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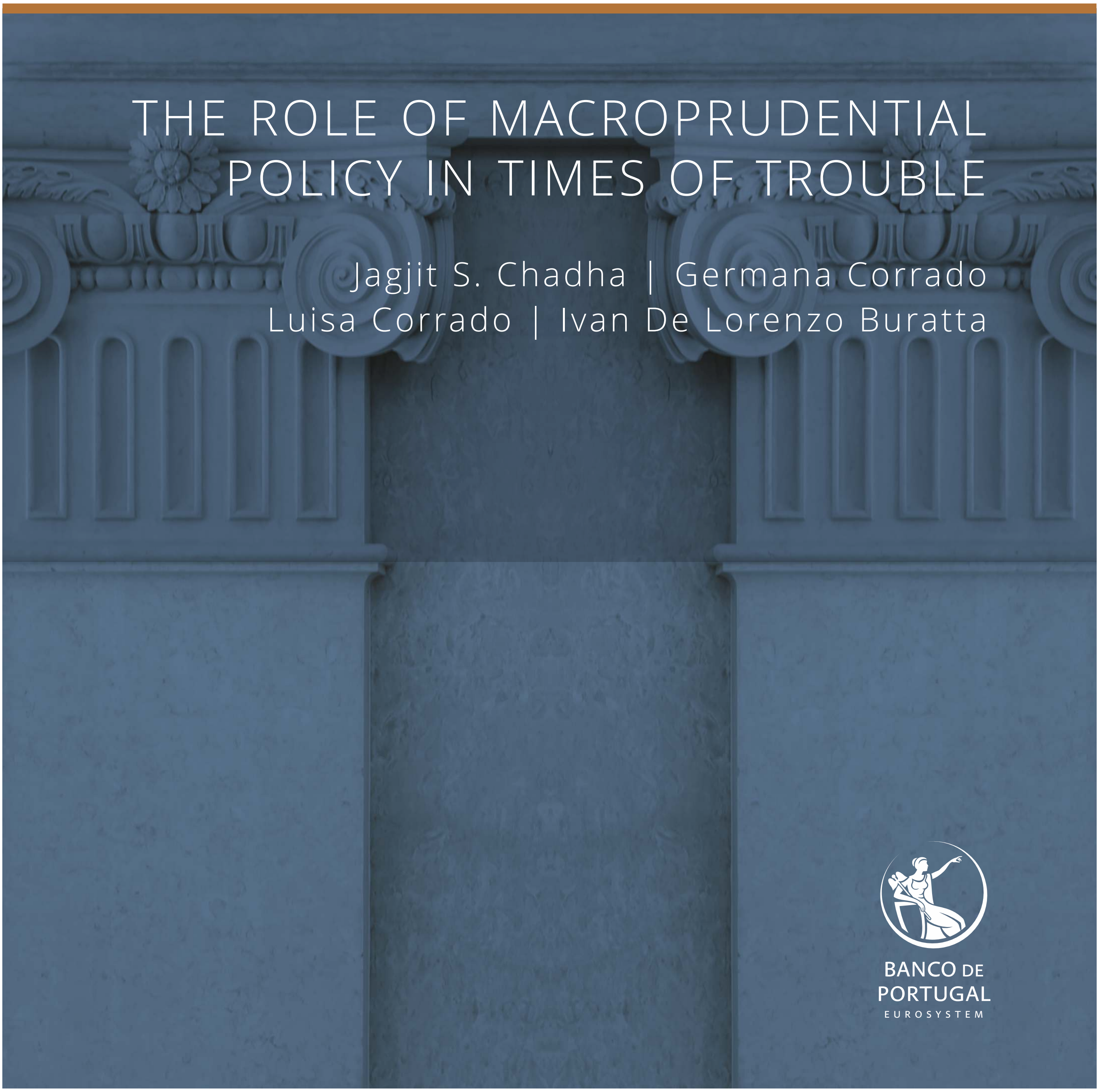

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The Role of Macroprudential Policy in Times of Trouble

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Abstract
We develop a DSGE model with heterogeneous agents, where savers own firms and risk-pricing banks while borrowers require loans to establish their consumption plans. The bank lends at an external finance premium (EFP) over the policy rate as a function of the asset price, housing collateral, the demand for loans and their perceived riskiness. We suggest that the close relationship between aggregate consumption and house prices is related to collateral effects. We also outline the role of the EFP in determining consumption spillovers between borrowers and lenders. We solve the model with occasionally-binding constraints to examine the redistributive role of macro-prudential policies in terms of welfare. Countercyclical deployment of the loan-to-value constraint placed on borrowers can limit the scale of the downturn from a negative house price shock. Furthermore, when the zero lower bound acts to constrain monetary policy, looser macroprudential policies can act as an effective substitute for lower policy rates. Finally, we show that co-ordinated macroprudential and fiscal policies can also attenuate the welfare losses that arise from uncertainty banks may face about default probabilities.

JEL: E32, E44, E58

Keywords: Heterogeneous households, Credit constraints, Housing collateral, Asset prices, Bank lending, Macro-prudential tools, Fiscal and monetary policy.

Non-technical Summary

We investigate the interplay between household consumption by borrowers and savers, house prices and housing wealth as a driver of business cycle fluctuations. The existing literature explains the observed links as a result of either or both of wealth or collateral effects. We examine what role there is for borrower-oriented macroprudential policies in stabilising boom and bust cycles in monetary regimes we might describe as normal and alternatively constrained by the zero lower bound in policy rates. Moreover, we investigate a channel through which macroprudential and fiscal authorities might coordinate their policy actions. We find that macro-prudential policies can attenuate business cycle fluctuations that might otherwise result from (i) large house price falls, (ii) a liquidity trap and (iii) support lending when bank perceive increased risks of default.

We develop a DSGE model with heterogeneous agents, where savers own firms and risk-pricing banks while borrowers require loans to establish their optimal consumption plans. The bank lends at an external finance premium (EFP) over the policy rate as a function of the asset price, housing collateral, the demand for loans and their perceived riskiness. The monetary policy maker sets the policy rate, the financial regulator sets the macroprudential policies and the fiscal policy decides about the quantity of bond issuance.

By matching the positive correlation between house price and borrower consumption, we argue that it is collateral effects that play a dominant role in driving the business cycle. This is because borrowers leverage their consumption plans from changes in house price and so turn out to be very sensitive to changes in the value of their collateral. We also show that the path of EFP determines the spillovers between borrower and saver spending and hence the intratemporal allocation of consumption across borrowers and savers.

We solve the model with occasionally-binding constraints to examine the helpful redistributive role that macro-prudential policies are able to play in terms of welfare. Specifically, the countercyclical deployment of the loan-to-value ratio faced by borrowers can limit the scale of the economic downturn resulting from a negative shock to asset prices. Indeed, negative spillovers between savers and borrowers can be limited over some ranges of responses as instrument control by the financial regulator in the loan market can act to decouple borrower and saver consumption plans and lead to smoother aggregate consumption paths.

Furthermore, when the zero lower bound acts to constrain monetary policy, looser macroprudential policies can act as an effective substitute for lower policy rates. This is because macroprudential policy can generate positive demand impulses in a liquidity trap when monetary policy is effectively constrained, altering the financial conditions of borrowers and allowing them to borrow and consume. Finally, we show that the coordination of macroprudential and fiscal policies can limit welfare losses for households that may result when banks are uncertain about the probability of default by borrowers and would otherwise restrict access to loans.

1. Introduction

The interplay between household consumption, house prices and housing wealth is a key channel for understanding business cycle fluctuations. Accordingly, the mechanisms of this interplay and its implications for broadly-defined macroeconomic policies have been the focus of much recent analysis. We pursue a line of enquiry suggested by several important studies that have employed collateral constrained models to understand better this interplay. We explore the collateral channel of housing demand - a variant of the 'financial accelerator' model developed by Bernanke *et al*. (1999) and Kiyotaki and Moore (1997) - to disentangle the role of house prices in the household consumption decision within the framework of a micro-founded macroeconomic model. We show that house prices are a function of credit constraints and directly affects the consumption plans of borrowers. Lending based on the value of the backing collateral accelerates borrowing and tends to exacerbate consumption volatility. We therefore find that macro-prudential constraints on borrowers can act to support macroeconomic adjustment.

Naturally, borrower plans have spillovers for savers. We emphasize the role of financial intermediation in our model by establishing a link between savers and borrowers mediated by a bank that picks an endogenous cost of borrowing for households, an external finance premium (EFP) which is defined as the difference between the cost of providing external funding by banks and the opportunity cost of internal funds. An advantage of our approach is that, as well as standard questions of monetary and fiscal policy interactions, we can then also consider the scope for macro-prudential instruments to stabilize borrower consumption, house prices and lending in our economy. In particular, we model the banking sector as pricing loans as a function of the value of housing collateral and because house price variation is endogenous, we show that it can lead to cycles in the house prices that can affect the real sector.

In this paper, we unbundle the representative agent assumption and consider two household types, saver and borrower. In standard manner, the saver household maximizes lifetime expected utility and behaves as a standard intertemporal optimizing consumer, but is asset rich from owning the housing stock, financial intermediaries, firms and government bonds. The borrower also maximizes utility, but obtains loans from banks based on the collateral (housing) value. Banks intermediate between saver deposits and loans to borrowers based on house prices and perceived default risk. We are thus able to analyze the interaction between both types of households, banks and assess the role of various policies in maximizing household welfare.

There has been increasing interest in introducing a banking sector within micro-founded macroeconomic models to analyze economies where different financial assets are available to agents. We have framed a banking sector where an ex-ante pricing of risk on residential loans is explicitly modelled. This element of uncertainty might explain why the anticipation of potential short-falls on loans leads to contractions of credit and deleveraging, even without the necessity of formal default events. Therefore, in our model, the accelerator effect from increasing asset prices operates through the ‘collateral’ channel of housing, and an attenuator operates via the lending rate which reflects the probability of shortfall on residential loans. Our work confirms that a strong shocks amplification and propagation mechanism originates from the EFP (Goodfriend and McCallum, 2007) and from fluctuations in asset (housing) prices, which determines what we might wish to term a collateral channel, for propagating real and monetary shocks.

The results of this paper can be summarized in four points as follows. First of all, the model captures the salient features of aggregate consumption dynamics and their apparent relationship to house prices, as it delivers strongly procyclical house prices without recourse to aggregate wealth effects (Attanasio *at al.,* 2009). We show that forward-looking house prices are closely linked to the path of borrower consumption, loan to value ratios, inflation and the lending rate.

Secondly, aggregate consumption dynamics are shown to follow a non-linear process. Saver households have considerable volatility injected into their consumption titling plans by movements in real deposit rates. Borrower households need to generate sufficient collateral to allow credit to flow to them in the form of loans and these loans then suppress consumption in future periods and lead to a cycle in aggregate consumption. There are also spillovers in this economy from one type of consumer to the other, as changes in the expected price of durable goods affect borrower consumption via bank lending; the opposite dynamics of the two types' consumption originates from the fully-fledged specification of the banking sector which incorporates the EFP.

Considering the model in a second-order approximation or in an occasionally binding framework helps us detecting the non-linearity arising from both the nature of two types of households with two different interest rates and the presence of a collateral constraint that is allowed to be slack. Moreover, limiting the policy rate fluctuations with the presence of a Zero Lower Bound constraint exacerbates the asymmetries of both credit and GDP cycles. We also consider the appropriate role of macro-prudential policies in stabilizing this economy. Our motivation is twofold. First, countercyclical macroprudential policy is linked to other policies that moderate cyclical fluctuations – above all monetary policy, which also affects macroprudential variables as asset prices and credit. Since macroprudential policy has direct or indirect effects on these variables, it is likely to influence the transmission mechanism of monetary policy. We show that macroprudential policy helps to reduce the non-linearities arising in the presence of a borrowing constraint and/or a Zero Lower Bound for the policy rate. Moreover, releasing the debt pressure on borrowers, macroprudential policy works as a substitute for unconventional monetary policy, since it reduces the periods spent at the Zero Lower Bound. Finally, we study how a macroprudential rule for the Loan-to-Value ratio (LTV) interacts with a government feedback rule for fiscal policy. We compute the optimal parameters of these rules when fiscal and macroprudential policies act in a coordinated way. We find that both policies acting together unambiguously improves the stability of the system in terms of welfare losses especially in the presence of parameter uncertainty.

The paper contributes to the literature on three dimensions. To our knowledge, this work represents the first attempt to endogenise the External Finance Premium in a model with collateral constraints and considering non-linear solutions. Moreover, we update the occasionally-binding DSGE models literature by explicitly addressing policy and social welfare implications. Finally, we explore the coordination of fiscal and macroprudential policy, whereas most of the research focuses on the interaction of monetary and macroprudential policy. Our choice stems from the observation of the post-crisis scenario, in which persistently low interest rates weakened conventional monetary policy. In sum, we suggest that more active macroprudential policies may be helpful in stabilizing economies in troubled times.

The paper is organized as follows. Section 2 describes how the model fits the existing literature. Section 3 presents the model comprising a household sector with two types of agents - savers and borrowers - a banking sector, real and public sectors, and different policy tools - monetary, fiscal and macroprudential policies -. Section 4 describes the steady-state of the model alongside the solution methods employed. Section 5 illustrates the response of key variables in our model to real and financial shocks, reports the main results, and considers the appropriate role of stabilization policy in this class of model, noting that in a traditional representative agent framework active interest rates tend to be sufficient to obtain a welfare allocation close to optimal levels under commitment. Section 6 concludes and offers a tentative normative conclusion.

2. Background

The role of collateral constraints has been mainly assessed in a closed economy setting, where agents are constrained in the amount of funds they can borrow by the value of collateral they can pledge as a guarantee to the lenders. For example, in the presence of durable goods, Kiyotaki and Moore (1997) consider the case of collateral constraints with heterogeneous agents. Their analysis shows that the collateral constraint plays an important role in transmitting the effects of various shocks to other sectors through the 'financial accelerator mechanism'. The benchmark model linking the macroeconomy to financial markets is Bernanke *et al.* (1999), which Bernanke and Gertler (2001) exploit to analyze the supply-side effects of asset-price fluctuations and assess the implications of an explicit monetary-policy response to stock prices.

Empirical work has also focussed on the relationship between consumption and house prices providing evidence from micro data in the United Kingdom and the United States (Campbell and Cocco 2007; Hurst and Stafford 2004). Among others, Attanasio *et al.* (2009) stress that over the past 25 years, house price and consumption growth have been highly correlated. Three main hypotheses for this have been proposed: increases in house prices raise household wealth and so their consumption; house price growth relaxes borrowing constraints by increasing the collateral available to households; and house prices and consumption are together influenced by common factors. Using microeconomic data from the Family Expenditure Survey (FES) for UK, they find that the relationship between house prices and consumption is stronger for borrowing constrained than saver households, contradicting the wealth channel.

Aggregating micro US data from the Panel Study of Income Dynamics (PSID) for the years 1999-2017 Figure 1 shows positive correlation between consumption and house prices for borrowers, validating the house price effect hypothesis on consumption for credit-constrained agents[1]. Savers, instead, display a significantly smaller correlation between house prices and consumption. The figure also suggests that – especially for savers – there is no evidence of a positive relationship between income and house price, contradicting the wealth channel hypothesis. So, homeowners who are not facing credit constraints seem to be more hedged against fluctuations in house prices; these fluctuations have no effect on their real wealth and do not affect their consumption choices.

Our work relates to different strands of literature. First, it is strictly related to some recent DSGE models with heterogeneous agents[2] and durables (housing). Iacoviello (2005), including housing as collateral into Kiyotaki and Moore (1997) structure, is the benchmark reference for this branch. The author shows that housing and prices co-move when demand shocks are triggered and how the presence of collateral constraints for impatient households and entrepreneurs exacerbates the magnitude and the persistence of these shocks. Moreover, a "decelerator" effect arises in this model framework: nominal debt absorbs the impact of supply shocks on output. As in Iacoviello (2005), a rise in asset prices increases the borrowing capacity of the debtors (both households and firms) in our framework, allowing them to consume and invest more. Hence collateral effects can significantly strengthen the response of the real economy to demand shocks, including those hitting house prices. This model framework has recently been enriched by the contribution of some papers which try to explore the non-linearity

1. This is also in line with the findings by Aoki *et al.* (2004) who pointed out that a rise in house prices increases the collateral available to homeowners encouraging them to borrow more and to finance higher consumption. More recent evidence shows that large effects of house prices changes on household durable spending and consumption (for example, Mian *et al.* (2013); Kaplan *et al.* (2020a)). Guren *et al.* (2020) and Guerrieri and Iacoviello (2017) note how the housing wealth effects have been economically important in determining housing cycles, showing how house prices have positively influenced employment in services, electricity consumption and car sales. Cloyne *et al.* (2019) demonstrate the positive effect of house prices on borrowing and associate it to the presence of collateral constraint, using administrative mortgage data for UK.

2. Iacoviello (2005) assumes that the heterogeneity among agents is in the discount rates. Aoki *et al.* (2004) assume instead that a certain fraction of households have accumulated enough wealth so that their consumption decisions are well approximated by the permanent income hypothesis. The other households do not have enough wealth to smooth consumption and they face borrowing constraints.

caused by the heterogeneity of agents and the presence of occasionally binding collateral constraints (see for example Guerrieri and Iacoviello, 2017). In our work we follow this particular path, proposing both a second-order and a piecewise linear solution to the model. The idea of considering multiple types of households and collateral constraints is also explored by Kaplan *et al.* (2020b). Their overlapping-generations model allows accounting for high heterogeneity in balance sheets' composition and debt condition.

