarios suggest that news shocks could play an important role in boom-bust housing market cycles, as they can generate co-movement between consumption, housing investment and house price, similar to what is observed in the data, especially during periods of housing booms. However, the co-movement is not the same as that expected for non-residential investment. In a closed-economy model (like the one we study), it would be hard to generate the right co-movement with non-residential investment, as the increase in marginal utility and decrease in marginal cost from housing stock would drain the resources in the economy, therefore reducing investment and capital stock. However, in an open-economy model, where agents can finance their capital stock with foreign saving, we would expect to attain the right co-movement for non-residential investment as well.

5.2 Countercyclical LTV

We now study the effectiveness of implementing a countercyclical LTV ratio to reduce or eliminate the amplitude of the boom-bust cycles described above (i.e. **anticipated shocks** case). First, we consider two countercyclical LTV ratios. In both cases, we assume that the central bank continues to follow the estimated monetary policy rule and we allow the LTV ratio to vary around its long-run setting of 91 percent. The first rule considered is based on the deviation of house price from its steady state

$$\omega_t = \omega \left(\frac{q_t^h}{q^h} \right)^{-\phi^\omega},$$

while the second rule is based on the deviation of the debt-to-GDP ratio from its steady state

$$\omega_t = \omega \left(\frac{M_t/y_t}{M/y} \right)^{-\phi^\omega},$$

with ϕ^{ω} being the countercyclical parameter.[37] Finally, we compare the results of these regulatory LTV policies with the performance of a Taylor-type monetary policy rule augmented with house price inflation

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

Figure 10, Figure 11 and Figure 12 show the simulation results. We implemented three cases of macroprudential policy. For those with countercyclical LTV, we implemented the rules with $\phi^{\omega} = \{0.0, 0.5, 1.0\}$, with the countercyclical parameter equal to 0, replicating the **anticipated shocks** case (no countercyclical LTV) to facilitate comparisons. In the case of monetary policy, three values of the parameters are considered, namely $\rho_{\pi^h} = \{0.0, 1.0, 2.0\}$, with the house price inflation parameter equal to 0, replicating **anticipated shocks** case (no countercyclical LTV) to facilitate comparisons. When policy is based on house price, for both parameter values the countercyclical LTV ratio does not reduce the surge in housing investment and house price. Expectations about the occurrence of positive housing demand shocks still immediately generate beliefs of future appreciation in housing price and fuel current housing demand. However, the transmission mechanism creating a spillover effect on consumption via loosening of the collateral constraint is greatly reduced when $\phi^{\omega} = 0.5$ and eliminated when $\phi^{\omega} = 1.0$. Therefore, we still experience a house price correction of nearly 6 percent and a housing investment decrease of 8 percent when agents realize that the expectations do not materialize, but this does not lead to a recession. When policy is based on the debt-to-GDP ratio, as in the previous rule studied, house price and housing investment are not affected by LTV, because the housing demand news shocks dominate, but the transmission mechanism is greatly reduced. However, when $\phi^{\omega} = 1.0$, the wealth effect via the collateral constraint is still materialized and we still observe a decline in consumption.

[37] This choice of tested policies is based on the literature but remains arbitrary. Many other rules for countercyclical LTV could be tested, but a full comparative study based on welfare criterion would be necessary. This paper can serve as a starting point to welfare studies.

Finally, we consider a modified Taylor-type rule augmented with house price inflation. As expected, the effects of including the house price inflation in the monetary policy rule are more diffuse and affect all the macroeconomic variables. It helps to reduce the house price and housing investment impacts of news shocks on housing demand; however, it is less effective than a sectoral policy like the LTV ratio to uniquely target the spillover of the wealth effect on consumption via the loosening of the collateral constraint.

6 Conclusion

In this paper, we perform an analysis to determine how well the introduction of a countercyclical LTV ratio can reduce household indebtedness and housing price fluctuations compared with a monetary policy rule augmented with house price inflation. To this end, we construct a New Keynesian model in which a fraction of households borrow against the value of their houses and we introduce news shocks on housing demand. We estimate the model with Canadian data using Bayesian methods.

We find that the introduction of news shocks can generate a housing market boom-bust cycle, the bust following unrealized expectations on housing demand. Housing values affect agents' net worth and their ability to borrow and spend. A housing cycle can therefore trigger co-movements in aggregate economic activities and generate a boom-bust. When optimistic economic news is unrealized, the fluctuations that were not based on fundamentals are cancelled by the realization of the real shocks.

Our study also suggests that a countercyclical LTV ratio, especially the rule based on house price deviation from its steady state, is a useful policy to reduce the spillover from housing market to consumption and to lean against news-driven boom-bust cycles in housing price and credit generated by expectations of future macroeconomic developments.

As pointed out in Iacoviello and Neri (2010), a good part of the fluctuations in housing price and housing investment observed in the data are viewed by the model as the outcome of the exogenous shift in housing demand. This shock potentially includes unmodelled features of the model. The housing investment is mainly made at the household level, while our data are per capita. With the constant decrease in the number of persons per household observed since the beginning the 1970s, this dynamic is probably captured within the housing demand shock. Also, using perturbation methods, it is hard to model exogenous change in policy, as the one we observed in regulatory LTV ratios over the last 15 years. Changes in LTV requirements could potentially have been captured in the housing demand shock. These elements are interesting questions for further research.

Given the results in this paper, we now have to enhance our understanding of housing boom-bust cycles and macroprudential policy in other respects. Our analysis is based on many assumptions. First, all data are perfectly measured without any vintage revisions. If data are revised, then the countercyclical LTV would not adequately measure the current state of the economy it is intended to target. Second, we supposed that the central authority managing the macroprudential policy can identify the news shocks from the unanticipated shocks. In the case of unanticipated shocks, the central authority does not necessarily want to react, since the housing demand increase is based on fundamentals. Third, we do not consider the possibility of precautionary savings, which can play a substantial role with the expectation channel. Finally, we perform simulation, while welfare analysis would consider more aspects, among them the reallocation of resources from patient to impatient households during the housing boom. We leave these for future research.

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Table 1: Calibrated Parameters

Parameter	Value	Parameter	Value
Households			
δ^h	0.01		
Lenders		*Borrowers*	
σ_P^x	1.2	σ_I^x	1.2
β_P	0.9925	β_I	0.9844
σ_P^x	1.2	σ_I^x	1.2
θ_P^x	0.4	θ_I^x	0.4
η_P	2.5	η_I	1.5
θ_P^n	10.0	θ_I^n	10.0
$\delta_0^{k^c}$	0.025		
$\delta_1^{k^c}$	0.0335		
$\delta_0^{k^h}$	0.03		
$\delta_1^{k^h}$	0.0385		
Production			
α	0.25		
Consumption Sector		*Housing Sector*	
γ^c	0.25	γ^h	0.1
θ^c	7.67	γ^l	0.35
θ^{n^c}	7.67	θ^{n^h}	7.67
Policy and Steady-State			
ω	0.91	ϵ^h	0.75
π^c	1.005	ϵ^n	0.5
l	1.0	ϵ^π	1.005
u^{k^c}	1.0	ϵ^{R^m}	0.066
u^{k^h}	1.0	z^c	1.0
ϕ^m	20.0	z^h	1.0
ϵ^b	1.0	z^{i^k}	1.0
ϵ^χ	1.0		

Table 2: Steady-State Ratios

Variable	Model Definition	Data					Model
		Obs	Mean	Std	Min	Max	
Inflation Rate	$100\left((\pi^c)^4 - 1\right)$	126	2.33	1.34	-0.53	6.41	2.00
Interest Rate							
Nominal Short-Term	$100\left(R^4 - 1\right)$	126	5.11	3.57	0.20	13.57	5.50
Nominal Long-Term	$100\left((R^m)^4 - 1\right)$	126	8.06	2.91	3.99	14.47	8.41
Real Short-Term	$100\left(R^4 - (\pi^c)^4\right)$	126	2.77	2.99	-2.79	10.65	3.50
Flow as a Share of GDP							
Consumption	$100\left(\frac{c}{y}\right)$	126	77.35	1.44	75.02	80.46	74.25
Non-Housing Investment	$100\left(\frac{\left(q^{k^c} i^{k^c} + q^{k^h} i^{k^h}\right)}{y}\right)$	126	12.88	1.44	10.20	15.51	15.57
Housing Investment	$100\left(\frac{q^h y^h}{y}\right)$	126	9.77	1.11	8.04	12.56	7.88
Stock to GDP							
Capital	$\frac{\left(q^{k^c} k^c + q^{k^h} k^h\right)}{4y}$	30	1.44	0.10	1.30	1.66	1.55
Residential Structures	$\frac{q^h y^h}{4y}$	30	1.24	0.12	1.05	1.46	1.97
Land	$\frac{q^l l}{4y}$	30	0.91	0.20	0.66	1.32	0.81
Mortgage Debt	$\frac{b_i}{4y}$	126	0.54	0.22	0.20	0.98	0.89
Hours Worked							
Consumption	$\frac{n^c}{\left(n^c + n^h\right)}$	126	94.90	0.75	92.97	95.87	92.00
Housing	$\frac{n^h}{\left(n^c + n^h\right)}$	126	5.10	0.75	4.13	7.03	8.00

Note: Capital, Residential Structures, and Land values are represented at 2011 values due to a total reconstruction of the National Balance Sheet (Table 378-0049).

Table 3: PRIOR AND POSTERIOR DISTRIBUTIONS OF STRUCTURAL PARAMETERS

Parameter	Prior Distribution			Posterior Distribution				
	Distribution	Mean	Std	Mode	Std	5%	Median	95%
Households								
ξ^{w^c}	Beta	0.5	0.22	0.9797	0.0039	0.9740	0.9813	0.9870
ξ^{w^h}	Beta	0.5	0.22	0.9650	0.0068	0.9524	0.9653	0.9747
ι^{w^c}	Beta	0.5	0.22	0.3723	0.1018	0.1531	0.2579	0.4901
ι^{w^h}	Beta	0.5	0.22	0.8386	0.1545	0.4147	0.7094	0.9220
Lenders								
$\phi^{i^{k^c}}$	Gamma	5.0	2.0	3.1955	0.7956	2.3023	3.5164	4.8926
$\phi^{i^{k^h}}$	Gamma	5.0	2.0	7.7145	2.5711	4.5198	8.0855	12.9464
$\delta_2^{k^c}$	Beta	0.125	0.025	0.0619	0.0174	0.0407	0.0627	0.0966
$\delta_2^{k^h}$	Beta	0.125	0.025	0.1526	0.0245	0.1161	0.1529	0.1965
Production								
Consumption Sector								
ξ^{p^c}	Beta	0.5	0.22	0.6226	0.0292	0.5573	0.6125	0.6528
ι^{p^c}	Beta	0.5	0.22	0.9598	0.0514	0.8203	0.9292	0.9833
Monetary Policy								
ρ_r	Beta	0.8	0.1	0.8604	0.0158	0.8189	0.8425	0.8701
ρ_{π^c}	Gamma	3.5	0.5	4.2291	0.3284	3.8153	4.3327	4.8643
ρ_y	Beta	0.30	0.025	0.3008	0.0199	0.2749	0.3075	0.3441

Note: As reported in the text, note that the parameters of the Taylor-type monetary policy rule are estimated on the sample covering 1992Q1 to 2014Q4 without any shock on inflation targeting. In the full sample estimation covering 1983Q3 to 2014Q4, the parameters of the Taylor-type monetary policy rule are calibrated and time-varying inflation targeting is introduced.