Our paper also relates to the literature on optimal policy with heterogeneous consumers and collateral constraints. It relates to the general literature of adding financial frictions to the New Keynesian Model (NKM), among the papers which adopts a similar approach we refer to Gertler and Karadi's paper (2013). The role of macroprudential policy has been analysed in several papers. Rubio and Carrasco-Gallego (2014) for example find that a countercyclical LTV rule that reacts to credit growth can moderate lending booms and be welfare-enhancing because it delivers a more stable system, in terms of output, inflation and financial stabilization. Other papers like Angelini *et al.* (2014) focus on policy coordination. They model macroprudential policy as capital requirements' regulation and find that lack of cooperation increases the volatility of both the policy rate and capital requirements in the case of financial shocks. Kannan *et al.* (2012) examine the potential role of monetary policy in mitigating the effects of asset price booms and study the role of macroprudential instruments (based on a LTV rule) in a NKM with a banking sector and financial accelerator effects. The main feature of this model is the presence of financial intermediaries. The analysis assumes that savers cannot lend to borrowers directly, whereas banks take deposits from savers and lend them to borrowers, charging a spread that depends on the net worth of borrowers. They find that having a monetary policy which responds to credit conditions or introducing a loan-to-value rule for borrowers helps to reduce the volatility of the output gap and credit aggregates when the economy is hit by financial or housing demand shocks; however, here the functional form for the determination of the spread is assumed rather than derived from a profit maximization problem. Whereas in our model, savers and borrowers face not only different degrees of impatience but also different interest rates; the wedge between the deposit rate and lending rate generates sources for banks' profits and credit frictions. Moreover, we assume that the interest rate wedge is not constant but varies with expected durable goods prices (i.e., the collateral value), and the amount of granted loans. Since durable goods are secured for loans, changes in the expected price of durable goods will affect the lending rate, borrowers' credit availability and consumption. Hence, given the extensive and established consensus that the origin of the last crisis is related to real estate booms and busts, we have focused on the effects of countercyclical macroprudential tools that prick the house price growth. Central banks should not be reluctant to employ these measures to the extent that they contain excessive lending or loan creation via short-term debt.

Finally, our model relates to the literature on the role of macroprudential policy in the Zero Lower Bound scenario. This strand includes for example the contributions by Farhi and Werning (2016) and Rubio and Yao (2020). Farhi and Werning (2016) show how macroprudential policy can act as a stabilizing tool for the economy in the presence of persistently low interest rates. Rubio and Yao (2020) transpose the above conclusions in a DSGE framework, allowing for the ZLB to be occasionally binding. We complement their study by considering and estimating a model with two occasionally binding constraints: a ZLB and a borrowing limit. We show that the presence of coordination between fiscal and macroprudential policies reduces the losses at the ZLB by improving the debt conditions of borrowers (i.e. leading the model in the regime where the borrowing constraint is slack). Macroprudential policy therefore acts like a substitute for unconventional policy when the model hits the ZLB.

3. The Model

It is therefore natural to consider heterogeneous agents who are either saver or borrowers (collateral constrained) and the link with the loan to value and the lending rate. As shown in Figure 2, the consumption of savers and borrowers will be negatively correlated and this will act to reduce overall aggregate consumption business cycle variance. At the unconstrained equilibrium, the external finance premium, the wedge between borrower and saver interest rates, is driven to zero and consumption is maximised at C^* for borrowers. When we add in an external finance premium, the level of consumption is lower for borrowers and higher for savers, as the latter save less. Indeed, as we move to the left of C^*, the consumption of borrowers falls and that of savers increases at time t, and thus the consumption of these two types of households may tend to be negatively correlated. The market-determined external finance premium, efp_t, reflects the sensitivity of borrower household consumption and C^{efp} is one possible equilibrium where consumption by borrower households is constrained. In presence of a noisy collateral the volatility of the lending rate, R_t^L, will translate into the volatility of borrower's consumption plans. Since creditor-borrower dynamics exacerbate intra and intertemporal volatility it may be appropriate to place a 'tax' on supply and this will tend to reduce further the consumption of borrowers. The tax can be any policy that reduces the supply of savings at every given interest rate and may include fiscal intervention that taxes the housing collateral, or simply macroprudential policies that limit supply in lending. The basic result would be to further limit the consumption of borrower-households: the lower level of consumption by borrowers would be designed to reduce the build-up in financial risks over the business cycle and can be modified separately from the policy rate thus offering policymakers an extra degree of freedom (Chadha, 2016). The presence of an external finance premium - deriving from the double interest rate structure of the economy - is the main novelty in the model structure compared to the related literature.

In this section, we illustrate the main features of our model summarized in Figure 3. The economy operates over an infinite time horizon and comprises a continuum of households in the interval $\mathbb{R} \in [0, 1]$. Households who consume, work and demand housing and financial assets are divided into two groups, which we refer to as saver (creditor) households and borrower households.[3] Saver households maximize their lifetime expected utility facing a resource constraint, while borrower (leveraged) households, whose ability of borrowing is endogenously linked to the market value of their housing wealth, face both resource and collateral (borrowing) constraints. Borrowers use their housing wealth as collateral to borrow from financial intermediaries and finance their current consumption with these additional credit lines and money. The dichotomy between savers, who are essentially standard optimizing consumers and borrowers who are credit constrained is key to this paper.

The banking sector collects money in the form of time deposits from savers and lends against housing equity to households who are borrowing constrained. Saver households purchase a positive amount of government bonds and deposits and do not borrow from banks, while leveraged households borrow from banks and have no financial assets (saving deposits or bonds). We assume that the savers are also the owners of monopolistic firms in the production sector and financial intermediaries in the banking sector. Saver households derive utility from consumption of non-durable goods (consumption goods) while leveraged households derive utility from consumption of both non-durable goods and durable goods (housing services). The choice of excluding housing from savers' utility represents another novelty in the literature. As we will further explain in the next paragraph, this specification triggers a home swap arrangement between households which allows us to easily model a fixed housing supply. Borrower households supply labor to firms. Entrepreneurs produce differentiated intermediate goods using leveraged households' labor. They sell the differentiated goods at a price that includes a markup over the purchasing cost and is subject to adjustment costs. Finally, the monetary authorities set the policy interest rate endogenously[4], in response to inflation and output gap, and macroprudential measures can be set to foster stabilization in bank lending, borrower's consumption and house prices.

3.1. Households' Utility Maximization

3.1.1. Saver Households. The preferences for this type of household can be expressed as:

$$\max_{c_t^s, d_t, b_t} U^s = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \log c_t^s \tag{1}$$

where $\beta \in (0, 1)$ is the discount or time-preference factor that measures how patient people are, c_t denotes household's real consumption of non-durable goods.

3. We use saver and creditor, as well as borrower and leveraged as interchangeable terms.

4. We will also consider a Zero Lower Bound scenario.

The representative saver household maximizes the above utility function subject to the following resource constraint expressed in real terms (i.e., in units of consumption) :

$$c_t^s + b_t + d_t \leq q_t(H_t^s - H_{t-1}^s) + R_{t-1}^B \frac{b_{t-1}}{\pi_t} + R_{t-1}^D \frac{d_{t-1}}{\pi_t} + \Theta + \Pi_t - \tau_y Y_t \quad (2)$$

Households enter each period t with real saving deposits at the bank, d_t. Saving deposits pay a gross nominal interest rate, R_t^D, at the end of the period, while government bonds, b_t, pay a (gross) nominal interest rate R_t^B and $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the (gross) inflation rate. In our model, deposits like a risk-free financial assets provide a store of value and no liquidity services to households, since we assume that they cannot be withdrawn from the bank before the beginning of the next period. In accordance with our time convention, d_t and b_t are respectively bank deposits and government bonds accumulated in period t and carried over into period $t+1$. We also assume that savers enters each period with an endowment of a fixed credit good, therefore it does not enter into savers' preferences. We might think of the durable good endowment as a fixed supply of housing units, H_t^s, which savers (capitalists/lenders) sell in period t to borrowers who demand and consume housing services in the same period. Savers also purchase the previous period stock of houses H_{t-1}^s at $t-1$ prices from borrowers that savers use as an input in the production function. Hence, agents trade houses in every period according to a 'sell-first' scheme: borrowers in each period sell the old property holdings to savers before buying from savers new houses: it is similar in spirit to a home swap arrangement.[5] Hence, the term $q_t \Delta H_t$ stands for net housing holdings evaluated today, with q_t denoting the relative price of residential goods expressed in term of non-durables, where $q_t \equiv \frac{Q_t}{P_t}$ and Q_t is the nominal house price. The terms Θ_t and Π_t denote real profits (dividends)[6] respectively from firms and banks owned by saver households; and the term and $\tau_y Y_t$ is income taxation.[7]

The first order conditions for this optimization problem read follows:[8]

- *Consumption:*

5. Swapping properties is like selling your home to a person and buying another home from that same person, ideally the two transactions happen at the same time. This mechanism strictly follows the baseline model in Kiyotaki and Moore (1997) where land is exchanged between gatherers and farmers in every period. By imposing a fixed amount of houses, the home swap allows us to avoid the explicit specification of the supply side of housing. Moreover, this specification reduces the number of equations in the final system and thus simplifies the calculation of steady state values.

6. Profits rebated to saver households by the real and banking sectors are respectively $\Theta_t = \int_0^1 \Theta_{z,t} dz$ and $\Pi_t = \int_0^1 \Pi_{j,t} dj$.

7. We assume in this model that savers who are also entrepreneurs use the housing units purchased by borrowers as an input in their production function.

8. For the sake of simplicity we will omit the expectations operator.

$$\frac{1}{c_t^s} - \lambda_t^s = 0 \tag{3}$$

- *Deposits*:

$$-\lambda_t^s + \beta E_t \frac{\lambda_{t+1}^s}{\pi_{t+1}} R_t^D = 0 \tag{4}$$

and replacing λ_t^s

$$\frac{1}{c_t^s} = \frac{\beta R_t^D}{\mathbb{E}_t \pi_{t+1} c_{t+1}^s} \tag{5}$$

Equation (5) is the relation between the marginal utility of current period consumption, next period consumption and the real interest rate. With respect to the standard consumption Euler condition, in (5) there is an additional cost defined as the opportunity cost of holding positive money balances, which is given by the foregone one-period deposit (bond) interest rate, R_t^D (R_t^B). In our model, therefore, savers are indifferent between holding bonds or deposits and the interest rates on these assets are equalised.

3.1.2. Borrower Households. Owning a house in our model serves a dual purpose; it provides the household housing services, and also allows household to own equity. Housing enters in this model both as a good but also as an asset which can be used as collateral to get loans in the credit market. This group of households is facing an additional borrowing constraint that limits the amount they can borrow to the expected market value of their housing holdings; home equity release scheme allows households to access their housing wealth for financing consumption and housing.

The representative borrower household's maximization problem then reads as:

$$\max_{c_t^b, H_t^b, l_t, N_t} U^b = E_0 \sum_{t=0}^{\infty} \breve{\beta}^t \left[\log c_t^b + \chi_H \log H_t^b - \frac{(N_t)^{1+\varsigma}}{1+\varsigma} \right] \tag{6}$$

where the discount factor is $\breve{\beta} \in (0,1)$ and $\breve{\beta} < \beta$ indicating that borrowers are also more impatient than savers. H^b denotes services from the fixed stock of residential goods (housing services), with a weight coefficient $\chi_H > 0$; N denotes labour supplied by borrower households to the goods sector, and $\varsigma > 0$ is the labour disutility parameter and it is equal to the inverse of the (Frisch) elasticity of labour supply with respect to the real wage. The superscript b denotes consumers who are subject to borrowing constraints.

This household maximizes the above utility function subject to the following constraints expressed in real terms (i.e. in units of consumption):

- *Resource constraint:*

$$c_t^b + q_t(H_t^b - H_{t-1}^b) + \frac{R_{t-1}^L l_{t-1}}{\pi_t} \leq l_t + w_t N_t - T \tag{7}$$

- *Borrowing constraint:*

$$l_t \leq \kappa_t \frac{\mathbb{E}_t\left(q_{t+1}\pi_{t+1}\right) H_t^b}{R_t^L} \tag{8}$$

In (7) among the resources there are wage earnings $w_t N_t$ from suppling labor to the goods sector with w_t denoting real wage and loans from the banking sector expressed in real terms, l_t, with R_{t-1}^L denoting the nominal interest rate on previous period borrowing. Finally, the last term on the right hand side of the resource constraint, T, denotes lump-sum tax payments to the government.

Following the 'collateral' channel of housing, our work aims at disentangling the important role of housing wealth in the households' decisions of consumption over the life-cycle. According to (8) in each period t borrower households cannot borrow from banks more than a fraction, κ_t, of the expected value of today's stock of housing which in real terms is equal to $E_t\left(q_{t+1}\pi_{t+1}\right) H_t^b$. The term $\kappa_t = \kappa(\frac{l_t}{l_{t-1}})^{-f_k}\xi_{k,t}$ depends on the Loan-to-Value (LTV) parameter κ and on the credit growth, $\frac{l_t}{l_{t-1}}$. We assume for the moment that $f_k = 0$ hence the LTV is a fixed parameter subject to a stochastic shock $\xi_{k,t}$.

This approach is a variant of the 'financial accelerator' model developed by Bernanke *et al.* (1999) where borrowing is procyclical with respect to the underlying business cycles which affect asset prices and therefore the value of the collateral. The collateral channel can work either by relaxing a credit constraint directly, by rising the loan to value ratio, or by providing equity that can be extracted at some point in the future, affecting individuals' consumption decisions. Among other things, the collateral channel can also amplify the effects of monetary policy in the economy (see Goodfriend and McCallum, 2007; Chadha *et al.*, 2014; Aoki *et al.*, 2004). As house prices affect the collateral value of houses, then real house price fluctuations have a considerable role in determining the access to credit lines (8).

We then differentiate (6) subject to constraints (7) and (8) and the efficiency conditions for borrower household are as follows:

- *Consumption:*

$$\frac{1}{c_t^b} - \lambda_t^b = 0 \tag{9}$$

- *Loans:*

$$\lambda_t^b - \frac{\breve{\beta} R_t^L \mathbb{E}_t \lambda_{t+1}^b}{\mathbb{E}_t \pi_{t+1}} = \nu_t \tag{10}$$

and replacing λ_t^b :

$$\frac{1}{c_t^b} - \frac{\breve{\beta} R_t^L}{\mathbb{E}_t c_{t+1}^b \pi_{t+1}} = \nu_t \tag{11}$$

where λ^b and ν are the Lagrange multipliers on the resource and the borrowing constraint, respectively; and in steady-state $\nu c^b = (1 - \breve{\beta} R^L)$. The model implies that house price movements have a mild effect on economic aggregates when borrowing constraints are slack. By contrast, when the constraints are binding, the interaction of house prices with borrowing and consumption decisions exert stronger effects in the economy. A binding collateral constraint, implying $\nu_t > 0$, has two main effects on household's decisions: *(i)* it prevents consumption smoothing by the borrower household (9); *(ii)* it increases the marginal value of housing as it is pledged as collateral (see below (13)).

- *Housing:*

$$\frac{\chi_H}{H_t^b} - \lambda_t^b q_t + \breve{\beta}\mathbb{E}_t q_{t+1}\lambda_{t+1}^b + \nu_t \frac{\kappa_t \mathbb{E}_t q_{t+1}\pi_{t+1}}{R_t^L} = 0 \tag{12}$$

Replacing λ_t^b from (9) the above relationship can be also rewritten as an indirect function of the house prices and we can thus study directly how asset prices interact with the consumption plans of borrowers:

$$\frac{q_t}{c_t^b} = \left[\frac{\chi_H}{H_t^b} + \frac{\breve{\beta}\mathbb{E}_t q_{t+1}}{\mathbb{E}_t c_{t+1}^b} + \nu_t \left(\frac{\kappa_t \mathbb{E}_t q_{t+1}\pi_{t+1}}{R_t^L}\right)\right] \xi_{q,t} \tag{13}$$

where $\xi_{q,t}$ is a non-fundamental shock to house prices.[9]

Equation (13) can be interpreted as a modified intertemporal Euler condition for residential goods. It states that the purchase of durable goods (housing) is partly an investment. In fact, (13) shows that the path of housing consumption is optimal when the marginal cost of acquiring one unit of housing is equal to its marginal utility. In (13) the third term in the squared brackets is linked to the shadow value of the collateral constraint (8) which depends on several model variables; the first variable is the loan-to-value ratio, κ_t, which is a measure of the flexibility of the credit market. The second variable is represented by the real expected house prices, $\mathbb{E}_t q_{t+1}$, which directly affects the ability of households to get loans by relaxing their collateral constraint. Consumption for borrower households is determined by their flow of funds (7).

- *Labor Supply:*

$$N_t^\varsigma c_t^b = w_t \tag{14}$$

The usual Euler condition (9) states that the utility foregone in sacrificing a unit of current consumption is equal to the expected marginal benefit of future additional consumption appropriately discounted. In addition, the collateral constraint implies that because the borrowing capacity, and therefore the

9. We assume that the house price shock evolves exogenously as follows:

$$\log \xi_{q,t} = \varphi_{\xi_q} \log \xi_{q,t-1} + u_{\xi_q,t}$$

where φ_{ξ_q} is the persistence of the shock, and the error term is i.i.d., with mean zero and variance σ_{ξ_q}.

availability of loans, is strictly tied to the real value of housing holdings we are also expecting a higher demand of housing.