Table 4: PRIOR AND POSTERIOR DISTRIBUTIONS OF EXOGENOUS PROCESSES

Parameter	Prior Distribution			Posterior Distribution				
	Distribution	Mean	Std	Mode	Std	5%	Median	95%
ρ_{ϵ^χ}	Beta	0.8	0.1	0.8656	0.0212	0.8339	0.8695	0.9034
ρ_{ϵ^b}	Beta	0.8	0.1	0.9777	0.0257	0.9174	0.9740	0.9952
ρ_{ϵ^h}	Beta	0.8	0.1	0.9526	0.0081	0.9406	0.9556	0.9677
ρ_{ϵ^n}	Beta	0.8	0.1	0.9991	0.0005	0.9974	0.9985	0.9992
$\rho_{\epsilon^{\pi^c}}$	Beta	0.8	0.1	0.8718	0.0180	0.8361	0.8674	0.8945
$\rho_{\epsilon^{R^m}}$	Beta	0.8	0.1	0.9893	0.0108	0.9603	0.9820	0.9944
ρ_{z^c}	Beta	0.8	0.1	0.4836	0.0608	0.3593	0.4601	0.5624
ρ_{z^h}	Beta	0.8	0.1	0.9581	0.0269	0.8907	0.9521	0.9768
$\rho_{z^{ik}}$	Beta	0.8	0.1	0.6819	0.0542	0.5650	0.6516	0.7447
σ_χ	Inv. Gamma	0.1	0.2	0.0272	0.0018	0.0247	0.0274	0.0307
σ_{ϵ^b}	Inv. Gamma	0.1	0.2	0.0171	0.0060	0.0114	0.0164	0.0287
$\sigma_{\epsilon^h,0}$	Inv. Gamma	0.1	0.2	0.0072	0.0009	0.0060	0.0073	0.0087
$\sigma_{\epsilon^h,4}$	Inv. Gamma	0.1	0.2	0.0044	0.0005	0.0037	0.0044	0.0052
$\sigma_{\epsilon^h,8}$	Inv. Gamma	0.1	0.2	0.0045	0.0005	0.0038	0.0045	0.0054
σ_{ϵ^n}	Inv. Gamma	0.1	0.2	0.0277	0.0061	0.0272	0.0360	0.0482
$\sigma_{\epsilon^{\pi^c}}$	Inv. Gamma	0.1	0.2	0.0034	0.0003	0.0031	0.0035	0.0040
σ_{ϵ^R}	Inv. Gamma	0.1	0.2	0.0035	0.0003	0.0032	0.0036	0.0041
$\sigma_{\epsilon^{R^m}}$	Inv. Gamma	0.1	0.2	0.1374	0.0170	0.0953	0.1229	0.1511
σ_{z^c}	Inv. Gamma	0.1	0.2	0.0090	0.0011	0.0072	0.0089	0.0109
σ_{z^h}	Inv. Gamma	0.1	0.2	0.0162	0.0010	0.0146	0.0161	0.0180
$\sigma_{z^{ik}}$	Inv. Gamma	0.1	0.2	0.0500	0.0136	0.0368	0.0567	0.0811

Table 5: Prior and Posterior Distributions of Measurement Errors

Parameter	Prior Distribution			Posterior Distribution				
	Distribution	Mean	Std	Mode	Std	5%	Median	95%
σ_{n^c}	Inv. Gamma	0.1	0.2	0.0164	0.0015	0.0148	0.0170	0.0196
σ_{w^c}	Inv. Gamma	0.1	0.2	0.0123	0.0008	0.0112	0.0125	0.0140
$\sigma_{u^{k^c}}$	Inv. Gamma	0.1	0.2	0.0379	0.0025	0.0344	0.0381	0.0426
σ_{n^h}	Inv. Gamma	0.1	0.2	0.0076	0.0005	0.0069	0.0077	0.0085
σ_{w^h}	Inv. Gamma	0.1	0.2	0.0147	0.0010	0.0131	0.0147	0.0165
$\sigma_{u^{k^h}}$	Inv. Gamma	0.1	0.2	0.0650	0.0041	0.0589	0.0650	0.0725

Table 6: Model Priors

Correlations	Prior Distribution			Posterior Distribution
	Distribution	Mean	Std	Mode
$corr\left(c_t, y_t^h\right)$	Normal	0.6590	0.1	0.5581
$corr\left(c_t, y_{t-1}^h\right)$	Normal	0.6811	0.1	0.5525
$corr\left(c_t, y_{t-2}^h\right)$	Normal	0.6589	0.1	0.5603
$corr\left(c_t, y_{t-3}^h\right)$	Normal	0.6204	0.1	0.5666
$corr\left(c_{t-1}, y_t^h\right)$	Normal	0.5493	0.1	0.5344
$corr\left(c_{t-2}, y_t^h\right)$	Normal	0.4279	0.1	0.5304
$corr\left(c_{t-3}, y_t^h\right)$	Normal	0.3185	0.1	0.5305
$corr\left(c_t, q_t^h\right)$	Normal	0.5074	0.1	0.4330
$corr\left(c_t, q_{t-1}^h\right)$	Normal	0.5256	0.1	0.4378
$corr\left(c_t, q_{t-2}^h\right)$	Normal	0.4766	0.1	0.4491
$corr\left(c_t, q_{t-3}^h\right)$	Normal	0.4043	0.1	0.4579
$corr\left(c_{t-1}, q_t^h\right)$	Normal	0.4634	0.1	0.3949
$corr\left(c_{t-2}, q_t^h\right)$	Normal	0.4335	0.1	0.3874
$corr\left(c_{t-3}, q_t^h\right)$	Normal	0.4079	0.1	0.3862
$corr\left(c_t, i_t^k\right)$	Normal	0.6713	0.1	0.5359
$corr\left(c_t, i_{t-1}^k\right)$	Normal	0.6293	0.1	0.5367
$corr\left(c_t, i_{t-2}^k\right)$	Normal	0.5508	0.1	0.5445
$corr\left(c_t, i_{t-3}^k\right)$	Normal	0.4747	0.1	0.5552
$corr\left(c_{t-1}, i_t^k\right)$	Normal	0.6937	0.1	0.5519
$corr\left(c_{t-2}, i_t^k\right)$	Normal	0.6498	0.1	0.5612
$corr\left(c_{t-3}, i_t^k\right)$	Normal	0.5695	0.1	0.5692
$corr\left(c_t, M_t\right)$	Normal	0.3335	0.1	0.7881
$corr\left(c_t, M_{t-1}\right)$	Normal	0.2441	0.1	0.5034
$corr\left(c_t, M_{t-2}\right)$	Normal	0.1474	0.1	0.4505
$corr\left(c_t, M_{t-3}\right)$	Normal	0.0514	0.1	0.4359
$corr\left(c_{t-1}, M_t\right)$	Normal	0.4231	0.1	0.4480
$corr\left(c_{t-2}, M_t\right)$	Normal	0.4871	0.1	0.3857
$corr\left(c_{t-3}, M_t\right)$	Normal	0.5306	0.1	0.3706

Table 7: Selected Autocorrelation and Cross-Correlation

Moments		Autocorrelation and Cross-Correlation of Order 0				
	Variables	Consumption	Non-Residential Investment	Residential Investment	Mortgage Debt	House Price
Sample	Consumption	1.00	0.67	0.66	0.33	0.51
Asymptotic		1.00	0.54	0.56	0.79	0.43
Sample	Non-Residential Investment	0.67	1.00	0.40	0.36	0.37
Asymptotic		0.54	1.00	0.64	0.39	0.58
Sample	Residential Investment	0.66	0.40	1.00	0.13	0.56
Asymptotic		0.56	0.64	1.00	0.54	0.72
Sample	Mortgage Debt	0.33	0.36	0.13	1.00	0.63
Asymptotic		0.79	0.39	0.54	1.00	0.57
Sample	House Price	0.51	0.37	0.56	0.63	1.00
Asymptotic		0.43	0.58	0.72	0.57	1.00
Moments		Autocorrelation and Cross-Correlation of Order 1				
	Variables	Consumption	Non-Residential Investment	Residential Investment	Mortgage Debt	House Price
Sample	Consumption	0.91	0.69	0.55	0.42	0.46
Asymptotic		0.78	0.55	0.53	0.45	0.39
Sample	Non-Residential Investment	0.63	0.93	0.28	0.40	0.31
Asymptotic		0.54	0.99	0.65	0.41	0.60
Sample	Residential Investment	0.68	0.48	0.90	0.24	0.54
Asymptotic		0.55	0.63	0.98	0.53	0.72
Sample	Mortgage Debt	0.24	0.30	0.02	0.99	0.57
Asymptotic		0.50	0.40	0.50	0.54	0.52
Sample	House Price	0.53	0.44	0.53	0.69	0.84
Asymptotic		0.44	0.57	0.71	0.58	0.98
Moments		Autocorrelation and Cross-Correlation of Order 4				
	Variables	Consumption	Non-Residential Investment	Residential Investment	Mortgage Debt	House Price
Sample	Consumption	0.60	0.48	0.22	0.56	0.39
Asymptotic		0.71	0.58	0.53	0.36	0.39
Sample	Non-Residential Investment	0.39	0.49	0.02	0.45	0.25
Asymptotic		0.57	0.88	0.66	0.48	0.62
Sample	Residential Investment	0.55	0.50	0.38	0.43	0.51
Asymptotic		0.57	0.61	0.92	0.54	0.70
Sample	Mortgage Debt	-0.04	0.09	-0.27	0.87	0.40
Asymptotic		0.43	0.40	0.48	0.40	0.48
Sample	House Price	0.31	0.39	0.12	0.77	0.59
Asymptotic		0.46	0.55	0.66	0.59	0.92

Table 8: Unconditional Forecast Error Variance Decomposition

Observables	$\varepsilon^{\epsilon^{\chi}}$	$\varepsilon^{\epsilon^{b}}$	$\varepsilon^{\epsilon^{h,0}}$	$\varepsilon^{\epsilon^{h,4}}$	$\varepsilon^{\epsilon^{h,8}}$	$\varepsilon^{\epsilon^{n}}$	$\varepsilon^{\epsilon^{\pi^c}}$	$\varepsilon^{\epsilon^{R}}$	$\varepsilon^{\epsilon^{R^m}}$	ε^{z^c}	ε^{z^h}	$\varepsilon^{z^{i^k}}$	m.e.
Consumption	18.02	0.24	6.06	2.32	1.93	54.00	9.80	3.29	2.64	0.19	0.96	0.55	0.00
Capital Price	24.90	0.73	9.48	7.76	7.64	1.01	3.19	3.56	3.20	2.41	1.61	34.51	0.00
Non-Residential Investment	4.99	5.34	5.19	2.73	4.63	39.58	12.06	0.99	0.35	0.27	0.53	23.36	0.00
House Price	0.95	1.23	20.32	8.07	8.40	24.15	2.81	0.62	17.22	0.16	14.63	1.46	0.00
Residential Investment	0.46	0.51	11.16	4.81	5.56	41.13	2.94	0.49	11.34	0.09	21.20	0.30	0.00
Mortgage Debt	35.32	0.49	14.72	2.60	2.00	14.83	8.53	4.91	14.31	0.13	1.66	0.50	0.00
Core CPI Inflation	2.02	0.30	0.67	0.11	0.08	90.84	2.52	0.44	0.24	2.09	0.11	0.58	0.00
Treasury Bill Rate, 3 month	12.15	0.68	4.08	1.50	1.09	74.17	2.84	0.66	1.29	0.54	0.65	0.35	0.00
Residential Mortgage Rate, 5 year	0.55	0.73	0.39	0.25	0.31	89.10	0.32	0.14	7.99	0.05	0.09	0.09	0.00
Hours Worked (Consumption)	35.71	0.08	10.80	1.57	1.03	24.92	11.90	6.59	3.77	0.72	1.46	0.88	0.57
Wage (Consumption)	3.99	12.58	10.63	3.38	2.64	4.71	9.42	0.61	1.48	4.45	0.68	19.32	26.10
Capacity Utilization Rate (Consumption)	37.13	1.86	12.48	2.47	1.66	1.14	9.52	5.40	3.89	0.72	1.60	2.94	19.19
Hours Worked (Housing)	0.54	0.42	13.19	5.61	6.39	42.38	3.73	0.64	12.25	0.12	5.24	0.29	9.19
Wage (Housing)	1.89	6.85	11.24	3.88	3.30	18.55	7.26	0.32	6.36	3.92	1.50	15.92	19.02
Capacity Utilization Rate (Housing)	0.14	0.41	4.70	1.83	1.78	1.19	1.23	0.18	2.12	0.02	1.85	0.35	84.19

Figure 1: Data from 1983Q3 to 2014Q4

Figure 2: Estimated (Smoothed) Shocks from 1983Q3 to 2014Q4

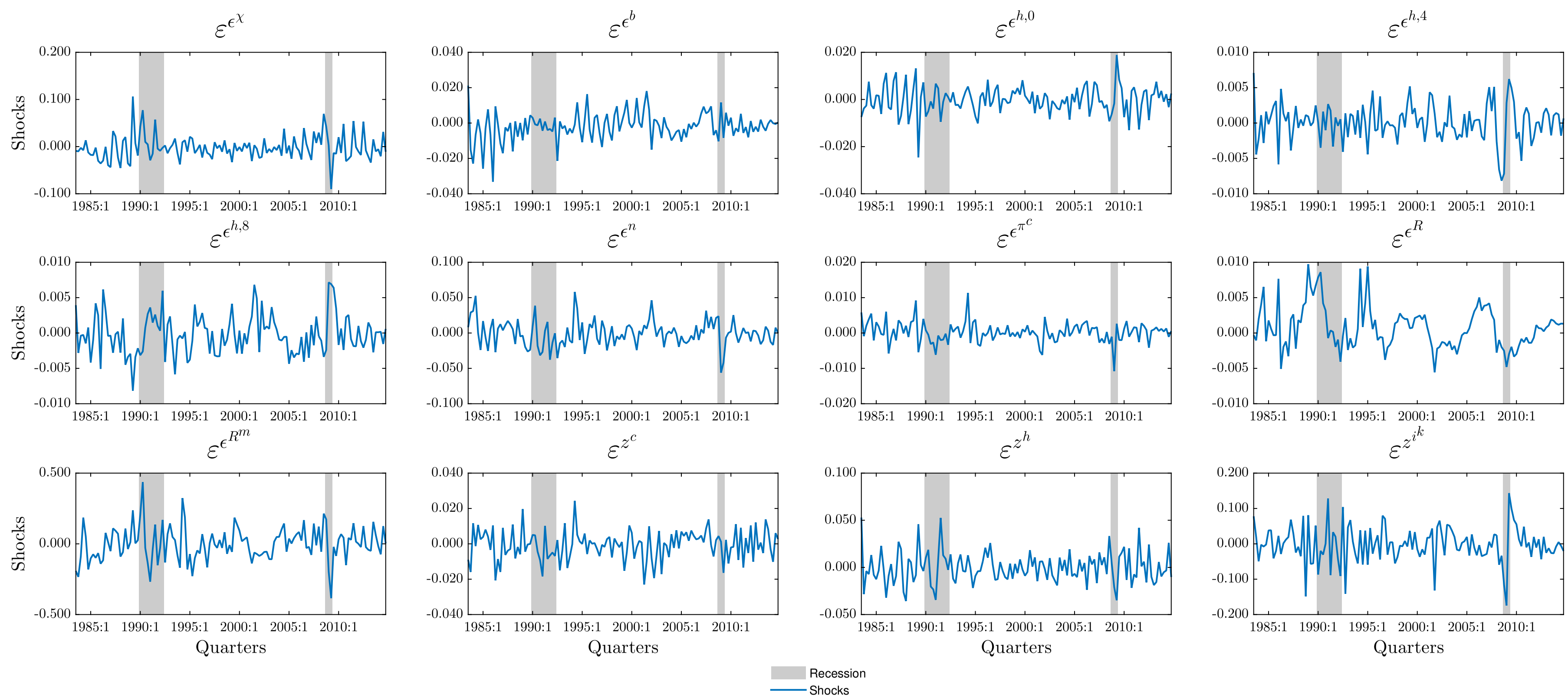


Figure 3: SELECTED HISTORICAL VARIANCE DECOMPOSITION

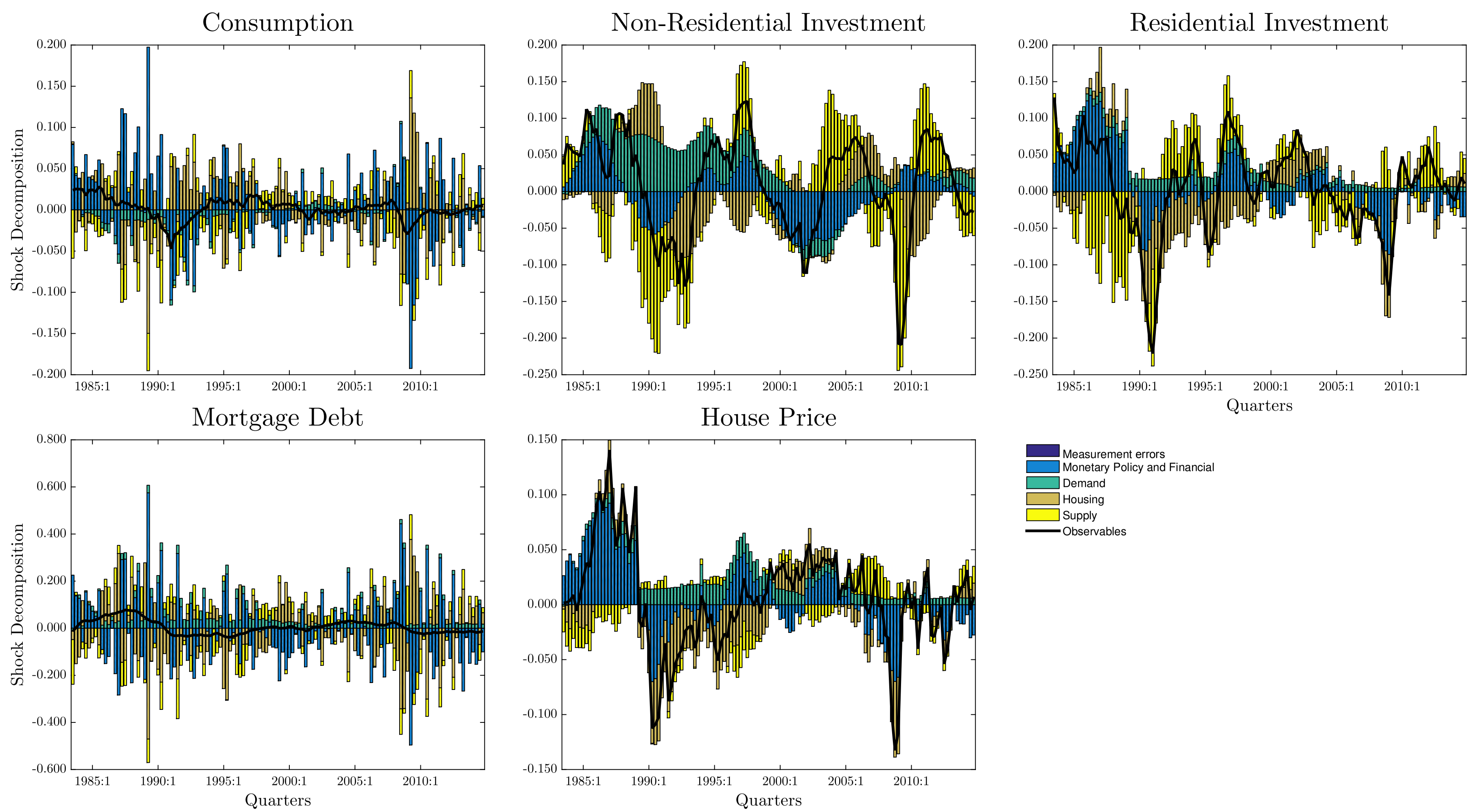


Figure 4: Shock Response Function – Housing Demand Shocks

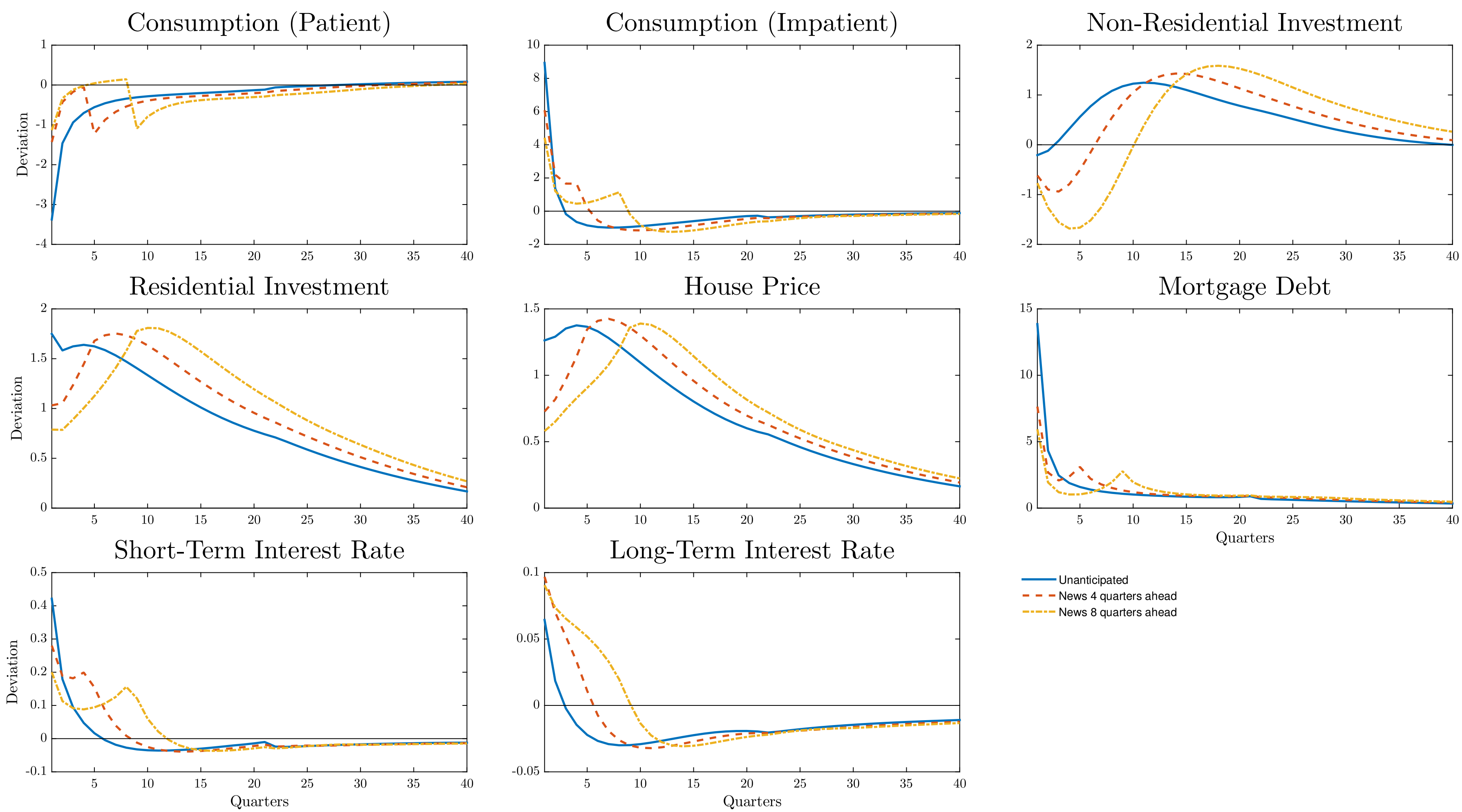


Figure 5: Shock Response Function – Labour Supply Shock

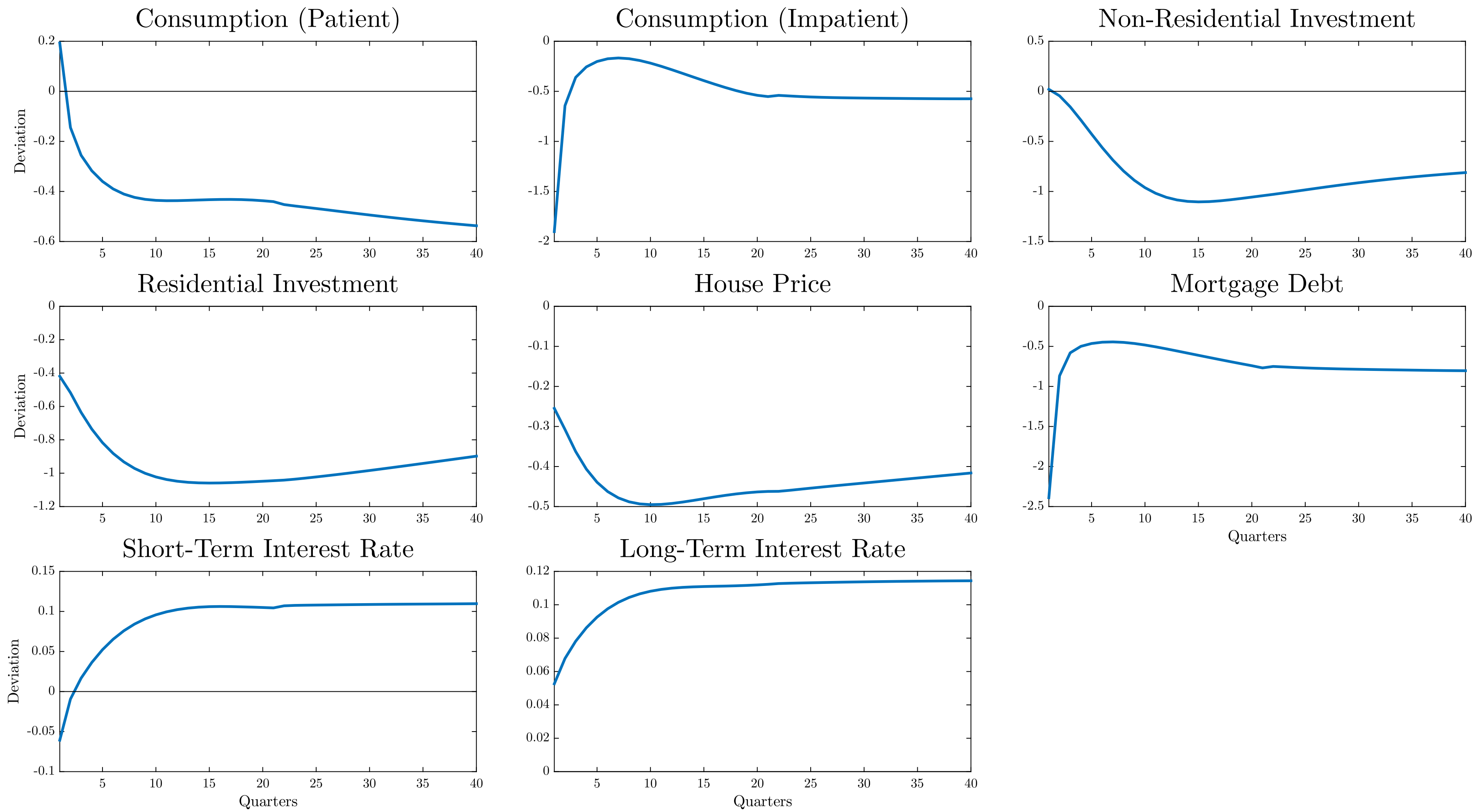


Figure 6: Shock Response Function – Inflation Targeting and Monetary Policy Shocks