3.2. Noisy House Prices, Borrowing Constraints and MPI

With a fixed supply of housing when house prices rise, especially in case of bubbles and overconfidence in future house prices, households will tend to borrow and spend more. The impact of an expected house price increase on current house price can be seen by rewriting relationship (13) as

$$\frac{q_t}{c_t^b} = \left[\frac{\chi_H}{H_t^b} + \frac{\breve{\beta}\mathbb{E}_t q_{t+1}}{\mathbb{E}_t c_{t+1}^b} + \underbrace{\frac{\nu_t}{H_t^b}\, l_t^D \left(\kappa_t, R_t^L, \mathbb{E}_t q_{t+1}\right)}_{\text{Binding Constraint}} \right] \xi_{q,t} \tag{15}$$

A cheaper and easier access to home equity credit lines will allow for additional borrowing to finance consumption ($l_t^D \uparrow$). The more intensive use of backing collateral will lead to reach the maximum amount of attainable credit, i.e. the constraint $l_t^D = \frac{\kappa_t \mathbb{E}_t q_{t+1}\pi_{t+1}}{R_t^L}$ will bind implying $\nu_t > 0$. This generates a further building up in house prices: this is shown in the left panel of Figure 4 as an upward shift in the demand for housing ($H_t^D \uparrow$). At the same time the right panel of Figure 4 shows that with a better collateral, the lending rate priced by the banking sector, R_t^L, will be lower leading to a further expansion of loans ($l_t^S \uparrow$). With a lower lending rate, R_t^L, there is a further possibility of expanding consumption by means of purchasing an additional unit of housing and increasing borrowing via the collateral constraint. As recalled above, these results occur because the borrowing constraints affect both intertemporal and within-period households' choices of lifetime consumption.

We now assume the introduction of a countercyclical LTV:

$$\kappa_t = \kappa \left(\frac{l_t}{l_{t-1}}\right)^{-f_k} \tag{16}$$

With an acceleration of lending activity, $l_t > l_{t-1}$, the LTV will be lowered and the borrowing constraint relaxed:

$$l_t \leq \underbrace{\kappa \left(\frac{l_t}{l_{t-1}}\right)^{-f_k}}_{\kappa_t \downarrow} \frac{\mathbb{E}_t \left(q_{t+1}\pi_{t+1}\right) H_t^b}{R_t^L} \tag{17}$$

A relaxation of the borrowing constraint implies that $\nu_t = 0$ in (15) so the introduction of a MPI can stabilise the current house price, q_t:

$$\downarrow \frac{q_t}{c_t^b} = \left[\frac{\chi_H}{H_t^b} + \frac{\breve{\beta}\mathbb{E}_t q_{t+1}}{\mathbb{E}_t c_{t+1}^b} \right] \xi_{q,t} \tag{18}$$

and so is lending and borrower's consumption. The stabilisation effect on borrowers' consumption is further mediated by the banking sector as the backing housing collateral is used less intensively and has a lower price leading to an increase in the lending rate, R_t^L. The attenuator effect of the MPI is shown in the right panel of Figure 4 as a backward shift of both the supply and demand of loans ($l_t^D \downarrow$ and $l_t^S \downarrow$). The relationship between the value of the backing collateral and the pricing of loans is further explored in the following section.

3.3. The Banking Sector

Banks collect deposits from savers and make loans to borrowers under monopolistic competition; this market power allows each individual bank to set its own interest rates on loans and deposits to maximize profits. In this section we outline the optimal lending and deposit rates and point to three parameters, the loan default rate, λ, the fraction of seizable collateral, δ, and the loan-to-value ratio, κ_t, that might be set to influence bank policy as part of a macroprudential framework. In our analysis of this model we will set these parameters to either a lax or restrictive level in order to understand the implications for monetary and fiscal policy.

3.3.1. Bank Profit Maximization. The representative bank j seeks to maximize profits:

$$\max \ E_t \sum_{s=0}^{\infty} \Lambda_{t+s} \Pi_{j,t+s} \tag{19}$$

where $\Pi_{j,t+s}$ denotes real profits and the nominal discount rate $\Lambda_{t+s} = \beta^s \left(\frac{C_t}{C_{t+s}} \right)$ comes from the saver households' maximization problem. The coincidence of discount factors comes from the assumption that households (saver households) are the ultimate owner of banks and their profits. Banks collect deposits from savers and make loans to borrowers under monopolistic competition; this market power allows each individual bank to set its own interest rates on loans and deposits to maximize profits.

Bank's profits, Π_j, expressed in real terms read:

$$\Pi_{j,t} = \int_{\overline{\omega}_t}^{\infty} \delta \omega_t \kappa_t q_t H_t^b \varphi(\omega_t) d\omega_t + \int_0^{\overline{\omega}_t} l_{j,t} R_{j,t}^L \varphi(\omega_t) d\omega_t - R_{j,t}^D d_{j,t} + R_t^M rr_{j,t} \tag{20}$$

where the first term indicates that when the borrower fails to repay the loan, bank recovers a fraction, δ, of the outstanding debt by the collateralised part of the housing value $\kappa_t q_t H_t^b$, while in the absence of default, bank's profit is equal to the expected operating income $\int_0^{\overline{\omega}_t} l_{j,t} R_{j,t}^L \varphi(\omega_t) d\omega_t - R_{j,t}^D d_{j,t}$, where $R_{j,t}^L$ and $R_{j,t}^D$ are respectively the loan and deposit rates.

The representative bank maximizes the expected flow of profits subject to the ex-ante real budget constraint:

$$rr_{j,t} + l_{j,t} = d_{j,t} \tag{21}$$

where $rr_{j,t}$ denotes high powered money (reserves) on which the Central Bank pays an interest rate equal to the policy rate, R_t^M , and since we assume a fractional reserves system then $rr_{j,t} = rrd_{j,t}$ where rr is the reserve requirement coefficient.

In the profit function $\varphi(\omega_t)$ is the probability density function of the idiosyncratic shock on the Loan-to-Value (LTV) or, equivalently, on house prices while δ is the fraction of collateral $\kappa_t q_t H_t$ seized by the bank in case of borrower's insolvency (Bernanke et al., 1999). Borrowers who default on their loan lose their housing holdings. By denoting with $\overline{\omega}_t$ the cutoff value of the idiosyncratic shock for which banks can potentially recover at mark-to-market the original value of the credit, the shortfall on the LTV reads as:

$$\overline{\omega}_t = \frac{l_{j,t}}{\delta \kappa_t q_t H_t^b} \tag{22}$$

Assuming an exponential distribution of the probability function for ω_t, what we observe is that with positive housing price shock (i.e. higher household's equity) the loan to value ratio will be in the 'safe' region; the loan relative to the mark-to-market value of the house falls short of - or is equal to - the initial cutoff value, so the expected loss given default is equal to what it was at origination and is correspondingly already priced in the lending rate by the bank. Whilst, with negative realizations of the house price shock (i.e. lower household's equity) the loan to value will lie in the 'default' region; the loan relative to the mark-to-market value of the house exceeds the cutoff value, then there is a potentially higher default effect on expected profits which should be priced in the optimal lending rate, R^L, by the bank (ex-post risk pricing).

Therefore, with high realizations of the idiosyncratic shock on house price loans are covered by the current market value of the collateral ($\omega_t \in [0, \overline{\omega}_t)$), with low realizations of the shock there is a potential shortfall risk on the LTV at the origination ($\omega_t \in [\overline{\omega}_t, \infty]$). Following Aiyagari (1994), we might think of the cutoff value as a housing-related version of the "ad hoc borrowing limit": over a critical amount, borrowing is no longer coherent with the optimal consumption decision of households (i.e. it is not feasible for the borrowers to repay their debt). A slack collateral constraint, on the other hand, links the cutoff value to the concept of "natural borrowing limit" by the same author.

Optimal Loan Rate. Deposit and loan contracts bought by households are a composite basket of slightly differentiated products, loans and deposits, each supplied by a branch of a bank j with elasticities of substitution equal to μ_L and μ_D respectively.[10]

10. Thus as in a standard Dixit-Stiglitz framework for goods markets, agents have to purchase loan (deposit) contracts by each banking intermediary in order to borrow (save) one unit of resources.

Given the assumption that banking intermediaries operate in a regime of monopolistic competition, each bank faces an upward sloping demand curve for deposits and a downward sloping demand for loans, as we will show below. This market power allows each individual bank to set its own interest rates on loans and deposits to maximize profits. As in Gerali *et al.* (2010), we assume that the individual bank j that operates in an environment that is characterized by banker-customer relationships faces the following demand for lending from households:

$$l_{j,t} = \left(\frac{R^L_{j,t}}{R^L_t}\right)^{-\mu_L} l_t \tag{23}$$

where $\mu_L > 1$ represents the interest rate elasticity of loan demand, $R^L_{j,t}$ is the interest rate on the loan $l_{j,t}$ provided by bank j, and l_t is the aggregate demand for loans. According to (23) we assume that banks provide differentiated loans as they act under monopolistic competition. Following Carletti *et al.* (2007), we interpret the parameter μ_L as the household's willingness to modify the customer relationship with the bank in the event of a change in loan rates. The higher is μ_L the weaker become the ties between the bank j and the customers, that is the market power measured by $1/\mu_L$ decreases; and for values of μ_L approaching infinity the loan market resembles perfect competition.

By replacing $rr_{j,t}$ using the resource constraint (21) bank's profits can be rewritten as follows:

$$\Pi_{j,t}=\int_{\overline{\omega}_t}^{\infty} \delta\omega_t\kappa_t q_t H^b_t\varphi(\omega_t)d\omega_t+\int_0^{\overline{\omega}_t} l_{j,t}R^L_{j,t}\varphi(\omega_t)d\omega_t - R^D_{j,t}d_{j,t}+R^M_t\left(d_{j,t}-l_{j,t}\right) \tag{24}$$

By maximizing the expected flow of profits (24) subject to (23) we get the optimal loan rate:

$$R^L_{j,t}=\frac{\mu_L}{(\mu_L-1)}\frac{1}{\int_0^{\overline{\omega}_t}\varphi(\omega_t)d\omega_t}R^M_t \tag{25}$$

By assuming that the probability function for ω_t has an exponential distribution[11] $\varphi(\omega_t) = \lambda e^{-\lambda\omega_t}$ we can write (25) in a more compact form as follows:

$$R^L_{j,t} = X_{\mu_L} R^M_t \underbrace{e^{\lambda\overline{\omega}_t}}_{\text{risk premium}} \tag{26}$$

This assumption allows to capture the existence of market power in the banking industry. In fact, leveraged households would allocate their borrowing among different banks so as to minimize the due total repayment. Saver households would allocate their savings in form of deposits among different banks so as to maximise the revenues.

11. The cumulative function reads as $\Phi(\omega_t) = \int_{\overline{\omega}_t}^{\infty}\lambda e^{-\lambda\omega_t}d\omega_t = 1-e^{-\lambda\overline{\omega}_t}$ so the probability of a loan repayment which is at the denominator of (25) is simply its complement $1-\Phi(\omega_t) = \int_0^{\overline{\omega}_t}\lambda e^{-\lambda\omega_t}d\omega_t = e^{-\lambda\overline{\omega}_t}$ where λ is the short-fall risk that is $\lambda = \frac{\varphi(.)}{1-\Phi(.)} = \frac{\lambda e^{-\lambda\omega}}{e^{-\lambda\omega}}$.

Note that the optimal loan rate, $R^L_{j,t}$, is given by a constant mark-up $X_{\mu_L} = \frac{\mu_L}{(\mu_L - 1)}$ over the policy rate R^M_t plus a risk premium $e^{\lambda \overline{\omega}_t}$ where where λ is the short-fall rate.

After imposing a symmetric equilibrium, log-linearising and using the definition of the shortfall risk in (22), we could write (26) as:

$$\hat{R}^L_t = \hat{R}^M_t + \lambda \frac{l}{\delta \kappa q H} \left[\hat{l}_t - \left(\hat{\kappa}_t + \hat{q}_t + \widehat{H}^b_t \right) \right] \tag{27}$$

Since the spread between $\hat{R}^L_t$ and $\hat{R}^M_t$ is the external finance premium efp_t, we can clearly see how the premium depends on the short-fall risk and the cutoff value for solvency of loans, which tells us if borrowers' debt is dangerous or not [12]. According to (27) a fall in leveraging, that is a decrease in the level of households' liability to asset ratio, leads to an increase in the probability of repayment thus reducing the lending rate; and such a fall depends on the coefficient λ. We can note immediately that this default rate, λ, the fraction of seizable collateral, δ, and the loan-to-value ratio, $\hat{\kappa}_t$, will each impact on the elasticity of the loan rate to the state of the economy.

The result in (27) introduces a 'financial accelerator' in monetary policy as lending will expand when the collateral value increases. In nominal terms, an increase in the house price as well as an increase in the fraction of the residential good that can be used as a collateral, raises the value of households' collateralized net worth relative to their stock of outstanding loans. The implication is that banks are willing to accept a lower risk premium, thus reducing the lending rate. The collateralized wealth could also act as a strict quantity constraint on bank borrowing, as for instance in the model of Kiyotaki and Moore (1997) and its variants where shocks to credit-constrained firms would then be amplified through changes in collateral values and transmitted to output.

Optimal Deposit Rate. In a similar way followed by Gerali *et al.* (2010), we also assume that the bank j faces the following demand for deposits:

$$d_{j,t} = \left(\frac{R^D_{j,t}}{R^D_t} \right)^{\mu_D} d_t \tag{28}$$

where $d_{j,t}$ is the demand for bank j deposits, d_t is the economy-wide demand for deposits, R^D_t is the average deposit interest rate prevailing in the market, taken as given by the single bank when solving the problem and μ_D is elasticity of substitution among deposit varieties. Banks exploit their market power to lower their marginal cost (deposit interest rates) in order to increase profits and μ_D is a measure of the existing competition in the banking sector; the degree of competition in the banking sector is measured by the inverse of μ_D.

12. From (27) we can see that $\hat{R}^L_t - \hat{R}^M_t = efp_t = F\left(\lambda, \frac{l_t}{\delta \kappa_t q_t H^b_t}\right)$.

By maximizing the flow of profits (24) with respect R^D subject to (28) we get the optimal deposit rate:

$$R^D_{j,t} = X_{\mu_D} R^M_t \tag{29}$$

where $X_{\mu_D} = \frac{(1+\mu_D)}{\mu_D}$. With fully flexible deposit rates, the cost of deposits depends on the elasticity of substitution among deposit varieties, μ_D, and the optimal deposit rate R^D_t would be determined as a mark-down, $\frac{1}{X_{\mu_D}}$, over the policy rate, R^M_t. The policy rate is therefore given by a constant mark-up over the deposit rate:

$$R^M_t = \left(X_{\mu_D}\right)^{-1} R^D_{j,t}. \tag{30}$$

This implies that the bank views households' deposits and reserves as perfect substitutes at the margin so the spread between the policy rate and the cost of deposits only depends on the elasticity of substitution among deposit varieties. The latter condition implies that money market credits and deposits are assumed to be perfect substitutes so that the deposit rate is then assumed to equal the policy rate, at least in log-linear form, and are therefore exogenous for the bank.

3.4. The Real Sector

3.4.1. Final Good Producers. In a perfectly competitive market, each firm producing final good uses a continuum of intermediate goods indexed by $z \in [0, 1]$ according to the following CES technology:

$$Y_t = \left(\int_0^1 Y_{z,t}^{\frac{\psi-1}{\psi}} dz \right)^{\frac{\psi}{\psi-1}} \tag{31}$$

where $Y_{z,t}$ is the demand by the final good producer of the intermediated good z, and $\psi > 1$ is the elasticity of substitution between differentiated varieties of intermediate goods.

Profit maximization implies a downward sloping demand function for the typical intermediate good z:

$$Y^d_{z,t} = \left(\frac{P_{z,t}}{P_t} \right)^{-\psi} Y_t \tag{32}$$

where $P_{z,t}$ denotes the price of the intermediate good, $Y_{z,t}$, and P_t is the price index of final consumption goods which is equal to:

$$P_t = \left(\int_0^1 P_{z,t}^{1-\psi} dz \right)^{\frac{1}{1-\psi}} \tag{33}$$

where the price index (33) is consistent with the maximization problem[13] of the final good producer earning zero profits and subject to the production function (31).

3.4.2. Intermediate Goods Producers. There is a continuum of firms producing intermediate goods. Each firm has a monopolistic power in the production of its own good variety and therefore has a leverage in setting prices. The representative monopolistic firm, z, will choose a sequence of prices and labour inputs $\{N_{z,t},\ P_{z,t}\}$ to maximize expected discounted profits:

$$\max\ \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t+s} \Theta_{z,t+s} \tag{34}$$

where $\Lambda_{t+s} = \beta^s \left(\frac{C_{t+s}}{C_t}\right)^{-1} \left(\frac{P_t}{P_{t+s}}\right)$ is the relevant creditor household discount factor and Θ denotes profits.