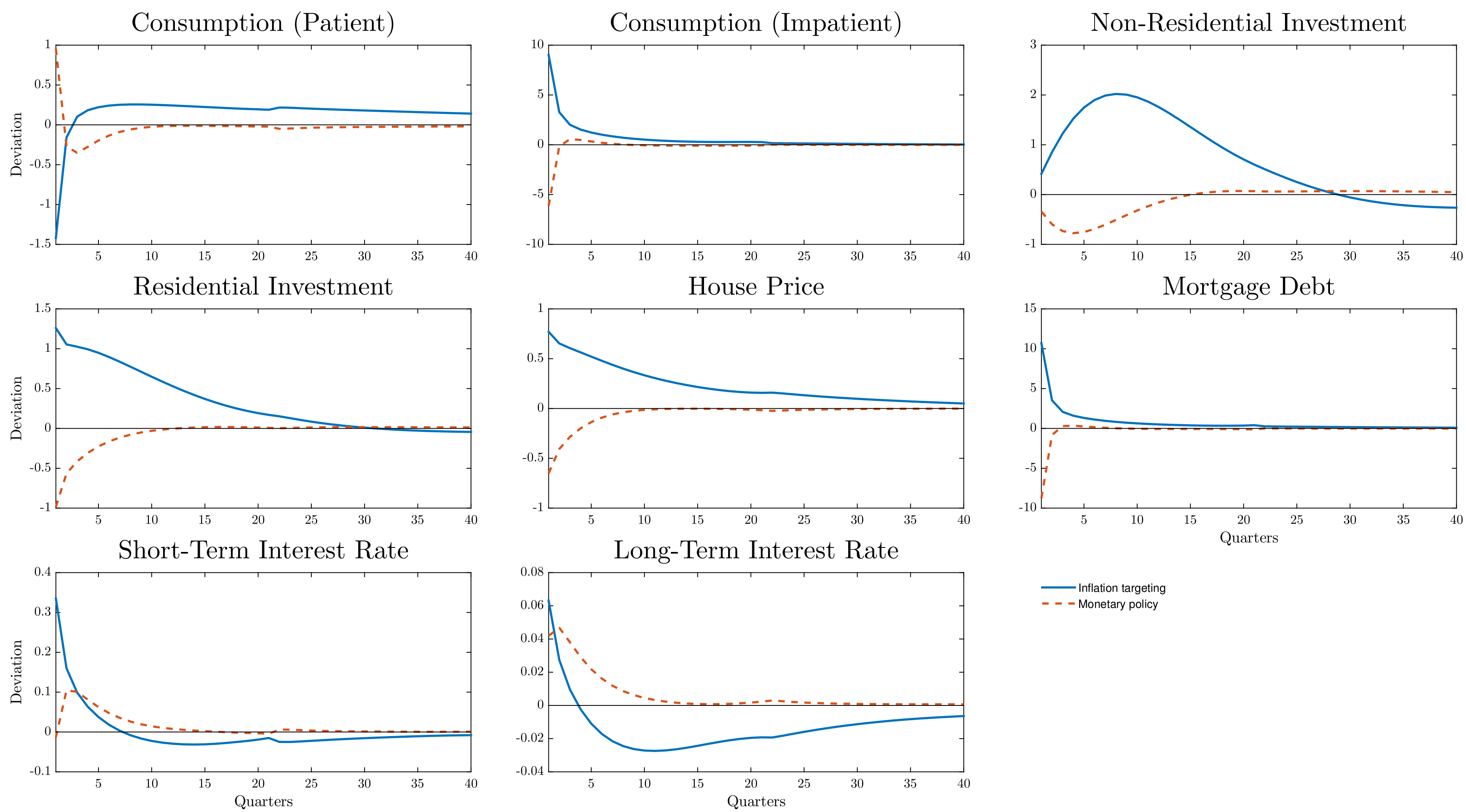


Figure 7: Shock Response Function – Mortgage Premium Shock

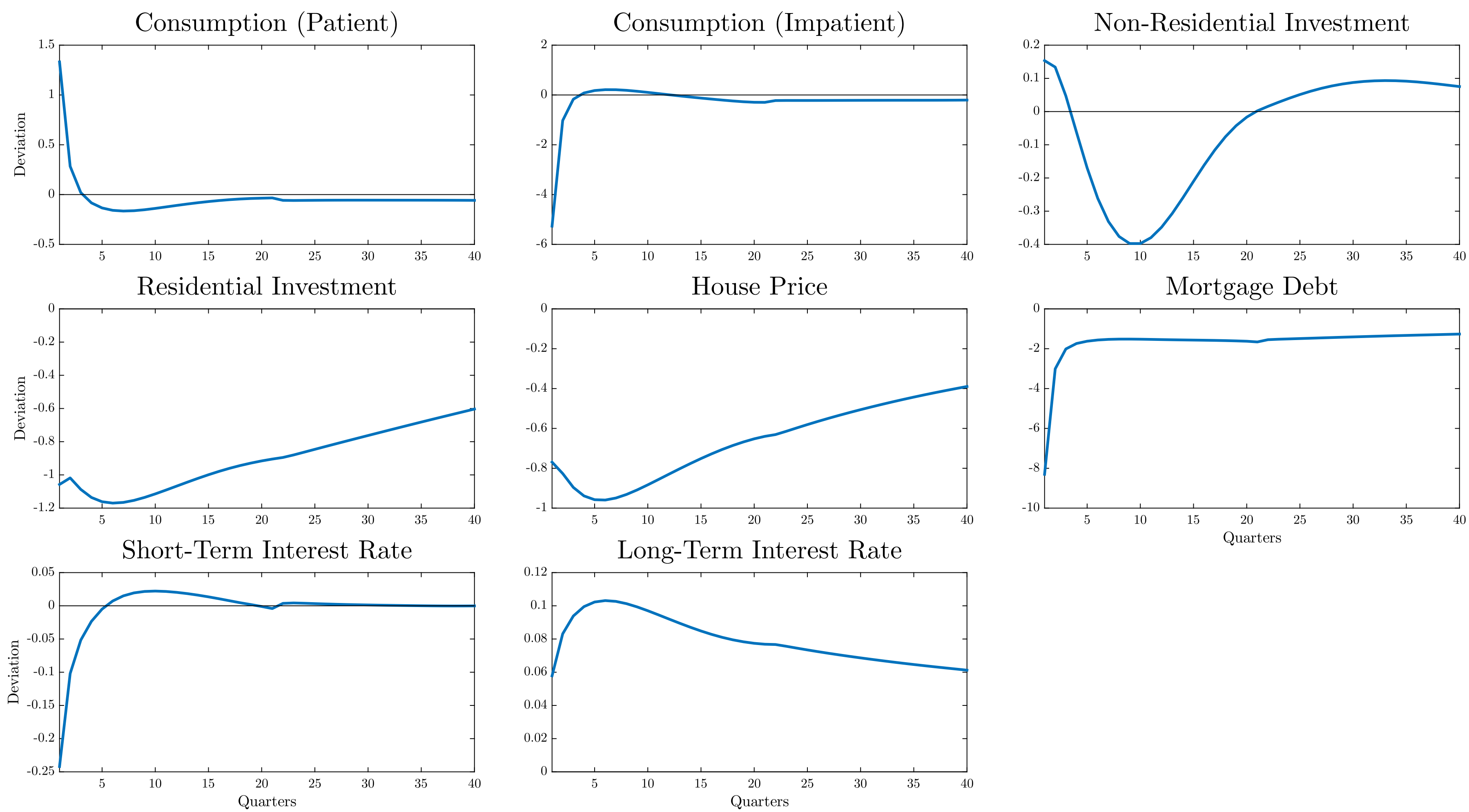


Figure 8: Shock Response Function – LTV Shock

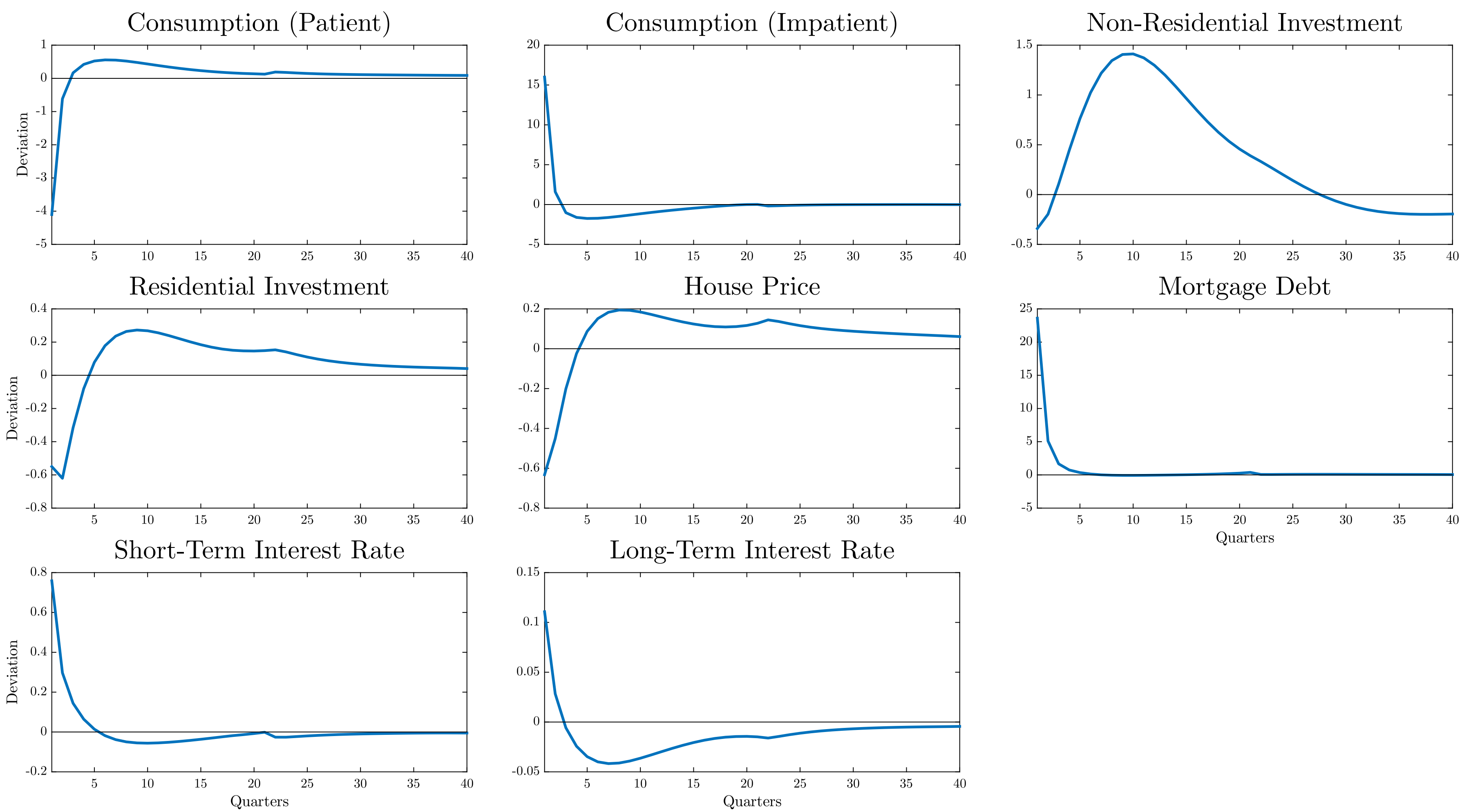


Figure 9: Anticipated and Unanticipated Housing Demand Shock