A Cobb-Douglas-type production function is adopted with decreasing return on labour which the only variable input, and with a fixed input represented by an endowment of wealth, H:

$$Y_{z,t} = A_t \left(N_{z,t}\right)^{1-\gamma} \left(H_{z,t-1}\right)^{\gamma} \tag{35}$$

where $0 < \gamma < 1$ is a measure of decreasing returns, $N_{z,t}$ denote firm's z demand of labor, and A_t is the productivity shock that is assumed to be common to all firms and evolves exogenously over time.[14]

The intratemporal demand function for good z is given by:

$$Y_{z,t}^{d} = \left(\frac{P_{z,t}}{P_t}\right)^{-\psi} Y_t \tag{36}$$

where ψ is the price elasticity of demand for individual goods faced by each monopolist and P is the general price level. Therefore, $\frac{P_{z,t}}{P_t}$ is the relative price of good variety z.

3.4.3. Inflation dynamics. As it is standard in the New Keynesian literature, we assume Calvo staggered nominal price adjustment[15]. We assume that intermediate firms set nominal prices in a staggered fashion, according to a stochastic time

13. Hence the problem of the final good producer is: max $P_{i,t}Y_{i,t} - \int_0^1 P_{i,t}(z)Y_{i,t}(z)$ subject to the demand function (32).

14. We assume that the productivity shock evolves exogenously as follows:

$$\log A_t = \varphi_a \log A_{t-1} + u_{a,t}$$

where φ_a is the persistence of the productivity innovation, and the error term is i.i.d., with mean zero and variance σ_a.

15. The section follows Matveev and Pfeifer (2017).

dependent rule. The sale price can be changed in every period only with probability $1-\theta$, independently of the time elapsed since the last adjustment.

Let $\Xi_t \subset [0,1]$ be the set of firms that keep the price of period t. Assuming that all the firms resetting the price will choose an identical price P_t^* and using the definition of aggregate price level we have

$$P_t = \left[\int_{\Xi_t} \left(P_{z,t-1}\right)^{1-\psi} dz + (1-\theta)\left(P_t^*\right)^{1-\psi}\right]^{\frac{1}{1-\psi}} = \left[\theta\left(P_{t-1}\right)^{1-\psi} + (1-\theta)\left(P_t^*\right)^{1-\psi}\right]^{\frac{1}{1-\psi}} \tag{37}$$

where the second equality simply states that the distribution of prices for non-adjusting firms in period t coincides with the one in period $t-1$ but with total mass reduced to θ.

Divinding both sides by $(P_t)^{1-\psi}$, the aggregate price level dynamic equation therefore is:

$$1 = \theta\pi_t^{\psi-1} + (1-\theta)\left(\pi_t^*\right)^{1-\psi} \tag{38}$$

where $\pi_t^* = \frac{P_t^*}{P_t}$ is the optimal reset price.

Since we choose to operate in a non-linear framework, we solve the model using a non-linear version of the Phillips curve: to do so we need to have explicit price dispersion (S_t) and optimal reset price equations in our model. Price dispersion evolves as follows:

$$S_t = (1-\theta)\left(\pi_t^*\right)^{-\frac{\psi}{1-\gamma}} + \theta\pi_t^{\frac{\psi}{1-\gamma}} S_{t-1} \tag{39}$$

while optimal price dispersion is

$$\left(\pi_t^*\right)^{1+\frac{\psi\gamma}{1-\gamma}} AUX_{2,t} = \xi_{mc,t}\frac{\psi}{\psi-1}AUX_{1,t} \tag{40}$$

where

$$AUX_{1,t} = \frac{Y_t MC_t}{c_t^s} + \beta\theta\mathbb{E}_t\pi_{t+1}^{\frac{\psi}{1-\gamma}} AUX_{1,t+1} \tag{41}$$

and

$$AUX_{2,t} = \frac{Y_t}{c_t^s} + \beta\theta\mathbb{E}_t\pi_{t+1}^{\psi-1} AUX_{2,t+1} \tag{42}$$

are two auxiliary variables and $\xi_{mc,t}$ is a cost-push shock[16]. Given the consumer' demand schedule (36) and taking wages as given, the cost minimization implies the following demand for labor:

16. We assume that the mark-up shock evolves exogenously as follows:

$$\log\xi_{mc,t} = \varphi_{\xi_{mc}}\log\xi_{mc,t-1} + u_{\xi_{mc},t}$$

where $\varphi_{\xi_{mc}}$ is the persistence of the shock, and the error term is i.i.d., with mean zero and variance $\sigma_{\xi_{mc}}$.

$$w_t = \frac{MPL_t}{X_{\psi,t}} = \frac{1}{X_{\psi,t}} (1-\gamma) A_t (N_t)^{-\gamma} (H_{z,t-1})^{\gamma} = (1-\gamma) MC_t \frac{Y_t}{N_t} \tag{43}$$

where $w_t = \frac{W_t}{P_t}$ is the real wage and $X_{\psi,t}$ is the markup (or the inverse of the real marginal cost, $MC_t = 1/X_{\psi,t}$) which in steady state is $X_\psi \equiv \frac{\psi}{\psi-1}$ and $MPL_t \equiv (1-\gamma) A_t (N_t)^{-\gamma} (H_{z,t-1})^{\gamma}$ is the marginal product of labor. Expanding (43) to $t+s$ we can include S_t in it as follows

$$MC_t = \frac{w_t}{(1-\gamma) A_t N_t^{-\gamma} H_t^{\gamma} S_t^{\gamma}} = \frac{w_t}{(1-\gamma)\frac{Y_t}{N_t} S_t} \tag{44}$$

The complete derivation of equations (39) to (44) is provided in the Appendix.

3.5. The Fiscal Rule

The government's budget constraint expressed in real terms is

$$b_t = \frac{R_{t-1}^B b_{t-1}}{\pi_t} + (g_t - tax_t) \tag{45}$$

where g_t is real net government spending (i.e., net of lump-sum taxes), b_t is the real value of one-period government liabilities issued at the end of period $t-1$ and with maturity in t, $\frac{R_{t-1}^B B_{t-1}}{\pi_t}$ denotes real debt service on existing government debt and $tax_t \equiv \tau_y Y_t + T$ are total tax revenues from income taxes $\tau_y Y_t$ plus lump-sum tax payments of borrowers to the government. We also assume a feedback rule on government spending:

$$g_t = g \left(\frac{Y_t}{Y}\right)^{-f_y} \left(\frac{tax_t}{tax}\right)^{f_T} \xi_{g,t} \tag{46}$$

f_T is a government spending feedback parameter[17] from tax revenues, f_y is the government spending parameter feedback on output. We are considering some feedback rules for fiscal policy which apply to government spending over the cycle $g_t = F(f_y,\, f_T)$. The term $\xi_{g,t}$ is a government spending shock.[18]

17. The parameters f_T , f_y and τ_y are set to zero in the benchmark impulse response analysis. We then choose optimally these parameter values when performing the welfare analysis.

18. We assume that the government spending shock evolves exogenously as follows:

$$\log \xi_{g,t} = \varphi_{\xi_g} \log \xi_{g,t-1} + u_{\xi_g,t}$$

where φ_{ξ_g} is the persistence of the shock, and the error term is i.i.d., with mean zero and variance σ_{ξ_g}.

3.6. Monetary Policy Rule

The model is closed by the Central Bank's reaction function. The Central bank is assumed to set the nominal interest rate according to a simple interest rate rule:

$$R_t^M = (R_{t-1}^M)^{\rho} \left[\frac{1}{\beta \mathsf{X}_{\mu D}} \left(\frac{\pi_t}{\pi} \right)^{\alpha_\pi} \left(\frac{Y_t}{Y_t^n} \right)^{\alpha_y} \right]^{1-\rho} \xi_{m,t} \tag{47}$$

where R^M is the (net) policy rate and ρ captures the degree of interest rate smoothing, while α_π and α_y are the central bank's reaction coefficients with respect to expected consumer price index (CPI) and the deviations of output from the natural level while $\xi_{m,t}$ denotes the monetary policy shock[19]. $\frac{1}{\beta \mathsf{X}_{\mu D}}$ is the steady state value of the policy rate. We define $\frac{Y_t}{Y_t^n}$ as the output gap[20] where Y^n is the natural (or potential) level of output, the one that would prevail in the economic system if prices were completely flexible. In the flexible prices' scenario, the stickiness in the Phillips Curve is $\theta = 0$ and all the variables converge to their natural level (denoted by the n superscript from now on). In this setting, the pricing first order condition collapses to

$$P_{z,t}^n = \frac{\psi}{\psi - 1} P_t^n MC_t^n = P_t^n \tag{48}$$

so when all firms can undertake optimal price setting with probability 1 (i.e $\theta = 0$), each of them sets its own period-t price as a constant mark-up over current nominal marginal costs. Given that marginal costs are constant over firms, they will also choose the same price P_t^n. As a consequence marginal costs in the flexible price scenario are always constant and equal to their steady state value

$$MC_t^n = \frac{\psi - 1}{\psi} = \frac{1}{X_\psi} = MC. \tag{49}$$

Given (49) and reminding that $S_t^n = 1$ (i.e. all the firms choose the same price) we can rewrite (44) to obtain the natural level of output

$$Y_t^n = \frac{X_\psi}{(1-\gamma)} w_t N_t = \frac{X_\psi}{(1-\gamma)} N_t^{1+\varsigma} c_t^b. \tag{50}$$

19. The monetary policy shock evolves as follows:

$$\log \xi_{m,t} = \varphi_{\xi_m} \log \xi_{m,t-1} + u_{\xi_m,t}$$

where φ_{ξ_m} is the persistence of the monetary policy innovation, and the error term is i.i.d., with mean zero and variance σ_{ξ_m}.

20. This section follows Nisticò (2012).

3.7. Macroprudential Rule

Among the three major macro-prudential policy tools (loan to value ratio, bank leverage ratio, tax tools to improve bank's net capital) we consider a countercyclical loan to value ratio policy of the form:

$$k_t = k \left(\frac{l_t}{l_{t-1}} \right)^{-f_k} \xi_{k,t} \tag{51}$$

where f_k is the macroprudential policy parameter that controls for credit volatility and can mitigate the negative impact of the real estate market shocks in the real economy. As one of the main tools for macro-prudential policy it not only has direct impact on the credit growth fluctuations, but also works as a very easy-to-understand tool as it clearly and accurately expresses the attitude of regulators towards credit risk.

3.8. Welfare Analysis

The aggregate welfare function depends on households' preferences over consumption, housing, labor, bonds[21] and public spending; the argument g_t represents government spending and is determined by the government in each period so that the representative consumer takes it as exogenously given. From (46) we know that public spending is a function of taxes and output, so the "social planner" wants to maximize consumption in order to provide the government with sufficient tax revenues to sustain the desired level of public expenditure. Thus social welfare is given by:[22]

$$W_t = U_t + \beta W_{t+1} \tag{52}$$

where

$$U_t = \frac{c^s}{Y} \left(\log c_t^s \right) + \frac{c^b}{Y} \left(\log c_t^b + \chi_H \log H_t^b - \frac{(N_t)^{1+\varsigma}}{1+\varsigma} \right) + \frac{g}{Y} \left(\log g_t \right) \tag{53}$$

where we attach weight coefficients equal to the steady state value of consumption over output, $\frac{c^s}{Y}$ and $\frac{c^b}{Y}$, and government spending over output, $\frac{g}{Y}$.

As shown in the Appendix the above welfare function can be also expressed in terms of aggregate welfare losses using the following purely quadratic loss function:

21. We assume that households' utility function is separable in consumption, labor, housing and bond holdings, which implies that all the cross-derivatives are zero.

22. Here we introduce a welfare function which is fairly standard in the literature (Schmitt-Grohé and Uribe, 2004, and Quint and Rabanal, 2014). The main difference in our framework stems from the introduction of government consumption.

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (U_t - U) = -\frac{1}{2} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t L_t + t.i.p + \mathcal{O}\left(\|a\|^3 \right) \tag{54}$$

$$\text{with } L_t = \varphi_Y \sigma_Y^2 + \varphi_{c^s} \sigma_{c^s}^2 + \varphi_{c^b} \sigma_{c^b}^2 + \varphi_g \sigma_g^2 + \varphi_{H^b} \sigma_{H^b}^2 + \varphi_\pi \sigma_\pi^2$$

where the hatted variable is the log-deviation from steady state, $\mathcal{O}\left(\|a\|^3 \right)$ collects all the terms of third order or higher, and "$t.i.p.$" denotes terms independent of policy. The weight coefficients are given by $\varphi_Y \equiv \frac{\varsigma+\gamma}{1-\gamma}$, $\varphi_{c^s} \equiv \frac{c^s}{Y}$, $\varphi_{c^b} \equiv \frac{c^b}{Y}$, $\varphi_{H^b} \equiv \frac{c^b}{Y} \chi_H$, $\varphi_g \equiv \frac{g}{Y}$and $\varphi_\pi \equiv \frac{\psi}{\eta}$ with $\eta \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\gamma}{1+\gamma(\psi-1)}$ and the welfare loss is given by a linear combination of the variances of output, inflation, consumption levels, housing and government bond holdings.

We can also easily derive the welfare for savers and borrowers:

$$W_t^s = U_t^s + \beta W_{t+1}^s \tag{55}$$

with $U_t^s = \log c_t^s$

$$W_t^b = U_t^b + \beta W_{t+1}^b \tag{56}$$

with $U_t^b = \log c_t^b + \chi_H log H_t^b - \frac{(N_t)^{1+\varsigma}}{1+\varsigma}$. The separate welfare functions will be useful to disentangle the effect of different policy rules on savers and borrowers (see Section 5.3 and 5.6).

4. Model Solution

4.1. Steady States

Table 1 reports the parameter values used to calibrate this model and the steady-state values. The saver households' intertemporal discount factor is set at the conventional (quarterly) value of $\beta = 0.99$. This implies a steady state real interest rate on (time) deposits of 4% in annual terms, as $(1/\beta)^4 = 1.04$. Empirical literature estimates intertemporal discount factors for poor households between 0.95 and 0.98 so we set the borrower intertemporal discount factor at $\breve{\beta} = 0.96$. Our calibration implies that borrowing constrained households using housing as collateral derive a higher per unit utility from housing services, so we set the housing parameter in the utility function $\chi_H = 0.1$. This value implies a steady-state ratio of total housing wealth to annualized GDP of 1.4. The corresponding ratio in U.S. data has ranged between 1.2 and 2.3 over the period 1952 to 2008, hence our steady state ratio is approximately an average of these values.[23] The

23. Data in the National Income and Product Accounts (NIPA) for U.S. are provided by the Bureau of Economic Analysis.

elasticity of substitution between varieties of nondurables, ψ, is set to 6 which yields a steady-state mark-up over the nominal costs of 20% in the real sector. We set the stickiness parameter for consumer prices, θ, equal to the standard value 0.667 which implies a mean duration of price contracts of three quarters. We also assume that house prices are flexible. We calibrate the loan-to-value ratio (LTV), κ, to 0.7. The inverse of the elasticity of labor supply, ς, is set equal to 1.01; and we set the parameter associated with the elasticity of output with respect to labor at 0.3 implying that γ is 0.7. The policy parameters are chosen as follows: we set the interest rate smoothing parameter, ρ, to 0.5, the size of the response to inflation, α_π, to 1.5, the response to output gap, α_y, to 0.5/4.

The steady-state[24] values of the endogenous variables as well as the value of the complex parameters are also reported in Table 1. Starting with the interest rates, note that the steady state is computed at zero inflation so that we can interpret all the interest rates as real interest rates. Calibrations give a policy rate, R^M, at 4.24%, a saving deposit rate, R^D, at 4.04% (equal to the bond rate, R^B) and a loan rate, R^L, at 5.52% per annum. For borrowing constrained households the consumption to output ratio, c^b/Y, is 0.54 (against a value for c^s/Y of 0.30 for savers). Finally, we set the steady state expected value of repayment of the leveraged households at 0.8 implying a value of λ, that is the default rate, of 1.25.

4.2. Going Non-Linear: Second Order Solution

The literature largely agrees on the fact that the financial crisis and its aftermath triggered nonlinear phenomena: interest rates hitting the Zero Lower Bound (Fernández-Villaverde *et al.* 2015), rollover crisis in the shadow banking sector, and central banks' forward guidance policies are only few of them. The presence of borrowing (or lending) constraints for economic agents, which can be tuned to guarantee financial stabilization, is clearly another scenario that is worth considering from a non-linear point of view[25].

The model is solved using Dynare: the main algorithm computes a Taylor approximation of the decision and transition functions[26]. For the impulse response analysis and simulation exercise we consider the real and financial shocks described in Table 1, which reports the volatility and persistence parameters chosen for the calibration and simulation exercise. These are standard parameters in the literature.

For the analysis of the optimal rule in the next section we minimize the variance of the arguments in the representative household's loss function, L:

$$L = \varphi_Y \sigma_Y^2 + \varphi_C \sigma_C^2 + \varphi_{C^b} \sigma_{C^b}^2 + \varphi_G \sigma_G^2 + \varphi_H \sigma_H^2 + \varphi_\pi \sigma_\pi^2 \tag{57}$$

24. For details on the derivation of the steady-states see the Appendix.

25. Richter *et al.* (2019) for example show how LTV limit tightenings have larger economic effects than loosenings.

26. In section D.1 of the Appendix we provide the "pencil and paper" derivation of the second order approximation.

In the Appendix, this expression is shown to be an approximation of welfare loss and it is minimized subject to policy choice on macroprudential and/or fiscal policy such that $[f_y, f_T, \tau_y, f_k] = \arg\min L$. We decided to exclude monetary policy from the welfare analysis since we wanted to simulate the post-crisis situation, in which the stagnation of low interest rates deprived central banks of scope for conventional monetary policy maneuvers.