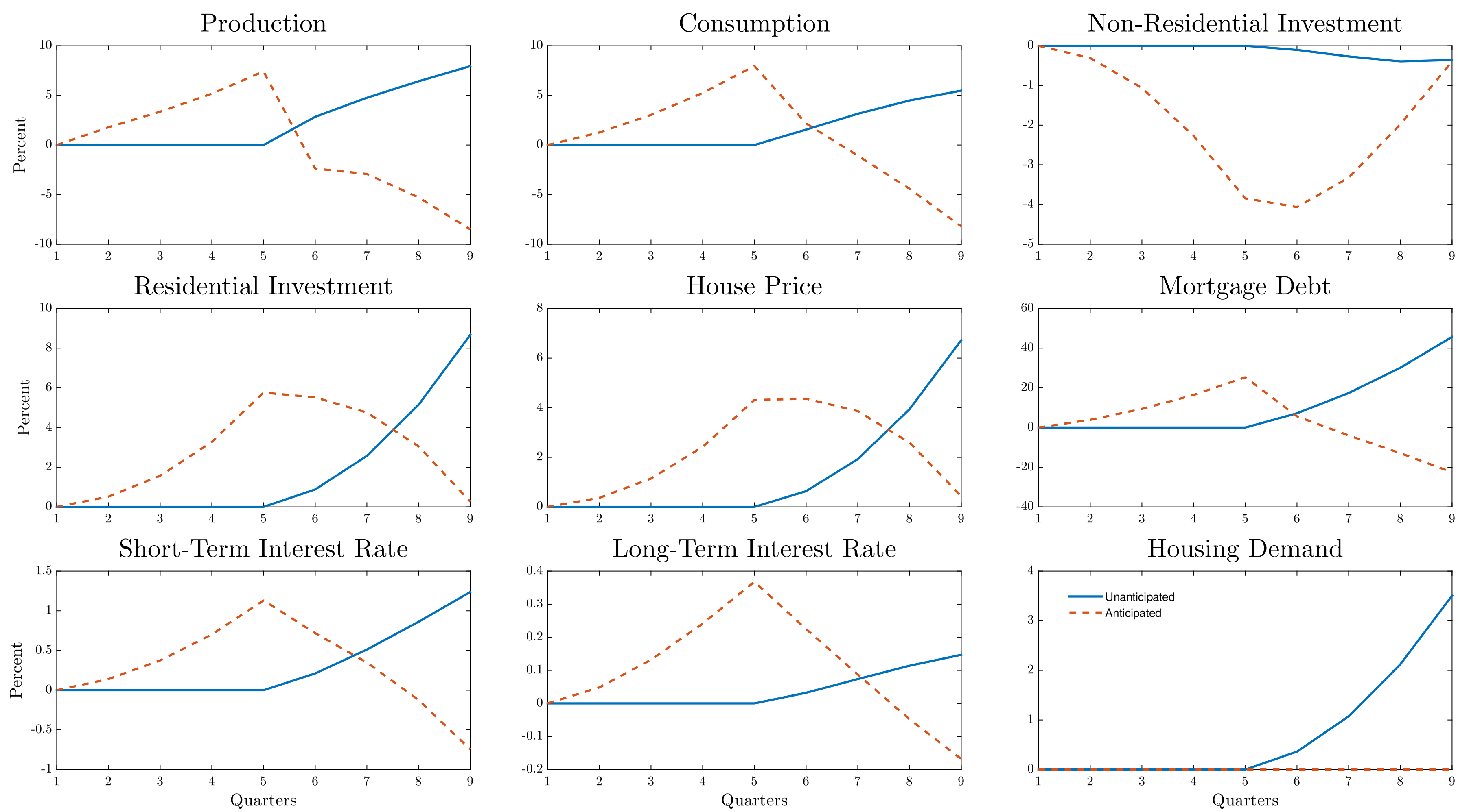


Figure 10: Countercyclical LTV Policy based on House Price

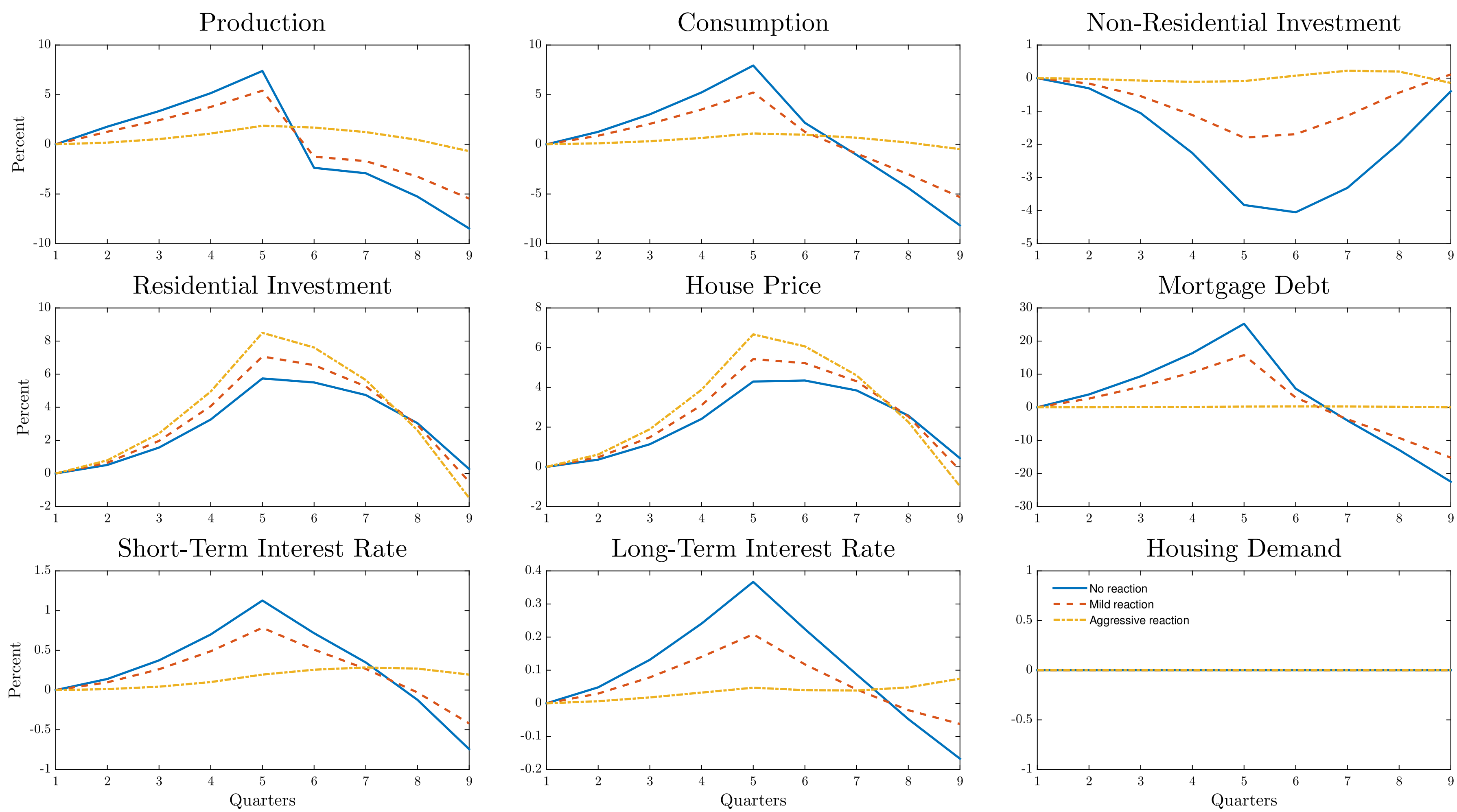


Figure 11: Countercyclical LTV Policy based on Debt-to-GDP Ratio

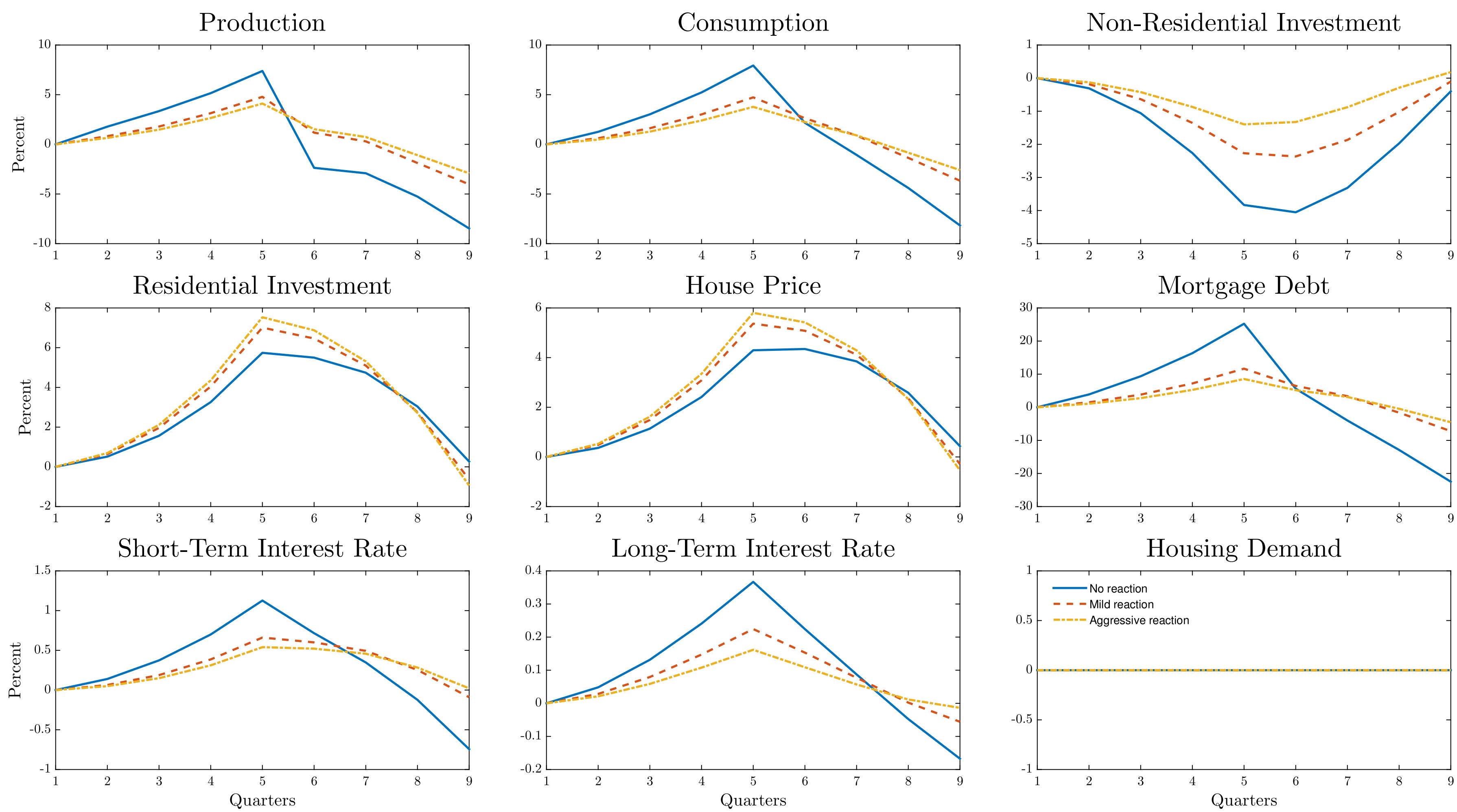
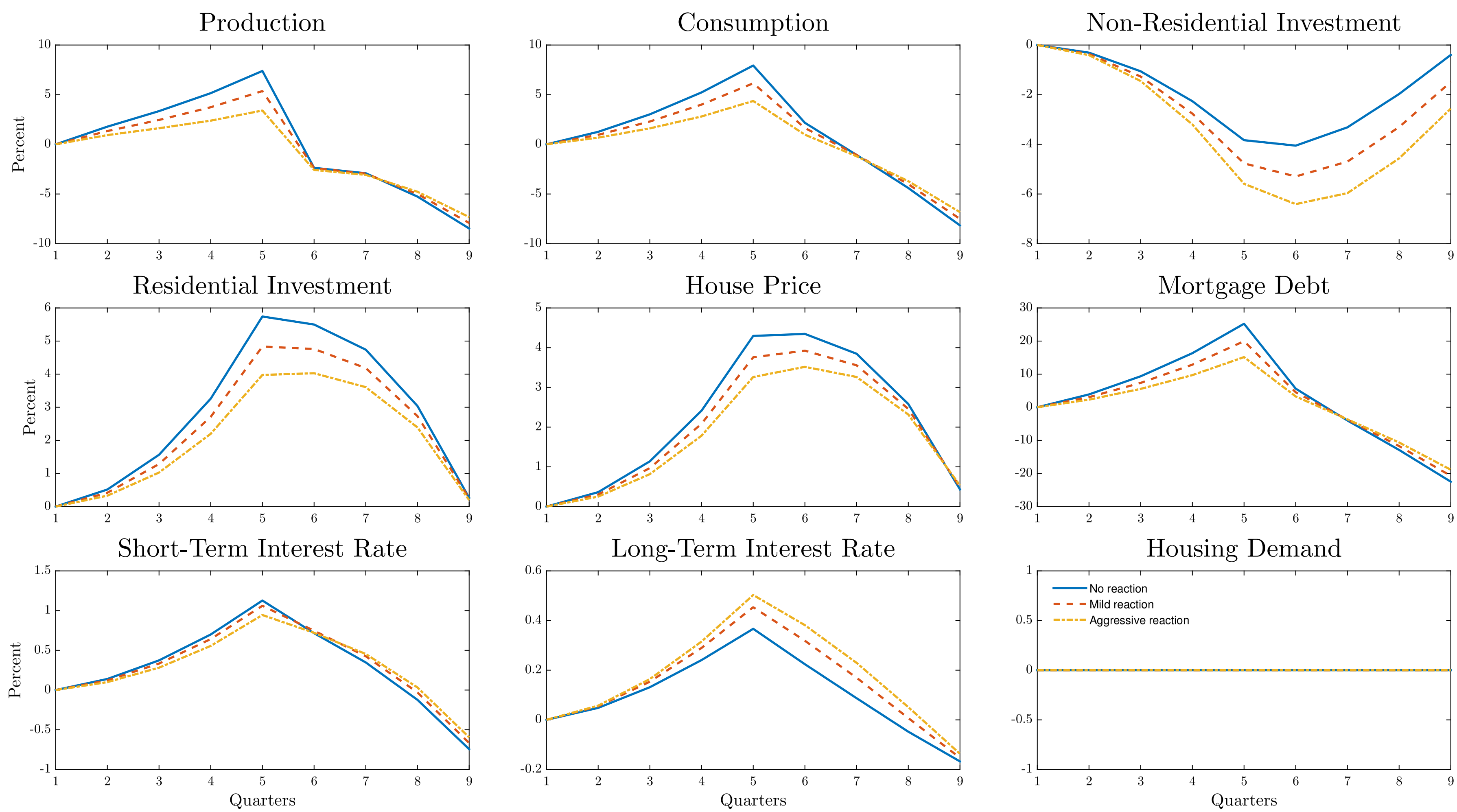