4.3. Going Non-Linear: Occasionally Binding Solution

We also consider an occasionally binding version of the model to fully explore the potential non-linearity arising from the model. Among the different methods in the literature we choose to implement the piecewise local perturbation solution by Guerrieri and Iacoviello (OCCBIN toolkit, 2015). The motivation is twofold: the toolkit is extremely rapid compared to the global perturbation methods and it is thought to run in the Dynare's code environment. For every occasionally binding constraint, the OCCBIN toolkit computes the log-linearised approximation around the steady state and allows the model to be in one of two different regimes: a slack regime or a binding regime. The solution builds on two assumptions: (i) Blanchard-Kahn's conditions for existence of a rational expectations solution hold in the initial regime (ii) the model must switch back to the initial regime in finite time when shocks occur, to guarantee convergence to the starting steady state values. The latter requirement clearly have some implications on the way agents anticipate and react to regime switching. When we implement the toolkit we are implicitly assuming that agents ignore the existence of two regimes and the possibility of switching between the two, but after the occurrence of the first switching they can predict the return to the initial regime and act consequently. We pay the price of this relatively strong assumption in exchange for the capability to capture a double non-linearity, arising from the switching mechanism itself and from the expected duration of the regime.

In the first experiment we only consider two possible regimes: in the reference regime the borrowing constraint binds (i.e. the relative Lagrangean multiplier is larger than zero), while in the alternative one the constraint is slack (i.e. the Lagrangean multiplier equals zero). As a consequence, the house price equation will be respectively

$$\frac{q_t}{c_t^b} = \left[\frac{\chi_H}{H_t^b} + \frac{\breve{\beta}\mathbb{E}_t q_{t+1}}{c_{t+1}^b} + \nu_t\left(\frac{\kappa_t \mathbb{E}_t q_{t+1}\pi_{t+1}}{R_t^L}\right)\right] \xi_{q,t} \tag{58}$$

in the binding regime and

$$\frac{q_t}{c_t^b} = \left[\frac{\chi_H}{H_t^b} + \frac{\breve{\beta}\mathbb{E}_t q_{t+1}}{c_{t+1}^b}\right] \xi_{q,t} \tag{59}$$

in the slack regime[27].

In the second experiment we also exclude the possibility for the policy rate to go below the Zero Lower Bound:

$$R_t^M = max\left[1, (R_{t-1}^M)^\rho \left(\frac{1}{\beta X_{\mu D}}\right)^{1-\rho} \left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi(1-\rho)} \left(\frac{Y_t}{Y_t^n}\right)^{\alpha_y(1-\rho)} \xi_{m,t}\right] \quad (60)$$

We therefore consider four possible regimes:

		ZLB	
		$R_t^M > 1$	$R_t^M = 1$
Borrowing	$\nu_t > 0$	regime 1	regime 2
constraint	$\nu_t = 0$	regime 3	regime 4

5. Dynamic Model Results

In this section we report the results of specific exercises designed to understand this model's properties. First, we examine the moments of the simulated model specifications in Table 3. Then in Figures 5 to 8, we show the impulse responses of the benchmark calibration model to a set of forcing variables used to drive this model: a shock in the loan to value ratio offered by commercial banks, a goods productivity shock, a canonical monetary policy shock to the interest rate rule, and an unanticipated shock to the house price [28]. The impulse response are drawn under a benchmark rule and under a coordinated MPI rule. We undertake a welfare analysis of the model under restrictive and lax regimes and finally we analyze the features of the non-linear estimated version.

5.1. Simulated model moments

The model can be solved for its moments to understand the basic relationships listed in the Appendix. Table 2 shows the coordinated policy parameters. Table 3 gives the relative standard deviation of key endogenous variables and their correlations with house price for the benchmark simulation, the coordinated rule simulation and US data. House prices are procyclical and noisy in this model and have a correlation of 0.67 with aggregate consumption. This relationship results to be well captured by the model, which gives correlation and relative standard deviation very similar to the data. The coordination between fiscal and macroprudential policies helps

27. We can easily predict that the effect of the house price shock would be smaller in the slack scenario.

28. The impulse responses to a cost-push shock and to a government spending shock are available on request.

to reduce both correlation and relative standard deviation of lending, aggregate consumption and borrowers' consumption.

5.2. Impulse responses

Figures 5 to 8 plot the responses of some key variables in this model to the forcing variables in each of two cases[29]. For the model under a benchmark monetary rule, which is indicated with blue lines, and for the coordinated rule indicated as a red line. Figure 5 shows a 1% negative shock to the loan to value ratio, a so-called collateral shock[30]. This shock can be interpreted as a tightening action of macroprudential policy. The lower is the loan to value ratio the lower is the marginal amount of new lending that can be accorded for a given value of the collateral (housing). The quantity of loans to borrower households then shrinks as housing demand lowers driving down the spread between the lending rate and the policy rate. Borrowers' consumption decreases as a result of decreased leverage and drives a temporary recessive period. But in this calibration the lending reduction is short lived and in later periods, borrowers are asking back for credit and gradually increasing the level of loans, which leads output back to the steady state. The savers reduce current consumption following the small increase in the saving deposit rate. Note that under the coordinated rule the reduction of lending is less and the drop of the EFP considerably weaker as the lower LTV means that there is less incentive to use houses as collateral. The magnitude of the negative effect on output (roughly 0.01%) is consistent with the local projection analysis by Richter *et al.* (2019), where a 1% reduction of maximum LTV ratio is associated with a 0.025% decrease of GDP after 3 quarters[31]. Figure 6 plots the response of this economy to a positive 1% shock in goods productivity. Wages and output rise and borrowers' consumption jumps up and remains persistent as loans are offered against a falling EFP following a decrease in the policy rate. Figure 7 plots the responses to a positive 1% shock in the policy rate. The reduction of inflation deteriorates the housing wealth of borrowers, which in turn lowers house prices and lending. Finally, leveraged households have to negatively reconsider their consumption and working plans, causing an output recession. Figure 8 shows that a positive and unanticipated 1% shock to house prices brings about a delayed boom as deposit rates fall and lending stimulates consumption. Note that initially the EFP reduces as the increase in the value of households' collateralized net worth relative

29. Note that given the second order approximation, the impulse responses are expressed as average percentage deviations from a baseline stochastic simulation of the model. They can be interpreted as Generalized IRFs at the ergodic mean.

30. This shock is conceptually similar to the "housing finance conditions" shock in Kaplan et al (2020b).

31. In Richter *et al.* (2019) the effect is even closer if only advanced countries are considered. Our model also reflects well the equivalence of the effect on output and consumption arising in their analysis.

to the stock of outstanding loans drives down the loan rate since the risk premium asked by lenders decreases. The reduction in the interest rate spread is weak and short-termed and then it starts increasing as demand for loans outstrips supply. In fact, the increase in house prices relaxes the credit constraint of the leveraged households, allowing them to borrow and consume more. The coordinated policy rule helps the central bank to limit the potential housing bubble: lending experiences half on the increase with respect to the benchmark case, which results in a weaker effect on real variables.

5.3. Central Bank Policies and Welfare Analysis

A model with an optimal fiscal rule has choices of the feedback from taxation receipts, output and money growth, set by parametric choice of minimization of the loss function. But note that fiscal policy acts on the tax and spends from the receipts of house purchases, and these purchases are the counterpart of bank lending in this model - recall that loans are used exclusively to finance borrower household consumption. Whereas a coordinated policy, by setting a countercyclical loan to value ratio, acts on the borrower household first by impacting on loans and the loan rate and so when the policy maker also reacts to the financial condition in the market, she is acting on the consumption plans of borrower whose optimal plans are directly affected by interest rates.

The occasionally binding version of the model gives us some intuitions about the potential non-linear dynamics that house price oscillations can determine. Figure 9 and 10 show the effect of series of very persistent shocks, which drives house price respectively 60% and 100% away from the steady state, in the base model and in the model including the Zero Lower Bound[32]. In both cases a positive shock leads the model in the slack regime: the value of the collateral dramatically increases and releases the debt conditions of borrowers. As described in section 3.2, in the slack regime the feedback effect between house prices and consumption is smaller with respect to the binding case (since $\nu_t = 0$). This mechanism drives the main non-linearity in the model: as shown in Figure 9, the Lagrangean hits zero in the positive shock scenario while varies in the binding one. In the baseline model, the asymmetry can be barely distinguished looking at aggregate consumption, but it is clear observing welfare. When we consider a Zero Lower Bound scenario, the overall effect on aggregate consumption is consistent with Guerrieri and Iacoviello (2015),

32. Since we want to give a readable intuition of the OCCBIN mechanism, we need to avoid too many switching between the binding and the slack regimes. To do so, we impose very strong and persistent shocks, keeping the Lagrangean multiplier of the borrowing constraint in the same regime for prolonged periods. Alternatively, we could rewrite the constraint incorporating a persistent inertia parameter to slow down the switching:

$$l_t \leq \gamma_k \frac{l_{t-1}}{\pi_t} + (1-\gamma_k)\frac{\mathbb{E}_t(q_{t+1}\pi_{t+1})H_t^b}{R_t^L}k_t \tag{61}$$

where the negative shock has roughly 2.5 times the effect of the positive one. In this case the effect on welfare is even stronger, suggesting how the presence of persistently low interest rates - mimicking a stagnating dynamics - exacerbates the loss in terms of utility of banks and households. Note also how the negative shock pushes the policy rate to the ZLB for most of the simulation: the central bank is forced to brutally reduce R_t^M to its bound in an attempt to stimulate the economy. In the figures we also compare two possible policy settings: in the former one there is no macroprudential rule ($f_k = 0$), in the latter the LTV feedback parameter is set to the optimal level. We can see how the macroprudential control over the loan-to-value ratio works reducing the asymmetry in the model, limiting the consumption losses in case of negative shocks. This evidence implies that higher macroprudential control over credit significantly reduces welfare losses when the model hits the ZLB, so that macroprudential policy acts as a substitute for unconventional monetary policy in this particular scenario. Macroprudential policy has also some redistributive power over welfare in the model. We run 10,000 periods simulations of the model for each of seven different values of the macroprudential parameter f_k[33], again discarding the first 500 observations and HP-filtering the series. Figure 11a shows how both correlation between savers and borrowers' consumption and correlation between savers and borrowers' welfare decrease as the macroprudential parameter increases. Moreover, in the second order approximation model, correlations start to stabilize beyond $f_k = 1$, which is close to the optimal value. The intuition is that the macroprudential stabilization in the model passes through the "de-anchoring" of borrowers and savers' utility paths. Finally, looking at the occasionally binding model, we can observe that by increasing the policy parameter we significantly reduce the periods spent in the binding regime (Figure 11b). This result suggests that higher macroprudential control over credit is associated on average with better debt conditions for borrowers (i.e. higher probability to be in the unconstrained regime).

5.4. Estimation

We finally try to estimate the piecewise linear solution of the model with Bayesian techniques, using the inversion filter as in Guerrieri and Iacoviello (2017). We use U.S. quarterly data from 1975 to 2011 to define total consumption, inflation, loans, house prices, worked hours and policy interest rate as described in the Appendix. In this exercise, we add to the computation some observation equations which link the data to the model. Given that the OCCBIN toolkit combines linear solutions of the different regimes, we can write the equations as

$$C_{obs,t} = \log \frac{c_t^s + c_t^b}{\frac{c^s + c^b}{Y}} \tag{62}$$

33. We reoptimize the fiscal parameters conditionally on the changing value of f_k.

$$\pi_{obs,t} = \log \frac{\pi_t}{\pi} \tag{63}$$

$$l_{obs,t} = \log \frac{l_t}{l} \tag{64}$$

$$q_{obs,t} = \log \frac{q_t}{q} \tag{65}$$

$$N_{obs,t} = \log \frac{N_t}{N} \tag{66}$$

$$R^M_{obs,t} = R^M_t - 1. \tag{67}$$

We estimate price stickiness, Taylor Rule's parameters and shock-related parameters using the prior means by Smets and Wouters (2007) and Iacoviello and Neri (2010). The prior distributions are standard in the literature and their choice follows in particular Guerrieri and Iacoviello (2017).

Table 4 reports the posterior mode, 90% probability intervals for the estimated parameters, together with the mean and standard deviation of the prior distributions. In the Appendix we provide the graphic representation of priors and posteriors. The posterior mode associated to the inertia of monetary policy is lower than our initial guess while the reaction to output gap is lower than expected and quite noisy. Both the results are coherent with the work by Guerrieri and Iacoviello (2017). The response to inflation also shows posterior values in line with previous literature. The stickiness of price is 0.57, implying that prices are re-optimized about half a year. Finally, all shocks but the monetary policy one are persistent, with autocorrelation coefficients ranging between 0.62 and 0.83.

5.5. Evaluating Policy Action under Uncertainty

In the current set-up, the Central Bank sets the policy rate to pursue the inflation target and it will be the Financial Policy Committee (FPC) that will have additional MPIs at its disposal to pursue financial stability. When it comes to MPIs, to the extent that we cannot be sure about the impact of an instrument, Brainard uncertainty introduces a trade-off between the achievement of the target and the minimisation of uncertainty induced by the use of an instrument. There are two problems in the case of MPIs: (i) there is likely to be considerably more uncertainty with a set of untried instruments (ii) since a countercyclical macroprudential policy is linked to other policies that moderate cyclical fluctuations – above all monetary policy, which also affects macroprudential variables as asset prices and credit - macroprudential policy is likely to influence the transmission mechanism of monetary policy. Ideally we want to think about which instruments may be used and how they might be used together in a manner that does not induce greater uncertainty into the operation of monetary policy. The use of MPIs may improve the trade-off in uncertainty-space available to policymakers, keeping inflation at tar To the extent that changing the constraints faced by financial intermediaries will alter the financial conditions, there may not only be an impact on the appropriate stance of monetary and fiscal policy but also an impact on the appropriate MPIs conditioned on the monetary policy stance. Consider a world in which the monetary policymaker wishes to smooth the response of consumption to a large negative shock to aggregate demand and reduces interest rates faced by collateral-constrained consumers. Simultaneously, financial stability may be considered to be threatened and various MPIs may be tightened, which would act against the interest rate changes made by the monetary policymaker and may need further or extended lower rates of interest rates. If, on the other hand, sufficient precautionary moves had been made by the FPC (and possibly the Fiscal Authorities) in advance there may be no immediate conflict (Chadha, 2016).

We calculate the welfare from a particular policy simulation of a model, M, with fixed structural parameters and shocks:

$$\mathbb{E}_0 \sum_{t=o}^{\infty} \beta^t \left(U_t - U\right) \mid M \approx -\frac{1}{2}\mathbb{E}_0 \sum_{t=o}^{\infty} \beta^t L_t + ... \tag{68}$$

So that we can evaluate the expected losses as some function of a policy function:

$$\Gamma\left(\text{policy}\right) \mid M = \Gamma\left(f_y, f_T, \tau_y, f_k\right) \tag{69}$$

where we can hold any given parameter constant. We can also seek to evaluate the optimal rule by seeking a solution to the following minimisation problem:

$$\Gamma\left(f_y, f_T, \tau_y, f_k\right) = \arg\min L(f_y, f_T, \tau_y, f_k) \mid M. \tag{70}$$

What we do not deal with is the possibility that the parameters within M are uncertain and so we may wish to assess the likely loss from uncertainty in the multiplicative parameter, e.g. the standard model we use takes the following form:

$$y = \gamma_1 + \gamma_2 r_t + \varepsilon_t \qquad \varepsilon_t \sim \left(0, \sigma_\varepsilon^2\right) \tag{71}$$

but we want to consider:

$$y = \gamma_1 + \hat{\gamma}_2 r_t + \varepsilon_t \qquad \varepsilon_t \sim \left(0, \sigma_\varepsilon^2\right) \quad \text{and} \quad \hat{\gamma}_2 \sim \left(\mu_\gamma, \sigma_\gamma^2\right) \tag{72}$$

Now clearly there are a number of possible uncertain parameters in our model. But if we look carefully at the endogenous pricing of the loan rate, it seems that λ the loan default rate parameter is key. As it determines the slope of the supply curve of bank loans and we can imagine that it might be flat (good times) or steep (bad times). In order to characterise the impact of the various rules under parameter uncertainty we follow the following steps:

1. We calculate the welfare loss for the benchmark model using a value of lambda in normal times i.e. $\mathbb{E}_0 L \mid M \cap \lambda^B = 1.05$ which corresponds to a 95% probability of getting paid back.
2. Now choose some range for lambda and some supporting distribution e.g. $\lambda \in [1, ..., 2]$ and suppose the median is 1.05 i.e. 95% probability of getting paid back and we have a diffuse prior with equal chances from 100% to 50% i.e. $1/0.5 = 2$.
3. We can calculate the losses under the Benchmark for each possible λ i.e. $\lambda_{i=1}^{n} [1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0]$.
4. We can then assess the mean absolute error across this lambda uncertainty relative to the certainty equivalent loss, $\mathbb{E}_0 L \mid M \cap \lambda^B$, where we know that $\lambda = 1.05$: $\frac{\left|\mathbb{E}_0 L | M \cap \lambda^i - \mathbb{E}_0 L | M \cap \lambda^B\right|}{n}$.
5. We can then assess how a coordinated or optimal rule for fiscal policy fares relative to a benchmark in the presence of parameter uncertainty. In Figure 12a we report the mean absolute error across this lambda uncertainty relative to the certainty equivalent loss and we show that a coordinated solution can minimise the overall losses within the economy. Finally, Figure 12b shows consumers' losses for the same λ support: borrowers experience the higher welfare gains in the coordinated policies' specification while savers are barely influenced by the rising perceived risk of insolvency.