Figure 12: MONETARY POLICY RESPONSIVE TO HOUSE PRICE INFLATION



Appendices

A Model

A.1 Households

Patient The Lagrangian for the patient optimization problem takes the following form:

$$
L = E_0 \sum_{t=0}^{\infty} \beta_P^t \epsilon_t^b \times
$$

$$
\left\{ \begin{array}{l}
U\left(c_{P,t}, h_{P,t}, n_{P,t}^c, n_{P,t}^h\right) + \lambda_{P,t}^c \times \\
\left\{ \begin{array}{l}
n_{P,t}^{c,d} \int\limits_0^1 w_{P,e,t}^c \left(\frac{w_{P,e,t}^c}{w_{P,t}^c}\right)^{-\theta^{n^c}} de + n_{P,t}^{h,d} \int\limits_0^1 w_{P,e,t}^h \left(\frac{w_{P,e,t}^h}{w_{P,t}^h}\right)^{-\theta^{n^h}} de \\
+ r_t^{k^c} u_t^{k^c} k_{t-1}^c + r_t^{k^h} u_t^{k^h} k_{t-1}^h + \left(q_t^l + r_t^l\right) l_{t-1} + \frac{R_{t-1} b_{P,t-1}}{\pi_t^c} + f_t^c + f_t^h + f_t^{fi} \\
+ \frac{1}{\phi^m} \sum_{s=1}^{\phi^m} \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} + \sum_{s=1}^{\phi^m} \left(R_{t-s}^d - 1\right) \left(\frac{\phi^m - s + 1}{\phi^m}\right) \frac{d_{t-s}}{\prod_{v=-s}^{0} \pi_{t+v}^c} \\
- c_{P,t} - q_t^{k^c} i_t^{k^c} - q_t^{k^h} i_t^{k^h} - q_t^l l_t - b_{P,t} - d_t \\
- q_t^h \left[h_{P,t} - \left(1 - \delta^h\right) h_{P,t-1}\right] \\
- q_t^{k^c} \left[k_t^c - \left(1 - \delta_t^{k^c}\right) k_{t-1}^c - z_t^{ik} i_t^{k^c} \left[1 - \frac{\phi^{k^c}}{2} \left(\frac{i_t^{k^c}}{i_{t-1}^{k^c}} - 1\right)^2\right]\right] \\
- q_t^{k^h} \left[k_t^h - \left(1 - \delta_t^{k^h}\right) k_{t-1}^h - z_t^{ik} i_t^{k^h} \left[1 - \frac{\phi^{k^h}}{2} \left(\frac{i_t^{k^h}}{i_{t-1}^{k^h}} - 1\right)^2\right]\right] \\
+ \frac{w_{P,t}^c}{\lambda_{P,t}^{n^c}} \left[n_{P,t}^c - n_{P,t}^{c,d} \int\limits_0^1 \left(\frac{w_{P,e,t}^c}{w_{P,t}^c}\right)^{-\theta^{n^c}} de\right] + \frac{w_{P,t}^h}{\lambda_{P,t}^{n^h}} \left[n_{P,t}^h - n_{P,t}^{h,d} \int\limits_0^1 \left(\frac{w_{P,e,t}^h}{w_{P,t}^h}\right)^{-\theta^{n^h}} de\right]
\end{array} \right\}
\end{array} \right\}
$$

The first-order necessary conditions for $c_{P,t}$, $h_{P,t}$, $n_{P,t}^c$, $n_{P,t}^h$, k_t^c, k_t^h, l_t, $u_t^{k^c}$, $u_t^{k^h}$, $i_t^{k^c}$, $i_t^{k^h}$, $b_{P,t}$ and d_t are, respectively,

$$
\lambda_{P,t}^c = \frac{\left(1 - \epsilon_t^h\right)^{\frac{1}{\theta_P^x}} c_{P,t}^{\frac{-1}{\theta_P^x}}}{x_{P,t}^{\frac{\sigma_P^x \theta_P^x - 1}{\theta_P^x}}}, \tag{36}
$$

$$\epsilon_t^b \lambda_{P,t}^c q_t^h - \beta_P \left(1-\delta^h\right) E_t \left[\epsilon_{t+1}^b \lambda_{P,t+1}^c q_{t+1}^h\right] = \epsilon_t^b \frac{\left(\epsilon_t^h\right)^{\frac{1}{\theta_P^x}} h_{P,t}^{\frac{-1}{\theta_P^x}}}{x_{P,t}^{\frac{\sigma_P^x \theta_P^x - 1}{\theta_P^x}}}, \tag{37}$$

$$\epsilon_t^n \left(\left(n_{P,t}^c\right)^{\frac{\theta_P^n+1}{\theta_P^n}} + \left(n_{P,t}^h\right)^{\frac{\theta_P^n+1}{\theta_P^n}}\right)^{\frac{\theta_P^n \eta_P - 1}{\theta_P^n+1}} \left(n_{P,t}^c\right)^{\frac{1}{\theta_P^n}} = \frac{\lambda_{P,t}^c w_{P,t}^c}{\lambda_{P,t}^{n^c}}, \tag{38}$$

$$\epsilon_t^n \left(\left(n_{P,t}^c\right)^{\frac{\theta_P^n+1}{\theta_P^n}} + \left(n_{P,t}^h\right)^{\frac{\theta_P^n+1}{\theta_P^n}}\right)^{\frac{\theta_P^n \eta_P - 1}{\theta_P^n+1}} \left(n_{P,t}^h\right)^{\frac{1}{\theta_P^n}} = \frac{\lambda_{P,t}^c w_{P,t}^h}{\lambda_{P,t}^{n^h}}, \tag{39}$$

$$\epsilon_t^b \lambda_{P,t}^c q_t^{k^c} = \beta_P E_t \left[\epsilon_{t+1}^b \lambda_{P,t+1}^c \left(u_{t+1}^{k^c} r_{t+1}^{k^c} + q_{t+1}^{k^c}\left(1-\delta_{t+1}^{k^c}\right)\right)\right], \tag{40}$$

$$\epsilon_t^b \lambda_{P,t}^c q_t^{k^h} = \beta_P E_t \left[\epsilon_{t+1}^b \lambda_{P,t+1}^c \left(u_{t+1}^{k^h} r_{t+1}^{k^h} + q_{t+1}^{k^h}\left(1-\delta_{t+1}^{k^h}\right)\right)\right], \tag{41}$$

$$\epsilon_t^b \lambda_{P,t}^c q_t^l = \beta_P E_t \left[\epsilon_{t+1}^b \lambda_{P,t+1}^c \left(q_{t+1}^l + r_{t+1}^l\right)\right], \tag{42}$$

$$r_t^{k^c} = q_t^{k^c}\left[\delta_1^{k^c} + \delta_2^{k^c}\left(u_t^{k^c} - 1\right)\right], \tag{43}$$

$$r_t^{k^h} = q_t^{k^h}\left[\delta_1^{k^h} + \delta_2^{k^h}\left(u_t^{k^h} - 1\right)\right], \tag{44}$$

$$\begin{aligned}\epsilon_t^b \lambda_{P,t}^c \left(1 - q_t^{k^c} z_t^{i^k}\left(1 - \frac{\phi^{k^c}}{2}\left(\frac{i_t^{k^c}}{i_{t-1}^{k^c}} - 1\right)^2 - \phi^{k^c}\left(\frac{i_t^{k^c}}{i_{t-1}^{k^c}} - 1\right)\frac{i_t^{k^c}}{i_{t-1}^{k^c}}\right)\right) = \\ \beta_P E_t \left[\epsilon_{t+1}^b \lambda_{P,t+1}^c q_{t+1}^{k^c} z_{t+1}^{i^k} \phi^{k^c}\left(\frac{i_{t+1}^{k^c}}{i_t^{k^c}} - 1\right)\left(\frac{i_{t+1}^{k^c}}{i_t^{k^c}}\right)^2\right],\end{aligned} \tag{45}$$

$$\begin{aligned}\epsilon_t^b \lambda_{P,t}^c \left(1 - q_t^{k^h} z_t^{i^k}\left(1 - \frac{\phi^{k^h}}{2}\left(\frac{i_t^{k^h}}{i_{t-1}^{k^h}} - 1\right)^2 - \phi^{k^h}\left(\frac{i_t^{k^h}}{i_{t-1}^{k^h}} - 1\right)\frac{i_t^{k^h}}{i_{t-1}^{k^h}}\right)\right) = \\ \beta_P E_t \left[\epsilon_{t+1}^b \lambda_{P,t+1}^c q_{t+1}^{k^h} z_{t+1}^{i^k} \phi^{k^h}\left(\frac{i_{t+1}^{k^h}}{i_t^{k^h}} - 1\right)\left(\frac{i_{t+1}^{k^h}}{i_t^{k^h}}\right)^2\right],\end{aligned} \tag{46}$$

$$\epsilon_t^b \lambda_{P,t}^c = \beta_P R_t E_t \left[\epsilon_{t+1}^b \frac{\lambda_{P,t+1}^c}{\pi_{t+1}^c}\right], \tag{47}$$

and

$$\epsilon^b_t \lambda^c_{P,t} = \sum_{s=1}^{\phi^m} \beta^s_P E_t \left[\epsilon^b_{t+s} \frac{\lambda^c_{P,t+s}}{\prod_{v=1}^{s} \pi^c_{t+v}} \left(\tfrac{1}{\phi^m} + \left(R^d_t - 1 \right) \left(\tfrac{\phi^m - s+1}{\phi^m} \right) \right) \right], \tag{48}$$

where $\lambda^c_{P,t}$ is the Lagrange multiplier on budget constraint (7), $\frac{\lambda^c_{P,t} w^j_{P,t}}{\lambda^{nj}_{P,t}}$ and $\lambda^c_{P,t} q^{kj}_t$ are the Lagrange multipliers on labour supply constraints (6) and the law of motion of capital (8), respectively. Equation (36) describes the marginal utility of current consumption of non-durable goods. Equation (37) requires that households equate the marginal utility of current consumption goods to the marginal utility increase of housing stock services, the latter being composed of two parts: (i) the direct utility gain of an additional unit of housing, and (ii) the expected utility stemming from the consumption of the resale value of housing purchased in previous periods. Equations (38) and (39) link real wages in both sectors to households' marginal rate of substitution between consumption goods and leisure. In equilibrium, real wages in the consumption and housing sectors are equal. Equations (40) and (41) require that households equate their marginal utility of current consumption goods to the marginal utility increase of an additional unit of capital, which includes two parts: (i) the rental rate of capital, and (ii) the expected utility stemming from the consumption of the resale value of undepreciated capital purchased in previous periods. Equations (43) and (44) link the variable capacity utilization rate to the rental rate of capital. Equations (45) and (46) require that households equate the investment cost, in terms of the foregone marginal utility of consumption goods, to the expected value of the rebate in adjustment cost in the following period. Equation (47) is the typical Euler condition that equates the cost of sacrificing one unit of consumption goods to the benefit of investing in the bond market.[38] Finally, equation (48) equates the cost of sacrificing one unit of consumption goods to the benefit of making deposits generating a flow of revenues for ϕ^m periods.

[38]Since lenders own all firms and financial intermediairies, it also determines the pricing kernel of the economy.

Impatient The Lagrangian for the impatient optimization problem takes the following form:

$$L = E_0 \sum_{t=0}^{\infty} \beta_I^t \epsilon_t^b \times$$
$$\left\{ \begin{array}{l} U\left(c_{I,t}, h_{I,t}, n_{I,t}^c, n_{I,t}^h\right) + \lambda_{I,t}^c \times \\ \left\{ \begin{array}{l} n_{I,t}^{c,d} \int\limits_0^1 w_{I,e,t}^c \left(\frac{w_{I,e,t}^c}{w_{I,t}^c}\right)^{-\theta^{n^c}} de + n_{I,t}^{h,d} \int\limits_0^1 w_{I,t}^h \left(\frac{w_{I,e,t}^h}{w_{I,t}^h}\right)^{-\theta^{n^h}} de \\ + \frac{R_{t-1}^m b_{I,t-1}}{\pi_t^c} + m_t - c_{I,t} - b_{I,t} - q_t^h \left[h_{I,t} - \left(1-\delta^h\right) h_{I,t-1}\right] \\ - \frac{1}{\phi^m} \sum_{s=1}^{\phi^m} \frac{m_{t-s}}{\prod_{v=-s}^0 \pi_{t+v}^c} - \sum_{s=1}^{\phi^m} \left(R_{t-s}^m - 1\right) \left(\frac{\phi^m - s + 1}{\phi^m}\right) \frac{m_{t-s}}{\prod_{v=-s}^0 \pi_{t+v}^c} \\ + \frac{w_{I,t}^c}{\lambda_{I,t}^{n^c}} \left[n_{I,t}^c - n_{I,t}^{c,d} \int\limits_0^1 \left(\frac{w_{I,e,t}^c}{w_{I,t}^c}\right)^{-\theta^{n^c}} de\right] + \frac{w_{I,t}^h}{\lambda_{I,t}^{n^h}} \left[n_{I,t}^h - n_{I,t}^{h,d} \int\limits_0^1 \left(\frac{w_{I,e,t}^h}{w_{I,t}^h}\right)^{-\theta^{n^h}} de\right] \\ + \lambda_{I,t}^b \left[M_t + \omega h_{I,t} q_t^h\right] \end{array} \right\} \end{array} \right\}$$

The first-order necessary conditions for $c_{I,t}$, $h_{I,t}$, $n_{I,t}^c$, $n_{I,t}^h$, $b_{I,t}$ and m_t are, respectively,

$$\lambda_{I,t}^c = \frac{\left(1-\epsilon_t^h\right)^{\frac{1}{\theta_I^x}} c_{I,t}^{\frac{-1}{\theta_I^x}}}{x_{I,t}^{\frac{\sigma_I^x \theta_I^x - 1}{\theta_I^x}}}, \tag{49}$$

$$\epsilon_t^b \lambda_{I,t}^c q_t^h - \beta_I \left(1-\delta^h\right) E_t \left[\epsilon_{t+1}^b \lambda_{I,t+1}^c q_{t+1}^h\right] = \epsilon_t^b \frac{\left(\epsilon_t^h\right)^{\frac{1}{\theta_I^x}} h_{I,t}^{\frac{-1}{\theta_I^x}}}{x_{I,t}^{\frac{\sigma_I^x \theta_I^x - 1}{\theta_I^x}}} + \epsilon_t^b \lambda_{I,t}^c \lambda_t^b \omega q_t^h, \tag{50}$$

$$\epsilon_t^n \left(\left(n_{I,t}^c\right)^{\frac{\theta_I^n + 1}{\theta_I^n}} + \left(n_{I,t}^h\right)^{\frac{\theta_I^n + 1}{\theta_I^n}}\right)^{\frac{\theta_I^n \eta_I - 1}{\theta_I^n + 1}} \left(n_{I,t}^c\right)^{\frac{1}{\theta_I^n}} = \frac{\lambda_{I,t}^c w_{I,t}^c}{\lambda_{I,t}^{n^c}}, \tag{51}$$

$$\epsilon_t^n \left(\left(n_{I,t}^c\right)^{\frac{\theta_I^n + 1}{\theta_I^n}} + \left(n_{I,t}^h\right)^{\frac{\theta_I^n + 1}{\theta_I^n}}\right)^{\frac{\theta_I^n \eta_I - 1}{\theta_I^n + 1}} \left(n_{I,t}^h\right)^{\frac{1}{\theta_I^n}} = \frac{\lambda_{I,t}^c w_{I,t}^h}{\lambda_{I,t}^{n^h}}, \tag{52}$$

$$\epsilon_t^b \lambda_{I,t}^c = \beta_I R_t E_t \left[\epsilon_t^b \frac{\lambda_{I,t+1}^c}{\pi_{t+1}^c}\right], \tag{53}$$

and

$$\epsilon_t^b \lambda_{I,t}^c \left(1-\lambda_t^b\right) = \sum_{s=1}^{\phi^m} \beta_I^s E_t \left[\epsilon_{t+s}^b \frac{\lambda_{I,t+s}^c}{\prod_{v=1}^s \pi_{t+v}^c} \left(\frac{1}{\phi^m} + (R_t^m - 1)\left(\frac{\phi^m - s + 1}{\phi^m}\right) + \lambda_{t+s}^b \left(\frac{\phi^m - s}{\phi^m}\right)\right)\right], \tag{54}$$

where $\lambda_{I,t}^c$ is the Lagrange multiplier on budget constraint (10), $\frac{\lambda_{I,t}^c w_{I,t}^j}{\lambda_{I,t}^{n^j}}$ and $\lambda_{I,t}^c \lambda_{I,t}^b$ are the Lagrange multipliers on labour supply constraint (6) and the borrowing constraint (11), respectively. Equations (49), (51), (52) and (53) have the same interpretation as for the lenders. Finally, equations (50) and (54) depend on the same two components as the lenders' equations, but also on the marginal utility of relaxing the borrowing constraint.

Wages The Lagrangian for wages optimization problem (for $i \in \{P, I\}$ and $j \in \{c, h\}$) takes the following form:

$$L = E_t \sum_{s=0}^{\infty} \left(\beta_i \xi^{w^j}\right)^s \epsilon_{t+s}^b \lambda_{i,t+s}^c n_{i,t+s}^{j,d} \left(\frac{\tilde{w}_{i,t}^j}{w_{i,t+s}^j}\right)^{-\theta^{n^j}} \prod_{k=1}^s \left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t+k-1}^c\right)^{1-\iota^{w^j}}}{\pi_{t+k}^c}\right)^{-\theta^{n^j}} \times \\ \left[\tilde{w}_{i,t}^j \prod_{k=1}^s \left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t+k-1}^c\right)^{1-\iota^{w^j}}}{\pi_{t+k}^c}\right) - \frac{w_{i,t+s}^j}{\lambda_{i,t+s}^{n^j}}\right]$$

The households' first-order necessary condition with respect to the optimally set wage rate in the current period in the production sector j, $\tilde{w}_{i,t}^j$, is

$$E_t \sum_{s=0}^{\infty} \left(\beta_i \xi^{w^j}\right)^s \epsilon_{t+s}^b \lambda_{i,t+s}^c n_{i,t+s}^{j,d} \left(\frac{\tilde{w}_{i,t}^j}{w_{i,t+s}^j}\right)^{-\theta^{n^j}} \prod_{k=1}^s \left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t+k-1}^c\right)^{1-\iota^{w^j}}}{\pi_{t+k}^c}\right)^{-\theta^{n^j}} \times \\ \left[\frac{\theta^{n^j} - 1}{\theta^{n^j}} \tilde{w}_{i,t}^j \prod_{k=1}^s \frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t+k-1}^c\right)^{1-\iota^{w^j}}}{\pi_{t+k}^c} - \frac{w_{i,t}^j}{\lambda_{i,t}^{n^j}}\right] = 0.$$

Using (38), (39), (51) and (52) to eliminate $\lambda_{i,t}^{n^j}$ yields

$$E_t \sum_{s=0}^{\infty} \left(\beta_i \xi^{w^j}\right)^s \epsilon_{t+s}^b \lambda_{i,t+s}^c n_{i,t+s}^{j,d} \left(\frac{\tilde{w}_{i,t}^j}{w_{i,t+s}^j}\right)^{-\theta^{n^j}} \prod_{k=1}^{s} \left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t+k-1}^c\right)^{1-\iota^{w^j}}}{\pi_{t+k}^c}\right)^{-\theta^{n^j}} \times$$
$$\left[\frac{\theta^{n^j}-1}{\theta^{n^j}} \tilde{w}_{i,t}^j \prod_{k=1}^{s} \frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_{t+k-1}^c\right)^{1-\iota^{w^j}}}{\pi_{t+k}^c} - \right.$$
$$\left. \frac{1}{\lambda_{i,t+s}^c} \epsilon_{t+s}^n \left(\left(n_{i,t+s}^c\right)^{\frac{\theta_i^n+1}{\theta_i^n}} + \left(n_{i,t+s}^h\right)^{\frac{\theta_i^n+1}{\theta_i^n}}\right)^{\frac{\theta_i^n \eta_i - 1}{\theta_i^n+1}} \left(n_{i,t+s}^j\right)^{\frac{1}{\theta_i^n}}\right] = 0.$$

This equation states that, in labour markets in which the wage rate is reoptimized in period t, the real wage is set to equate the expected future average marginal revenue to the average marginal cost of supplying labour. In this equation, $\frac{\theta^{n^j}}{\theta^{n^j}-1}$ represents the markup of wages over the marginal cost of labour that would prevail in the absence of wage stickiness and trend inflation. To write the wage-setting equation in recursive form,[39] we need to define intermediate variables $f_{i,t}^{1,j}$ and $f_{i,t}^{2,j}$. This yields

$$f_{i,t}^{1,j} = \epsilon_t^b \frac{\theta^{n^j}-1}{\theta^{n^j}} \left(\tilde{w}_{i,t}^j\right)^{1-\theta^{n^j}} \left(\frac{1}{w_{i,t}^j}\right)^{-\theta^{n^j}} \lambda_{i,t}^c n_{i,t}^{j,d} +$$
$$\beta_i \xi^{w^j} E_t \left[\left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_t^c\right)^{1-\iota^{w^j}}}{\pi_{t+1}^c}\right)^{1-\theta^{n^j}} \left(\frac{\tilde{w}_{i,t}^j}{\tilde{w}_{i,t+1}^j}\right)^{1-\theta^{n^j}} f_{i,t+1}^{1,j}\right],$$
$$f_{i,t}^{2,j} = \epsilon_t^b \epsilon_t^n \left(\left(n_{i,t}^c\right)^{\frac{\theta_i^n+1}{\theta_i^n}} + \left(n_{i,t}^h\right)^{\frac{\theta_i^n+1}{\theta_i^n}}\right)^{\frac{\theta_i^n \eta_i - 1}{\theta_i^n+1}} \left(n_{i,t}^j\right)^{\frac{1}{\theta_i^n}} \left(\frac{\tilde{w}_{i,t}^j}{w_{i,t}^j}\right)^{-\theta^{n^j}} n_{i,t}^{j,d} +$$
$$\beta_i \xi^{w^j} E_t \left[\left(\frac{\left(\pi^c\right)^{\iota^{w^j}} \left(\pi_t^c\right)^{1-\iota^{w^j}}}{\pi_{t+1}^c}\right)^{-\theta^{n^j}} \left(\frac{\tilde{w}_{i,t}^j}{\tilde{w}_{i,t+1}^j}\right)^{-\theta^{n^j}} f_{i,t+1}^{2,j}\right],$$
$$f_{i,t}^{1,j} = f_{i,t}^{2,j}.$$

[39]Which is necessary for the representation of the model in state-space form.

A.2 Firms

A.2.1 Consumption Sector

Final-Goods Producers For any given level of final consumption goods produced, final-goods producers must solve the expenditure-minimizing problem

$$\min_{\left\{y^c_{m,t}\right\}} \int_0^1 P^c_{m,t} y^c_{m,t} dm$$

subject to aggregation constraint (13).

Intermediate-Goods Producers The nominal profits (i.e. dividends) of the firm are denoted by

$$F^c_{m,t} = P^c_{m,t} y^c_{m,t} - R^{k^c}_t k^c_{m,t} - W^c_{P,t} n^{c,d}_{P,m,t} - W^c_{I,t} n^{c,d}_{I,m,t}.$$

The firm's objective is a static problem of profit maximization

$$\max_{\left\{k^c_{m,t}, n^{c,d}_{P,m,t}, n^{c,d}_{I,m,t}\right\}} F^c_{m,t}$$

subject to demand function (14). Real wages and the real rental rate of capital are then given by

$$r^{k^c}_t = mc_t z^c_t \gamma^c \left(k^c_{m,t}\right)^{\gamma^c - 1} \left(\left(n^{c,d}_{P,m,t}\right)^{\alpha^c} \left(n^{c,d}_{I,m,t}\right)^{1-\alpha^c}\right)^{1-\gamma^c},$$

$$w^c_{P,t} = mc_t z^c_t \left(1 - \gamma^c\right) \alpha^c \left(k^c_{m,t}\right)^{\gamma^c} \left(\left(n^{c,d}_{P,m,t}\right)^{\alpha^c} \left(n^{c,d}_{I,m,t}\right)^{1-\alpha^c}\right)^{(-\gamma^c)} \left(\frac{n^{c,d}_{P,m,t}}{n^{c,d}_{I,m,t}}\right)^{\alpha^c - 1},$$

and

$$w^c_{I,t} = mc_t z^c_t \left(1 - \gamma^c\right) \left(1 - \alpha^c\right) \left(k^c_{m,t}\right)^{\gamma^c} \left(\left(n^{c,d}_{P,m,t}\right)^{\alpha^c} \left(n^{c,d}_{I,m,t}\right)^{1-\alpha^c}\right)^{(-\gamma^c)} \left(\frac{n^{c,d}_{P,m,t}}{n^{c,d}_{I,m,t}}\right)^{\alpha^c},$$

where mc_t is the firm's real marginal cost. From the optimality conditions, all firms m face the same prices of factors, and since they have access to the same technology, marginal cost is equal across all firms at every period t.