6. Conclusions

In this paper, we develop a model with two types of households, ones that are savers and ones that face a borrowing constraint. The second type of households (borrowers) take on debt to finance their consumption. In this model banks have a specific role in pricing the loan rate for borrower households by setting the margin for lending rates as a spread over the deposit rates in proportion to the risk of default and the value of collateral posted. We examine the paths of individual household consumption as a way of decomposing a standard representative agent model. Credit availability plays a key role in amplifying the cycle. As the countercyclical operation of lending spreads, access to credit pushes borrower consumption up but the requirement for debt repayments pulls consumption back again. And a complementary cycle emerges for savers. So a deeper and more persistent business cycle emerges endogenously from this model.

Overall household (borrower and saver) welfare is shown not necessarily to be maximised solely under a standard interest rate rule. In fact, stabilising inflation and output with a jointly determined macroprudential and fiscal policy responses seem preferable, as macroprudential policy (MPI) reduces the asymmetric effects of large changes in house prices. We analyse the aggregate welfare of households when some form of macroprudential policy also operates, which limits the lending, capital returns and perceived default rate of loans, and these produce lower losses for the representative household. In particular we show that with MPI there are welfare gains especially for borrowers as house prices are better stabilised and less correlated with consumption. Moreover, MPI reduces the asymmetric response of households to housing-related shocks and acts as a substitute for unconventional monetary policy, reducing the losses when the central bank is constrained by the zero lower bound. It seems that some augmentation of policy to include an additional role for macroprudential policy may improve welfare even in the case of uncertainty over some of the parameters governing banking decision, such as the loan default rate. Two tentative normative points emerge from this analysis. First, there may be more scope for countercyclical fiscal and macroprudential policy to stabilize the economy than we thought when models were unable to speak about intermediation. Secondly, when banks do not fully price default risk, the policy frontier deteriorates and this would imply there is a an ongoing need to calibrate macroprudential and fiscal policies.

Parameter	Description	Value	Parameter	Description	Value
Preference Parameters and Collateral			*Baseline Model Shocks*		
β	Inter. discount rate for savers	0.99	φ_κ	AR(1) of the collateral shock	0.95
$\breve{\beta}$	Inter. discount rate for borrowers	0.96	φ_{ξ_q}	AR(1) of house price shock	0.45
χ_H	Housing weight for borrowers	0.1	φ_a	AR(1) of productivity shock	0.70
ς	Labour supply aversion	1.01	φ_{ξ_m}	AR(1) of monetary policy shock	0.10
κ	Loan-to-Value	0.7	φ_{ξ_g}	AR(1) of fiscal policy shock	0.70
δ	Fraction of seizable collateral	1	$\varphi_{\xi_{mc}}$	AR(1) of the cost-push shock	0.92
Sticky Prices			σ_κ	Std. of the loan to value shock	0.01
ψ	Elasticity of subs. between goods	6	σ_{ξ_q}	Std. of house price shock	0.01
X_ψ	Price markup	1.2	σ_{ξ_a}	Std. of productivity shock	0.01
θ	Sticky prices adjustment	0.667	σ_{ξ_m}	Std. of monetary policy shock	0.01
			σ_{ξ_g}	Std. of the fiscal policy shock	0.01
Technology			$\sigma_{\xi_{mc}}$	Std. of the cost-push shock	0.01
γ	Decreasing returns to labor	0.7			
			IMPLIED STEADY STATES		
Loans, Deposits and Fractional Reserves			*Banking Sector*		
X_{μ_D}	Markup down of deposit rate	0.95	$R^D \times 4$	Deposit rate	4.04%
X_{μ_L}	Markup on loan rate	1.01	$R^M \times 4$	Policy rate	4.24%
rr	Fractional reserve coefficient	0.005	$R^L \times 4$	Loan rate	5.52%
λ	Default rate	1.25			
			Public Sector		
Savers			$R^B \times 4$	Bond rate	4.04%
c^s/Y	Consumption to output ratio	0.3			
			Borrowers		
Fiscal Policy			c^b/Y	Consumption to output ratio	54%
g/Y	Government spending to output	0.16	wN/Y	Income to output	24%
Monetary Policy					
ρ	Degree of interest rate smoothing	0.5			
α_π	CB reaction to exp. inflation	1.5			
α_y	CB reaction to output gap	0.5/4			

Table 1. Calibrated parameters

Notes: Calibrated parameters used to solve the model at second order approximation using Dynare. The calibration for shocks' parameters is taken from Chadha *et al.* (2014).

	Government Spending		Tax	MPI
	f_Y	f_T	τ_Y	f_k
Benchmark	0	0	0	0
Coordinated MPI	0.45	3.32	2.19	2.04

Table 2. Optimal Policy Parameters

Notes: The parameters on the second line are in order: the government spending feedback parameter from output, the government spending feedback parameter from tax revenues, the lump-sum tax parameter and the macroprudential policy parameter. They minimize welfare losses for the model solved at second order approximation. For the optimization we use the non-linear optimizer *csminwel* by Chris Sims, which uses a quasi-Newton method with BFGS update of the estimated inverse hessian.

	Benchmark		Coordinated MPI		US Data	
	Rel std (q)	Corr (q)	Rel std (q)	Corr (q)	Rel std (q)	Corr (q)
C	0.46	0.67	0.27	0.46	0.35	0.66
c^s	0.77	-0.45	0.78	-0.47		
c^b	0.84	0.79	0.65	0.61		
l	0.73	0.75	0.49	0.59	0.95	0.54
R^L	0.16	-0.44	0.21	-0.64	0.12	-0.07
efp	0.34	-0.51	0.30	-0.47	0.05	-0.26
π	0.75	0.42	0.77	0.51	4.39	0.38

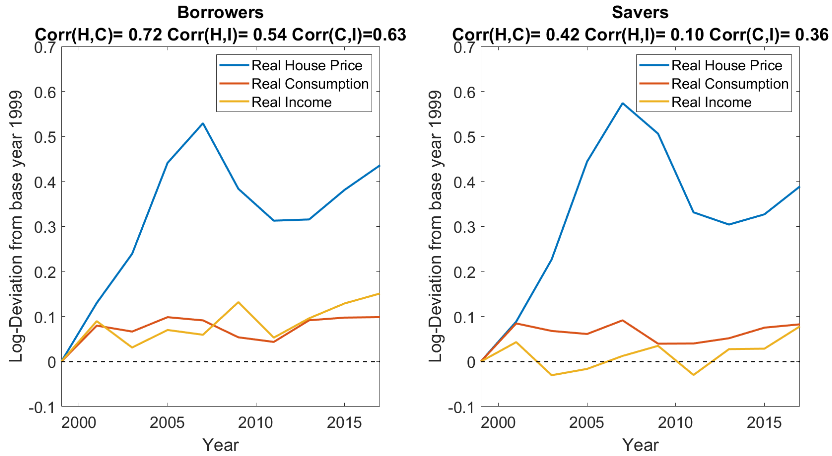
Table 3. Moments

Notes: The table reports approximate theoretical moments and correlations for two specifications of the model and real moments and correlations for US data. The first two columns show relative standard deviation (i.e. standard deviation of each variable in the first column divided by the standard deviation of house price) and correlations for the benchmark model. Third and fourth columns show relative standard deviation and correlations for the model where the parameters are optimized as in Table 2. All variables are in logs to make them comparable with data. Fifth and sixth columns show relative standard deviations and correlations taken from U.S. data (Federal Reserve Bank of St. Louis). R^L is derived from the Average 30-Year Fixed Mortgage Rate. efp is computed as the difference between R^L and the Effective Federal Funds Rate. All the series but the interest rates are normalized relative to 1975Q1, then log-transformed, and lastly detrended by series-specific one-sided HP filters, with a smoothing parameter set to 100,000.

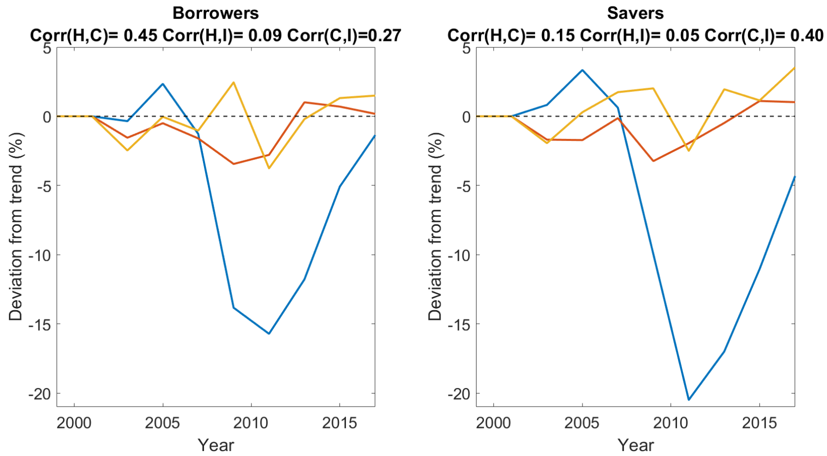
Parameter	Description	Prior Distribution	Prior mean	Prior STD	Post. mode	90% HPD interval	
ρ	Degree of int. rate smoothing	beta	0.75	0.10	0.58	0.55	0.63
α_y	Reaction to output gap	beta	0.125	0.10	0.03	0.01	0.07
α_π	Reaction to expected inflation	normal	1.5	0.10	1.53	1.31	1.65
θ	Calvo parameter	beta	0.667	0.10	0.58	0.54	0.60
φ_k	AR(1) of collateral shock	beta	0.80	0.10	0.82	0.80	0.88
$\varphi_{\xi q}$	AR(1) of house price shock	beta	0.80	0.10	0.73	0.68	0.76
φ_a	AR(1) of productivity shock	beta	0.80	0.10	0.64	0.61	0.66
$\varphi_{\xi m}$	AR(1) of monetary policy shock	beta	0.20	0.10	0.34	0.30	0.41
$\varphi_{\xi g}$	AR(1) of fiscal policy shock	beta	0.80	0.10	0.63	0.57	0.66
$\varphi_{\xi mc}$	AR(1) of cost-push shock	beta	0.80	0.10	0.83	0.69	0.91
σ_k	Std. of collateral shock	invgamma	0.01	0.10	0.0292	0.0252	0.0329
$\sigma_{\xi q}$	Std. of house price shock	invgamma	0.01	0.10	0.0746	0.0656	0.0848
σ_a	Std. of productivity shock	invgamma	0.01	0.10	0.5087	0.4437	0.5818
$\sigma_{\xi m}$	Std. of monetary policy shock	invgamma	0.01	0.10	0.0116	0.0108	0.0145
$\sigma_{\xi g}$	Std. of fiscal policy shock	invgamma	0.01	0.10	0.0019	0.0017	0.0021
$\sigma_{\xi mc}$	Std. of cost-push shock	invgamma	0.01	0.10	0.0062	0.0054	0.0068

Table 4. Estimated Parameters

Notes: The table reports priors (type of distribution, mean and standard deviation) and posteriors (mode and 90% probability intervals) for the parameters estimated by the model with occasionally binding collateral constraint and ZLB. Since the OCCBIN routine consider combination of linear solutions, we use different values of the optimal policy parameters, obtained with a linear optimizer (osr command in Dynare): $f_Y = 0.5608$, $f_T = 0.1094$, $\tau_Y = 0.1576$ and $f_k = 0.7823$. We use US data from 1975Q1 to 2011Q4. More details about the data and the estimation are provided in the Appendix.



(a) Not detrended series



(b) Detrended Series

Figure 1. House Price, Consumption and Income Correlations in US micro data

Notes: The figure shows correlations between house price, consumption and income for savers and borrowers using micro US data (Panel Study of Income Dynamics, PSID). All the series are obtained mean-collapsing by wave the panel family-level observations. The computation includes longitudinal weights taking into account the extension of the survey to immigrant respondents, and it is robust to the use of time-invariant family weights. All the series are in real terms. In the two bottom panels the series are detrended using one-sided HP filters, with a smoothing parameter set to 100. The series for house price is obtained by the question concerning the self-estimated present house value, and it consistent with the FRED house price series (over 90% correlation). The series for income comes from the question on total family money income. The series for consumption aggregates total family expenditures for food, utilities, transports, education and health. Respondents are divided into savers and borrowers depending on their answer to the question "Do you have a mortgage on this property?".

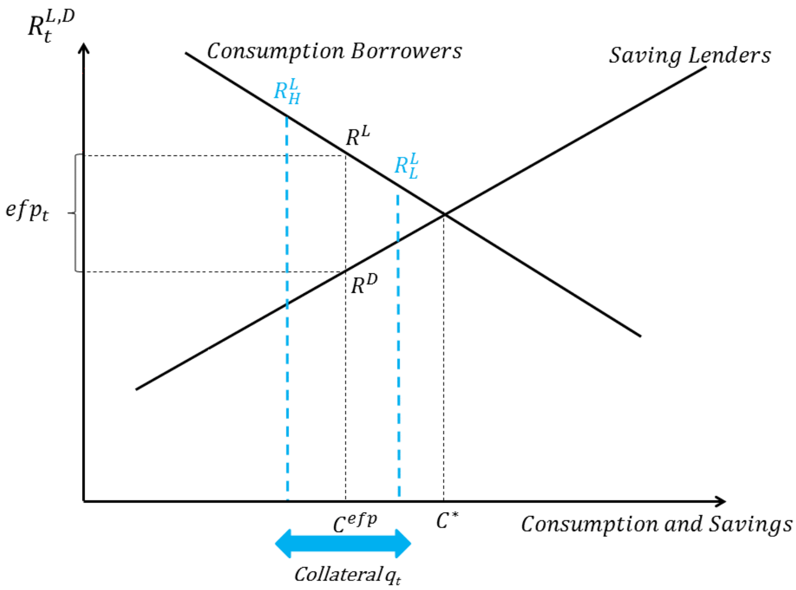


Figure 2: Negative Correlation between Consumption of Savers and Borrowers

Notes: The figure shows how the presence of the external finance premium exacerbates the negative correlation of different households' behavior. The noisy collateral induces volatility of both the lending rate and borrower's consumption.

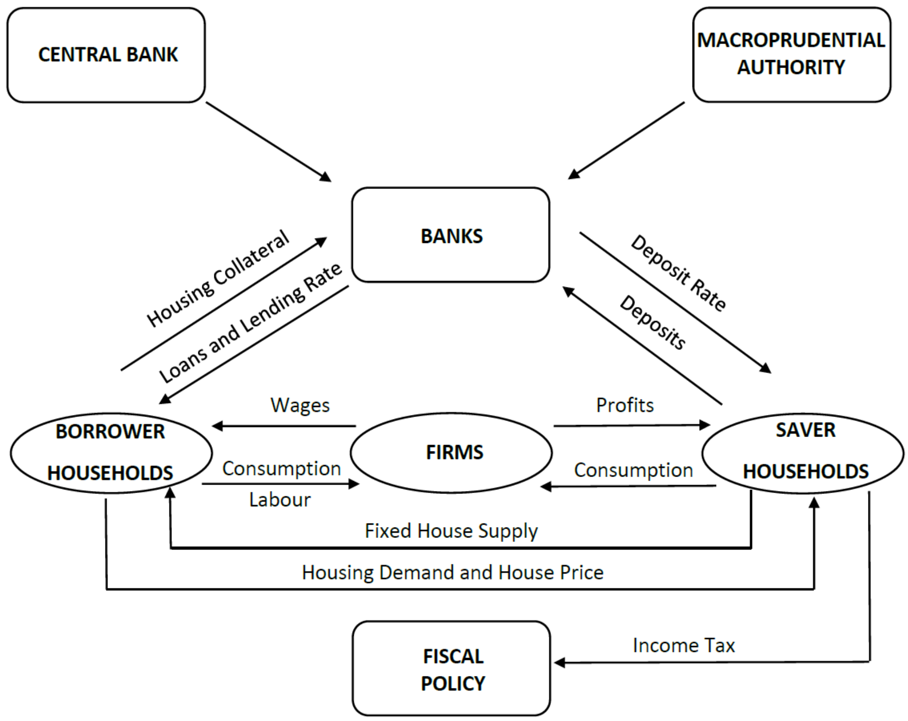


Figure 3: The Model

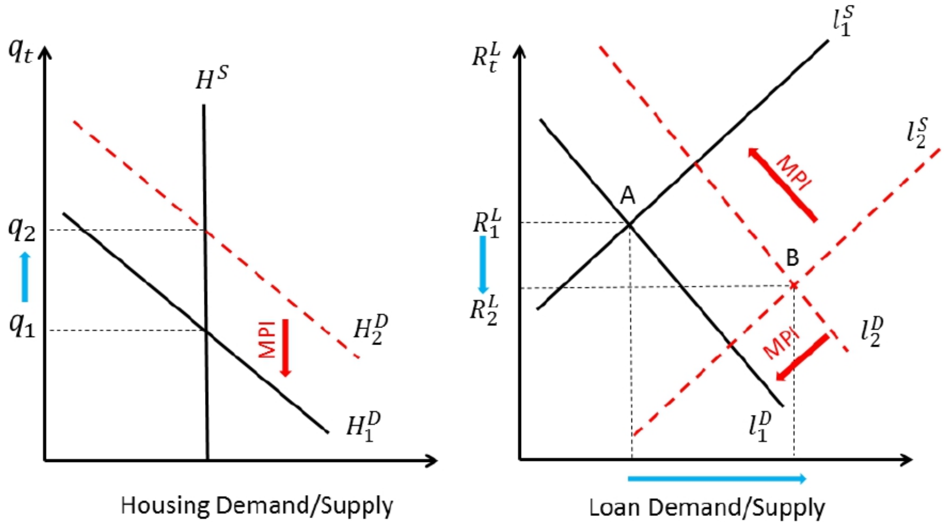


Figure 4: Noisy House Price, Borrowing Constraint and MPI.

Notes: The figure shows how a better collateral expands lending and consumption by increasing the demand for houses (red dotted lines). The role of macroprudential policy in both the housing and the loan market is expressed by the red arrows. Tightening the loan-to-value ratio, the macroprudential authority shrinks the demand for housing services of borrowers. As a consequence, borrowers are not able to sustain the same amount of lending and the demand for loans reduces.

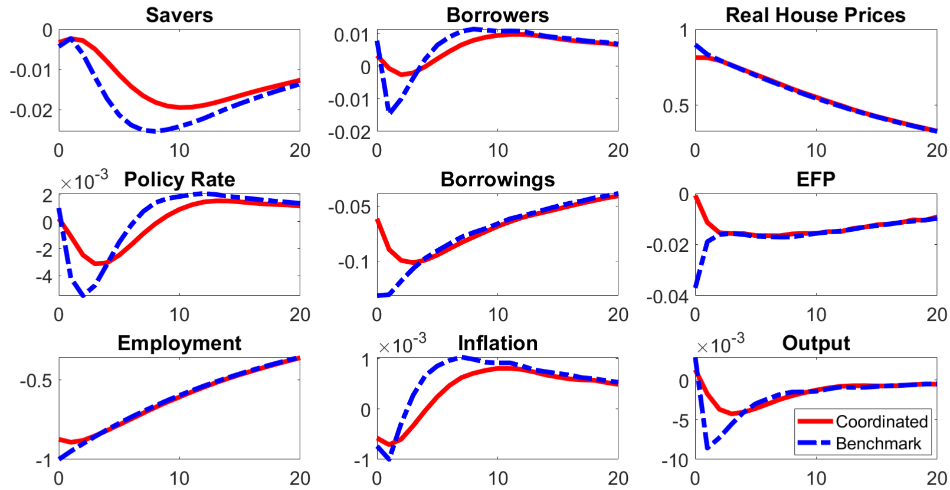


Figure 5: Negative Collateral Shock.

Notes: The graph shows the response to a 1% decrease in the allowed loan-to-value for borrowers, which corresponds to a tightening action of macroprudential policy. All the IRFs are expressed as average percentage deviations from a baseline stochastic simulation where we draw a series of random shocks for 120 periods. We average over the effect of idiosyncratic shocks other than the one we are interested in by performing 50 replications of previous operations and reporting the average. Initial 100 warming periods are dropped. The units for the horizontal axes are quarters. The blue dotted line reports the response of the model under the benchmark specification. The red line reports the response of the model under the coordinated MPI rule.

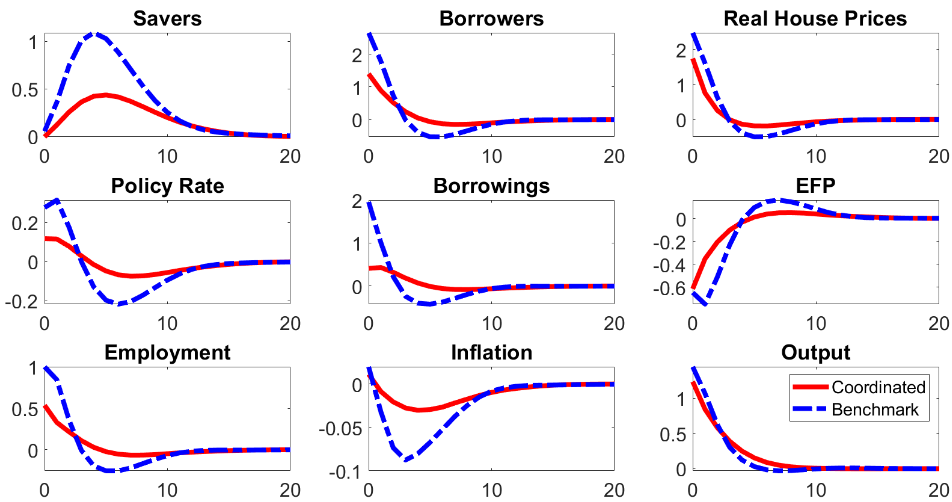


Figure 6: Productivity Shock.

Notes: The graph shows the response to a 1% increase in productivity. All the IRFs are expressed as average percentage deviations from a baseline stochastic simulation where we draw a series of random shocks for 120 periods. We average over the effect of idiosyncratic shocks other than the one we are interested in by performing 50 replications of previous operations and reporting the average. Initial 100 warming periods are dropped. The units for the horizontal axes are quarters. The blue dotted line reports the response of the model under the benchmark specification. The red line reports the response of the model under the coordinated MPI rule.

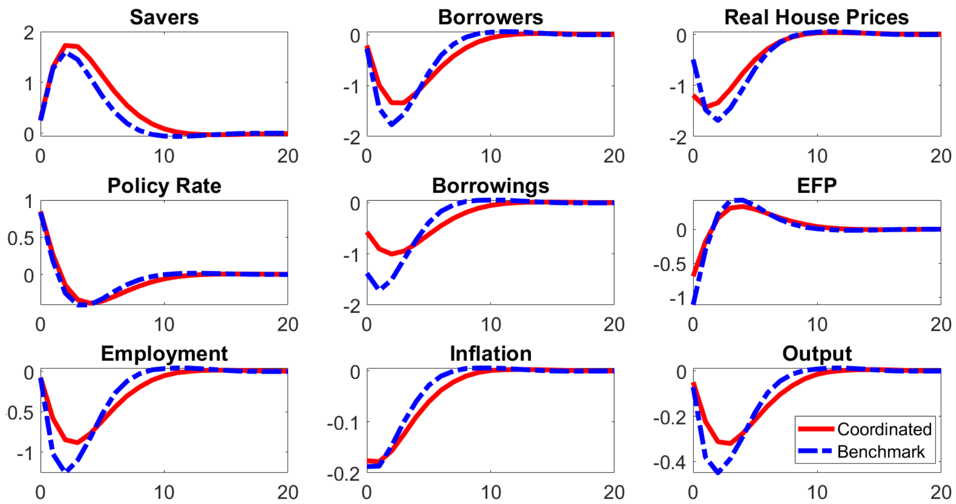


Figure 7: Monetary Shock.

Notes: The graph shows the response to a 1% shock in the policy rate. All the IRFs are expressed as average percentage deviations from a baseline stochastic simulation where we draw a series of random shocks for 120 periods. We average over the effect of idiosyncratic shocks other than the one we are interested in by performing 50 replications of previous operations and reporting the average. Initial 100 warming periods are dropped. The units for the horizontal axes are quarters. The blue dotted line reports the response of the model under the benchmark specification. The red line reports the response of the model under the coordinated MPI rule.

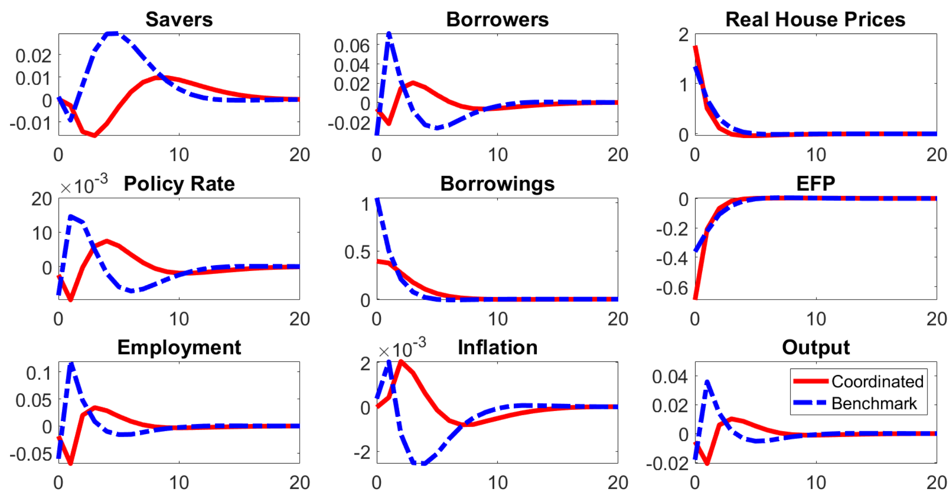


Figure 8: House Price Shock.

Notes: The graph shows the response to a positive 1% non-fundamental house price shock. In our model, this shock is qualitatively equivalent to a 1% change in housing preferences of borrowers. All the IRFs are expressed as average percentage deviations from a baseline stochastic simulation where we draw a series of random shocks for 120 periods. We average over the effect of idiosyncratic shocks other than the one we are interested in by performing 50 replications of previous operations and reporting the average. Initial 100 warming periods are dropped. The units for the horizontal axes are quarters. The blue dotted line reports the response of the model under the benchmark specification. The red line reports the response of the model under the coordinated MPI rule.

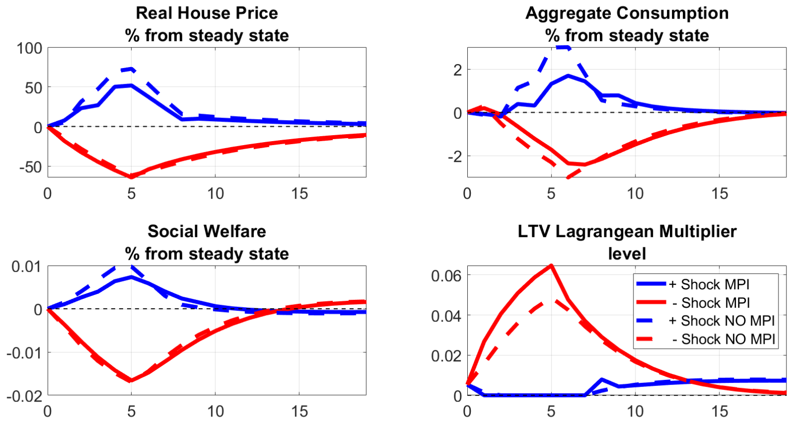
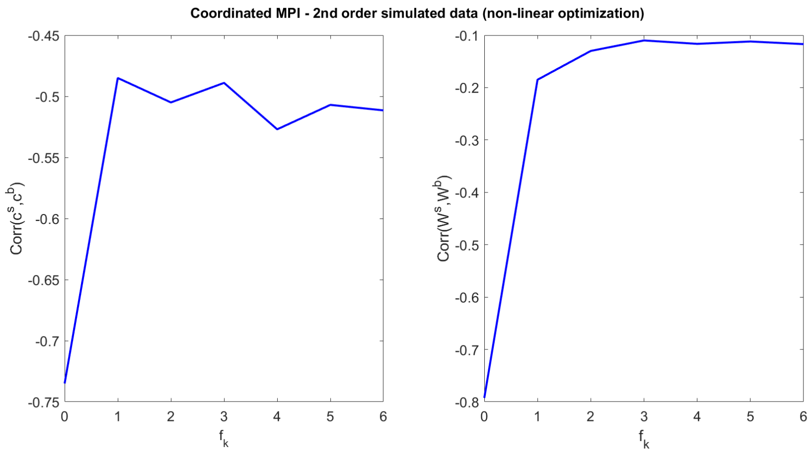


Figure 9: House Price Shock in the occasionally binding model.

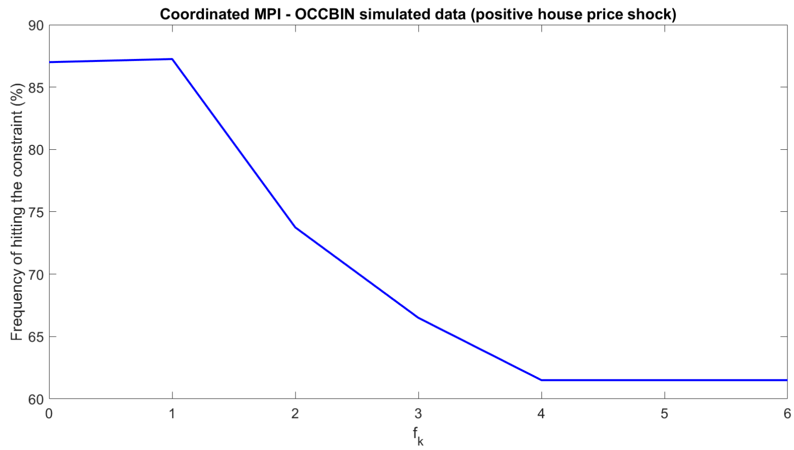
Notes: Impulse responses to positive and negative housing demand shocks in the occasionally binding model without ZLB. The simulation shows the dynamic responses to sequence of housing demand shocks of equal size but opposite sign that move house prices up (blue lines) and down (red lines) by 60% relative to the steady state. Dotted lines report responses when $f_k = 0$, while full lines report responses when $f_k = 0.7823$, as result of the optimal routine. The units for the horizontal axes are quarters.

Figure 10: House Price Shock in the occasionally binding model with ZLB.

Notes: Impulse responses to positive and negative housing demand shocks in the occasionally binding model with ZLB. The simulation shows the dynamic responses to sequence of housing demand shocks of equal size but opposite sign that move house prices up (blue lines) and down (red lines) by 100% relative to the steady state. Dotted lines report responses when $f_k = 0$, while full lines report responses when $f_k = 0.7823$, as result of the optimal routine. The units for the horizontal axes are quarters.



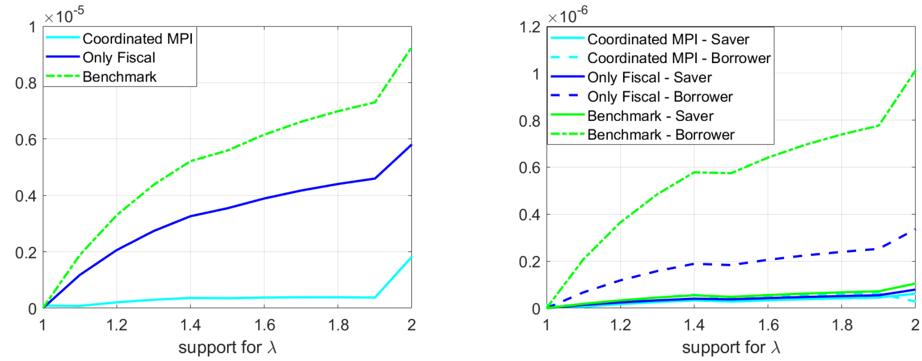
(a) Consumption and Welfare



(b) Frequency of periods in the binding regime (%)

Figure 11. The power of the MPI parameter in different model specifications.

Notes: Graph (a) shows the relationship between the intensity of the macroprudential policy parameter and the correlation between households consumption and welfare. We simulated 10,000 data points (discarding the first 500 observations and HP filtering the data) from the second-order model for 7 different values of f_k, reoptimizing the fiscal parameters conditionally on its changing value. Graph (b) shows the relationship between the intensity of the macroprudential policy parameter and the frequency of hitting the collateral constraint (i.e. $\nu_t > 0$). We simulated 10,000 data points (discarding the first 500 observations and HP filtering the data) from an occasionally binding version of the model where only positive shocks can occur for 7 different values of f_k, reoptimizing the fiscal parameters conditionally on its changing value. The frequency is calculated dividing the number of periods in which the Lagrangean is different from zero by the total number of simulated periods.



(a) Total Welfare Loss

(b) Consumer Welfare Loss

Figure 12. Mean Absolute Error with respect to Certainty Equivalent Loss (%).

Notes: Loss of various rules under uncertainty over λ compared to the certainty equivalent loss. The mean absolute error is computed as the mean of the differences between the welfare loss for each possible value of λ and the welfare loss in a benchmark case where loans have a 95 % probability of getting paid back. In this exercise we also include a specification where the fiscal parameters are active and the macroprudential parameter is set to 0. As expected this regime performs better than the benchmark case and worse than the coordinated rule case.