Prices The Lagrangian for wages optimization problem takes the following form:

$$L = E_t \sum_{s=0}^{\infty} \left(\beta_P \xi^{p^c}\right)^s \epsilon^b_{t+s} \frac{\lambda^c_{P,t+s}}{\lambda^c_{P,t}} \frac{P^c_t}{P^c_{t+s}} \left\{ \begin{array}{c} \left[\begin{array}{c} \tilde{P}^c_t \left(\dfrac{\tilde{P}^c_t}{P^c_{t+s}} \right)^{-\theta^c} y^c_{t+s} - r^{k^c}_{t+s} k^c_{m,t+s} \\ - w^c_{P,t+s} n^{c,d}_{P,m,t+s} - w^c_{I,t+s} n^{c,d}_{I,m,t+s} \end{array} \right] \\ + MC_{m,t+s} \times \\ \left[\begin{array}{c} z^c_{t+s} \left(k^c_{m,t+s}\right)^{\gamma^c} \left(\left(n^{c,d}_{P,m,t+s}\right)^{\alpha} \left(n^{c,d}_{I,m,t+s}\right)^{1-\alpha} \right)^{1-\gamma^c} \\ - \left(\dfrac{\tilde{P}^c_t}{P^c_{t+s}} \right)^{-\theta^c} y^c_{t+s} \end{array} \right] \end{array} \right\}.$$

To maximize the expected present value of their real dividends, the producers of intermediate goods in the consumption sector must meet the following first-order necessary condition with respect to $\tilde{P}^c_t$:

$$E_t \sum_{s=0}^{\infty} \left(\beta_P \xi^{p^c}\right)^s \epsilon^b_{t+s} \frac{\lambda^c_{P,t+s}}{\lambda^c_{P,t}} \left(\frac{\tilde{P}^c_t}{P^c_t} \right)^{-\theta^c} \prod_{k=1}^{s} \left(\frac{\left(\pi^c\right)^{\iota^{p^c}} \left(\pi^c_{t+k-1}\right)^{1-\iota^{p^c}}}{\pi^c_{t+k}} \right)^{-\theta^c} y^c_{t+s}$$
$$\left[\frac{\theta^c - 1}{\theta^c} \left(\frac{\tilde{P}^c_t}{P^c_t} \right) \prod_{k=1}^{s} \left(\frac{\left(\pi^c\right)^{\iota^{p^c}} \left(\pi^c_{t+k-1}\right)^{1-\iota^{p^c}}}{\pi^c_{t+k}} \right) - mc_{t+s} \right] = 0,$$

with $\beta^s_P \epsilon^b_{t+s} \frac{\lambda^c_{P,t+s}}{\lambda^c_{P,t}} \frac{P^c_t}{P^c_{t+s}} MC^j_{t+s}$ being the Lagrange multiplier on demand function (14), and MC^j_{t+s} is the firm's nominal marginal cost. Since firms are assumed to act in the best interest of their owners (i.e. the lenders), the Lagrange multiplier is the marginal rate of substitution for consumption goods over time (i.e. Equation (47)). According to this expression, optimizing firms set nominal prices so that average future expected marginal revenues equate average future expected marginal costs.

The expression above does not have a direct recursive formulation, making the computation difficult. However, writing the price-setting equation in recursive form eases this process. To do so, we need to define intermediate variables $x_t^{c,1}$ and $x_t^{c,2}$:

$$
\begin{aligned}
x_t^1 &= \epsilon_t^b \frac{\theta^c - 1}{\theta^c} \tilde{p}_t^{c\,1-\theta^c} y_t^c + \beta_P \xi^{p^c} E_t \left[\frac{\lambda_{P,t+1}^c}{\lambda_{P,t}^c} \left(\frac{(\pi^c)^{\iota^{p^c}} (\pi_t^c)^{1-\iota^{p^c}}}{\pi_{t+1}^c} \right)^{1-\theta^c} \left(\frac{\tilde{p}_t^c}{\tilde{p}_{t+1}^c} \right)^{1-\theta^c} x_{t+1}^1 \right], \\
x_t^2 &= \epsilon_t^b \tilde{p}_t^{c\,-\theta^c} y_t^c mc_{m,t} + \beta_P \xi^{p^c} E_t \left[\frac{\lambda_{P,t+1}^c}{\lambda_{P,t}^c} \left(\frac{(\pi^c)^{\iota^{p^c}} (\pi_t^c)^{1-\iota^{p^c}}}{\pi_{t+1}^c} \right)^{-\theta^c} \left(\frac{\tilde{p}_t^c}{\tilde{p}_{t+1}^c} \right)^{-\theta^c} x_{t+1}^2 \right], \\
x_t^1 &= x_t^2.
\end{aligned}
$$

A.2.2 Housing Sector

The nominal profits (i.e. dividends) of the firm are denoted by

$$
F_t^h = Q_t^h y_t^h - R_t^{k^h} u_t^{k^h} k_{t-1}^h - R_t^l l_{t-1} - W_{P,t}^h n_{P,t}^{h,d} - W_{I,t}^h n_{I,t}^{h,d}.
$$

The firm's objective is a static problem of profit maximization

$$
\max_{\left\{u_t^{k^h} k_{t-1}^h, n_{P,t}^{h,d}, n_{I,t}^{h,d}\right\}} F_t^h
$$

subject to (18). Real wages and real rental rates of capital and land are then given by

$$
r_t^{k^h} = q_t^h z_t^h \gamma^h \left(u_t^{k^h} k_{t-1}^h \right)^{\gamma^h - 1} l_{t-1}^{\gamma^l} \left(\left(n_{P,t}^{h,d} \right)^{\alpha^h} \left(n_{I,t}^{h,d} \right)^{1-\alpha^h} \right)^{1-\gamma^h-\gamma^l},
$$

$$
r_t^l = q_t^h z_t^h \gamma^l \left(u_t^{k^h} k_{t-1}^h \right)^{\gamma^h} l_{t-1}^{\gamma^l - 1} \left(\left(n_{P,t}^{h,d} \right)^{\alpha^h} \left(n_{I,t}^{h,d} \right)^{1-\alpha^h} \right)^{1-\gamma^h-\gamma^l},
$$

$$
\begin{aligned}
w_{P,t}^h = q_t^h z_t^h \left(1 - \gamma^h - \gamma^l\right) \alpha^h \left(u_t^{k^h} k_{t-1}^h \right)^{\gamma^h} l_{t-1}^{\gamma^l} \times \\
\left(\left(n_{P,t}^{h,d} \right)^{\alpha^h} \left(n_{I,t}^{h,d} \right)^{1-\alpha^h} \right)^{-\gamma^h-\gamma^l} \left(\frac{n_{P,t}^{h,d}}{n_{I,t}^{h,d}} \right)^{\alpha^h - 1},
\end{aligned}
$$

and

$$w_{I,t}^{h} = q_t^h z_t^h \left(1-\gamma^h-\gamma^l\right)\left(1-\alpha^h\right)\left(u_t^{k^h} k_{t-1}^h\right)^{\gamma^h} l_{t-1}^{\gamma^l} \times$$
$$\left(\left(n_{P,t}^{h,d}\right)^{\alpha^h}\left(n_{I,t}^{h,d}\right)^{1-\alpha^h}\right)^{-\gamma^h-\gamma^l}\left(\frac{n_{P,t}^{h,d}}{n_{I,t}^{h,d}}\right)^{\alpha^h}.$$

A.2.3 Labour Input

The firm's objective is a static problem of cost minimization

$$\min_{\left\{n_{P,e,t}^{j,d}, n_{I,e,t}^{j,d}\right\}} \int_0^1 W_{P,e,t}^j n_{P,e,t}^{j,d} de + \int_0^1 W_{I,e,t}^j n_{I,e,t}^{j,d} de.$$

A.3 Financial Intermediaries

To maximize the expected present value of their real dividends, financial intermediaries must solve

$$\max_{\{d_t, m_t\}} E_t \sum_{s=0}^{\infty} \left(\beta_P\right)^s \epsilon_{t+s}^b \left[\frac{\lambda_{P,t+s}^c}{\lambda_{P,t}^c}\frac{P_t^c}{P_{t+s}^c}\right] F_{t+s}^{fi}$$

subject to their balance sheet.

A.4 Competitive Equilibrium

An (imperfectly) competitive equilibrium is an allocation for:

- the lenders: $\mathcal{C}_P = \left\{c_{P,t}, h_{P,t}, n_{P,t}^j, b_{P,t}, i_t^{k^j}, k_t^j, u_t^{k^j}, d_t\right\}_{t=0, j\in\{c,h\}}^{\infty}$,
- the borrowers: $\mathcal{C}_I = \left\{c_{I,t}, h_{I,t}, n_{I,t}^j, b_{I,t}, m_t\right\}_{t=0, j\in\{c,h\}}^{\infty}$,
- the firms in consumption sector: $\mathcal{F}^c = \left\{y_{m,t}^c, K_{m,t}^c, n_{i,m,t}^{c,d}, F_{m,t}^c\right\}_{t=0, m\in[0,1], i\in\{P,I\}}^{\infty}$,
- the firms in housing sector: $\mathcal{F}^h = \left\{y_t^h, k_t^h, n_{i,t}^{h,d}, F_t^h, l_t\right\}_{t=0, i\in\{P,I\}}^{\infty}$, and
- prices system: $\mathcal{P} = \left\{R_t, R_t^m, R_t^d, \pi_t^c, \tilde{p}_t^c, q_t^h, q_t^l, w_{i,t}^j, \tilde{w}_{i,t}^j, q_t^{k^j}\right\}_{t=0, i\in\{P,I\}, j\in\{c,h\}}^{\infty}$,

such that, given initial conditions on predetermined variables, the exogenous processes, and the prices system, the allocations $\mathcal{C}_P$, $\mathcal{C}_I$, $\mathcal{F}^c$ and $\mathcal{F}^h$ solve the households' and firms' problems, and all market clearing conditions in Section 2.6 are satisfied.

B Definitions and Data Sources

Consumption (c_t)

1983Q3 to 2014Q4 data

Real (chained 2007 dollars) household consumption expenditure on non-durable goods, semi-durable goods, durable goods, and services per capita (number of persons of working age, 15 years and over), seasonally adjusted at annual rates. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 282-0001 and 380-0064), Internal Calculations

Core CPI inflation rate (π_t^c)

1983Q3 to 2014Q4 data

All-items CPI excluding eight of the most volatile components and the core CPI. We splice both series, compute the annualized quarterly growth rate and remove the Bank of Canada's inflation target of 2 percent.

Source: Statistics Canada (Table 326-0020), Internal Calculations

Residential investment (y_t^h)

1983Q3 to 2014Q4 data

Real (chained 2007 dollars) business gross fixed capital formation in residential structures per capita (number of persons of working age, 15 years and over), seasonally adjusted at annual rates. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 282-0001 and 380-0064), Internal Calculations

House price (π_t^h)

1983Q3 to 2014Q4 data

Real (core CPI) house price. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Multiple Listing Service (MLS)

Non-residential investment (i_t^k)

1983Q3 to 2014Q4 data

Real (chained 2007 dollars) business gross fixed capital formation in non-residential structures, machinery and equipment per capita (number of persons of working age, 15 years and over), seasonally adjusted at annual rates. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 282-0001 and 380-0064), Internal Calculations

Capital price (π_t^k)

1983Q3 to 2014Q4 data

Real (core CPI) implicit price index of business gross fixed capital formation in non-residential structures, machinery and equipment. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Table 380-0066), Internal Calculations

Mortgage debt ($b_{i,t}$)

1983Q3 to 2014Q4 data

Real (core CPI) residential mortgage credit per capita (number of persons of working age, 15 years and over), seasonally adjusted. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 282-0001 and 176-0069), Internal Calculations

Nominal short-term interest rate (R_t)

1983Q3 to 2014Q4 data

Treasury bills rate, 3-months. We remove a linear time trend.

Source: Statistics Canada (Cansim Table 176-0043), Internal Calculations

Nominal long-term interest rate (R_t^m)

1983Q3 to 2014Q4 data

Average residential mortgage lending rate, 5 years. We remove a linear time trend.

Source: Statistics Canada (Cansim Table 176-0043), Internal Calculations

Hours worked in consumption sector (n_t^c)

1983Q3 to 2014Q4 data

Hours worked in the consumption sector per capita (number of persons of working age, 15 years and over). The full computation methodology for this series is available upon request. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 281-0001, 281-0002, 281-0023, 281-0026 and 282-0001), Internal Calculations

Wage in consumption sector ($\pi_t^{w^c}$)

1983Q3 to 2014Q4 data

Real (core CPI) wages in the consumption sector. The full computation methodology for this series is available upon request. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 281-0004, 281-0029 and 281-0031), Internal Calculations

Capacity utilization rate in consumption sector ($u_t^{k^c}$)

1983Q3 to 2014Q4 data

Capacity utilization rate in the consumption sector. The full computation methodology for this series is available upon request. We remove the mean.

Source: Statistics Canada (Cansim Tables 028-0001, 028-0002, 031-0005 and 031-0006), Internal Calculations

Hours worked in housing sector (n_t^h)

1983Q3 to 2014Q4 data

Hours worked in the housing sector per capita (number of persons of working age, 15 years and over). The full computation methodology for this series is available upon request. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Table 281-0001, 281-0002, 281-0023, 281-0026 and 282-0001), Internal Calculations

Wage in housing sector ($\pi_t^{w^h}$)

1983Q3 to 2014Q4 data

Real (core CPI) wages in the housing sector. The full computation methodology for this series is available upon request. We remove the trend and isolate the cycle by applying a one-sided HP filter.

Source: Statistics Canada (Cansim Tables 281-0004, 281-0029 and 281-0031), Internal Calculations

Capacity utilization rate in housing sector ($u_t^{k^h}$)

1983Q3 to 2014Q4 data

Capacity utilization rate in the housing sector. The full computation methodology for this series is available upon request. We remove the mean.

Source: Statistics Canada (Cansim Tables 028-0001, 028-0002, 031-0005 and 031-0006), Internal Calculations