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Appendix A: List of Steady-State Equations

$$A = 1$$
$$H = 1$$
$$S = 1$$

$$\pi = \pi^* = 1$$
$$R^B = R^D = \frac{1}{\beta}$$
$$R^M = \frac{1}{\mathsf{X}_{\mu D} R^D}$$
$$\overline{\omega} = \frac{l}{\delta H q l t v} = 1$$
$$R^L = \mathsf{X}_{\mu L} R^M e^{\lambda \overline{\omega}}$$
$$MC = \frac{\psi - 1}{\psi} = \frac{1}{X_\psi}$$
$$N = \left[\frac{(1-\gamma) MC}{1 - \frac{c^s}{Y} - \frac{g}{Y}} \right]^{\frac{1}{1+\varsigma}}$$
$$Y = A \left(\frac{N}{S} \right)^{1-\gamma} H^\gamma$$

$$AUX_1 = \frac{YMC}{c^s \left(1 - \beta\theta\pi^{\frac{\psi}{1-\gamma}}\right)}$$
$$AUX_2 = \frac{Y}{c^s \left(1 - \beta\theta\pi^{\psi - 1}\right)}$$
$$c^b = Y - c^s - g$$
$$w = N^\varsigma c^b$$
$$v = \frac{(1 - \tilde{\beta} R^L)}{c^b}$$
$$q = c^b \frac{\chi_H}{H} \left[1 - \tilde{\beta} - (1 - \tilde{\beta} R^L) \frac{k}{R^L} \right]^{-1}$$
$$l = \frac{kqH}{R^L}$$
$$T = \frac{(wN + kqH - c^b)(1 - R^L)}{R^L}$$
$$d = \frac{l}{(1 - rr)}$$
$$b = \frac{g - (\tau_y Y + T)}{1 - R^D}$$

where $X_{\mu_L} \equiv \frac{\mu_L}{(\mu_L - 1)}$ is the loan interest rate markup, $1/X_{\mu_D} = \frac{1+\mu_D}{\mu_D}$ denotes the policy rate markup and X_ψ is the price markup.

Appendix B: The Complete Model

The model can be reduced to the following system in which all the variables without subscript denote steady-state values:

B.1. Saver Household

- Consumption Demand:

$$\frac{1}{c_t^s} = \frac{\beta R_t^D}{E_t \pi_{t+1} c_{t+1}^s} \tag{B.1}$$

B.2. Borrower Household

- Budget Constraint:

$$c_t^b + q_t\left(H_t^b - H_{t-1}^b\right) + \frac{R_{t-1}^L l_{t-1}}{\pi_t} = l_t + w_t N_t - T \tag{B.2}$$

- Housing Demand:

$$\frac{q_t}{c_t^b} = \left[\frac{\chi_H}{H_t^b} + \frac{\breve{\beta}\mathbb{E}_t q_{t+1}}{\mathbb{E}_t c_{t+1}^b} + \nu_t\left(\frac{\kappa_t \mathbb{E}_t q_{t+1}\pi_{t+1}}{R_t^L}\right)\right]\xi_{q,t} \tag{B.3}$$

where $\nu_t = \frac{1}{c_t^b} - \frac{\breve{\beta}R_t^L}{c_{t+1}^b \pi_{t+1}}$ and $\xi_{q,t}$ denotes a non-fundamental shock to house prices.[34]

- Loan Demand from Leveraged Households:

$$l_t = k_t \frac{\mathbb{E}_t\left(q_{t+1}\pi_{t+1}\right)H_t^b}{R_t^L} \tag{B.4}$$

- Labor Supply:

$$N_t^\varsigma c_t^b = w_t \tag{B.5}$$

B.3. The Banking Sector

- Loan Rate:

$$R_t^L = X_{\mu L} R_t^M e^{\lambda\bar{\omega}_t} \tag{B.6}$$

where $\bar{\omega}_t = \frac{l_t}{\delta k_t q_t H_t^b}$.

- Deposit Rate:

$$R_t^D = X_{\mu D} R_t^M \tag{B.7}$$

B.4. The Real Sector

- Price Dynamics (to synthetize a non-linear Phillips Curve):

34. We assume that the house price shock evolves exogenously as follows:

$$\log\xi_{q,t} = \varphi_{\xi_q}\log\xi_{q,t-1} + u_{\xi_q,t}$$

where φ_{ξ_q} is the persistence of the shock, and the error term is i.i.d., with mean zero and variance σ_{ξ_q}.

$$1 = \theta \pi_t^{\psi-1} + (1-\theta)\left(\pi_t^*\right)^{1-\psi} \tag{B.8}$$

$$\left(\pi_t^*\right)^{1+\frac{\psi\gamma}{1-\gamma}} AUX_{2,t} = \xi_{mc,t} \frac{\psi}{\psi-1} AUX_{1,t}{}^{35} \tag{B.9}$$

$$S_t = (1-\theta)\left(\pi_t^*\right)^{-\frac{\psi}{1-\gamma}} + \theta \pi_t^{\frac{\psi}{1-\gamma}} S_{t-1} \tag{B.10}$$

$$AUX_{1,t} = \frac{Y_t MC_t}{c_t^s} + \beta\theta \mathbb{E}_t \pi_{t+1}^{\frac{\psi}{1-\gamma}} AUX_{1,t+1} \tag{B.11}$$

$$AUX_{2,t} = \frac{Y_t}{c_t^s} + \beta\theta \mathbb{E}_t \pi_{t+1}^{\psi-1} AUX_{2,t+1} \tag{B.12}$$

- Output:

$$Y_t = A_t \left(\frac{N_t}{S_t}\right)^{1-\gamma} H_{t-1}^{\gamma} \tag{B.13}$$

- Labor Demand (derived from the marginal cost equation including S_t):

$$w_t = \frac{MC_t Y_t S_t}{N_t} \tag{B.14}$$

B.5. Monetary Policy

$$R_t^M = (R_{t-1}^M)^{\rho} \left[\frac{1}{\beta X_{\mu D}} \left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_t^n}\right)^{\alpha_y}\right]^{1-\rho} \xi_{m,t} \tag{B.15}$$

where

$$Y_t^n = \frac{X_\psi}{1-\gamma} N_t^{1+\varsigma} c_t^b \tag{B.16}$$

B.6. Fiscal Policy

- Government's budget constraint:

$$b_t = \frac{R_{t-1}^B b_{t-1}}{\pi_t} + (g_t - tax_t) \tag{B.17}$$

where taxation is

$$tax_t = \tau_y Y_t + T \tag{B.18}$$

and the feedback rule on government spending is:

35. We assume that the mark-up shock evolves exogenously as follows:

$$\log \xi_{mc,t} = \varphi_{\xi_{mc}} \log \xi_{mc,t-1} + u_{\xi_{mc},t}$$

where $\varphi_{\xi_{mc}}$ is the persistence of the shock, and the error term is i.i.d., with mean zero and variance $\sigma_{\xi_{mc}}$.

$$g_t = g\left(\frac{Y_t}{Y}\right)^{-f_y}\left(\frac{tax_t}{tax}\right)^{f_T}\xi_{g,t} \tag{B.19}$$

B.7. MPI

$$k_t = k\left(\frac{l_t}{l_{t-1}}\right)^{-f_k}\xi_{k,t} \tag{B.20}$$

B.8. Market Clearing

$$d_t = \frac{l_t}{1-rr} \tag{B.21}$$

$$Y_t = c_t^s + c_t^b + g_t \tag{B.22}$$

$$H_t^b = 1 \tag{B.23}$$

Appendix C: Derivation of the Recursive Pricing Equation

Given the intratemporal demand function and the Cobb-Douglas-type production function, market clearing for labour can be written as:

$$N_t = \left(\frac{Y_t}{A_t}\right)^{\frac{1}{1-\gamma}} H_t^{-\frac{\gamma}{1-\gamma}} \int_0^1 \left(\frac{P_{z,t}}{P_t}\right)^{-\frac{\psi}{1-\gamma}} dz \tag{C.1}$$

and from this follows

$$Y_t = A_t\left(\frac{N_t}{S_t}\right)^{1-\gamma} H_t^{\gamma} \tag{C.2}$$

where

$$S_t = \int_0^1 \left(\frac{P_{z,t}}{P_t}\right)^{-\frac{\psi}{1-\gamma}} dz. \tag{C.3}$$

is the price dispersion equation which can be solved recursively as:

$$\begin{aligned}
S_t &= (1-\theta)\left(\frac{P_t^*}{P_t}\right)^{-\frac{\psi}{1-\gamma}} + \int_{S_z}\left(\frac{P_{z,t-1}}{P_t}\right)^{-\frac{\psi}{1-\gamma}} dz \\
&= (1-\theta)\left(\frac{P_t^*}{P_t}\right)^{-\frac{\psi}{1-\gamma}} + \int_{S_z}\left(\frac{P_{t-1}}{P_{t-1}}\frac{P_{z,t-1}}{P_t}\right)^{-\frac{\psi}{1-\gamma}} dz \\
&= (1-\theta)\left(\frac{P_t^*}{P_t}\right)^{-\frac{\psi}{1-\gamma}} + \Pi_t^{\frac{\psi}{1-\gamma}}\int_{S_z}\left(\frac{P_{z,t-1}}{P_{t-1}}\right)^{-\frac{\psi}{1-\gamma}} dz \\
&= (1-\theta)\left(\frac{P_t^*}{P_t}\right)^{-\frac{\psi}{1-\gamma}} + \theta\Pi_t^{\frac{\psi}{1-\gamma}} S_{t-1}
\end{aligned}$$

S_t enters in the demand function as follows:

$$A_{t+s}N_{t+s|t}^{1-\gamma}H_{t+s}^{\gamma} = Y_{t+s|t} = \left(\frac{P_t^*}{P_{t+s}}\right)^{-\psi} Y_{t+s} \tag{C.4}$$

$$N_{t+s|t} = \left[\left(\frac{P_t^*}{P_{t+s}}\right)^{-\psi} \frac{Y_{t+s}}{A_{t+s}} H_{t+s}^{-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{C.5}$$

$$\frac{N_{t+s|t}}{N_{t+s}} = \frac{\left[\left(\frac{P_t^*}{P_{t+s}}\right)^{-\psi} \frac{Y_{t+s}}{A_{t+s}} H_{t+s}^{-\gamma}\right]^{\frac{1}{1-\gamma}}}{\frac{Y_{t+s}}{A_{t+s}}^{\frac{1}{1-\gamma}} H_{t+s}^{-\frac{\gamma}{1-\gamma}} S_t} = \frac{\left(\frac{P_t^*}{P_{t+s}}\right)^{-\frac{\psi}{1-\gamma}}}{S_t}. \tag{C.6}$$

Given the consumer' demand schedule and taking wages as given, the cost minimization implies the following demand for labor:

$$w_t = \frac{MPL_t}{X_{\psi,t}} = \frac{1}{X_{\psi,t}} (1-\gamma) A_t (N_t)^{-\gamma} (H_{z,t-1})^{\gamma} = (1-\gamma) MC_t \frac{Y_t}{N_t}$$

where $w_t = \frac{W_t}{P_t}$ is the real wage and $X_{\psi,t}$ is the markup (or the inverse of the real marginal cost, $MC_t = 1/X_{\psi,t}$) which in steady state is $X_\psi \equiv \frac{\psi}{\psi-1}$ and $MPL_t \equiv (1-\gamma) A_t (N_t)^{-\gamma} (H_{z,t-1})^{\gamma}$ is the marginal product of labor. Expanding the demand for labour to $t+s$ we can include S_t in it as follows

$$MC_{t+s|t} = \frac{w_{t+s}}{\frac{(1-\gamma)Y_{t+s|t}}{N_{t+s|t}}} \tag{C.7}$$

$$= \frac{w_{t+s}}{(1-\gamma)A_{t+s|t}N_{t+s|t}^{-\psi}H_{t+s}^{\psi}} \tag{C.8}$$

$$= \frac{w_{t+s}}{(1-\gamma)A_{t+s|t}N_{t+s}^{-\psi}H_{t+s}^{\psi}} \frac{N_{t+s}^{-\gamma}}{N_{t+s|t}^{-\gamma}} \tag{C.9}$$

$$= \frac{w_{t+s}}{(1-\gamma)A_{t+s|t}N_{t+s}^{-\psi}H_{t+s}^{\psi}} \left(\frac{N_{t+s|t}}{N_{t+s}}\right)^{\gamma} \tag{C.10}$$

$$= \frac{w_{t+s}}{(1-\gamma)A_{t+s|t}N_{t+s}^{-\psi}H_{t+s}^{\psi}} \left(\frac{\frac{P_t^*}{P_{t+s}}^{-\frac{\psi}{1-\gamma}}}{S_t}\right)^{\gamma} \tag{C.11}$$

$$= MC_{t+s} \left(\frac{P_t^*}{P_{t+s}}\right)^{-\frac{\gamma\psi}{1-\gamma}} \tag{C.12}$$

where:

$$MC_t = \frac{w_t}{(1-\gamma)A_t N_t^{-\gamma} H_t^{\gamma} S_t^{\gamma}} = \frac{w_t}{(1-\gamma)\frac{Y_t}{N_t} S_t}.$$

The pricing first order condition gives us the optimal reset price (Π_t^*) dynamic equation.

$$\sum_{s=0}^{\infty} \theta^s \mathbb{E}_t \left[\Lambda_{t,t+s} Y_{t+s|t} \frac{1}{P_{t+s}} \left(P_t^* - \frac{\psi}{\psi-1} MC_{t+s|t} P_{t+s}\right)\right] = 0 \tag{C.13}$$

Using the demand function including S_t, FOC can be written as

$$\sum_{s=0}^{\infty} \theta^s \mathbb{E}_t \left[\Lambda_{t,t+s} \left(\frac{P_t^*}{P_{t+s}}\right)^{-\psi} Y_{t+s} \frac{1}{P_{t+s}} \left(P_t^* - \frac{\psi}{\psi-1} MC_{t+s|t} P_{t+s}\right)\right] = 0. \tag{C.14}$$

Divinding and multiplying by P_t we have

$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\Lambda_{t,t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi}\left(\frac{P_t^*}{P_t}\right)^{-\psi}Y_{t+s}\frac{P_t}{P_{t+s}}\left(\frac{P_t^*}{P_t}-\frac{\psi}{\psi-1}MC_{t+s|t}\frac{P_{t+s}}{P_t}\right)\right]=0. \tag{C.15}$$

Plugging the discount factor $\Lambda_{t,t+s}$ and dividing by C_t we obtain

$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi}\left(\frac{P_t^*}{P_t}\right)^{-\psi}Y_{t+s}\frac{P_t}{P_{t+s}}\left(\frac{P_t^*}{P_t}-\frac{\psi}{\psi-1}MC_{t+s|t}\frac{P_{t+s}}{P_t}\right)\right]=0. \tag{C.16}$$

Recalling that $\frac{P_t^*}{P_t}=\Pi_t^*$, we can write

$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi}\left(\Pi_t^*\right)^{1-\psi}Y_{t+s}\right]=$$
$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi}\left(\Pi_t^*\right)^{-\psi}Y_{t+s}\frac{\psi}{\psi-1}MC_{t+s|t}\right] \tag{C.17}$$

Now we can substitute idiosyncratic marginal costs with average marginal costs

$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi}\left(\Pi_t^*\right)^{1-\psi}Y_{t+s}\right]=$$
$$\frac{\psi}{\psi-1}\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi}\left(\Pi_t^*\right)^{-\psi}Y_{t+s}MC_{t+s}\left(\frac{P_t^*}{P_{t+s}}\right)^{-\frac{\gamma\psi}{1-\gamma}}\right], \tag{C.18}$$

expand the equation to obtain Π_t^* on the right-hand side in the equation

$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi}\left(\Pi_t^*\right)^{1-\psi}Y_{t+s}\right]=$$
$$\frac{\psi}{\psi-1}\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi}\left(\Pi_t^*\right)^{-\psi}Y_{t+s}MC_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\frac{\gamma\psi}{1-\gamma}}\left(\frac{P_t^*}{P_t}\right)^{-\frac{\gamma\psi}{1-\gamma}}\right] \tag{C.19}$$

and bring it to the left-hand side

$$\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi}\left(\Pi_t^*\right)^{1+\frac{\psi\gamma}{1-\gamma}}Y_{t+s}\right]=$$
$$\frac{\psi}{\psi-1}\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}Y_{t+s}MC_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi-\frac{\gamma\psi}{1-\gamma}}\right]. \tag{C.20}$$

Finally, we can factor out the optimal reset price and obtain

$$\left(\Pi_t^*\right)^{1+\frac{\psi\gamma}{1-\gamma}}\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi}Y_{t+s}\right]=$$
$$\frac{\psi}{\psi-1}\sum_{s=0}^{\infty}\theta^s\mathbb{E}_t\left[\beta^s C_{t+s}^{-1}Y_{t+s}MC_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi-\frac{\gamma\psi}{1-\gamma}}\right]. \tag{C.21}$$

To simplify the notation, we can define the above equation as

$$\left(\Pi_t^*\right)^{1+\frac{\psi\gamma}{1-\gamma}} AUX_{2,t} = \frac{\psi}{\psi-1} AUX_{1,t}$$

with

$$\begin{aligned}
AUX_{1,t} &= \sum_{s=0}^{\infty}\theta^s \mathbb{E}_t\left[\beta^s C_{t+s}^{-1} Y_{t+s} MC_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi-\frac{\gamma\psi}{1-\gamma}}\right]\\
&= c_t^{-1} Y_t MC_t + \mathbb{E}_t \sum_{s=1}^{\infty}\theta^s\left[\beta^s C_{t+s} Y_{t+s} MC_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi-\frac{\gamma\psi}{1-\gamma}}\right]\\
&= c_t^{-1} Y_t MC_t + \mathbb{E}_t\left(\frac{P_t}{P_{t+1}}\right)^{-\psi-\frac{\gamma\psi}{1-\gamma}}\sum_{s=1}^{\infty}\theta^s\left[\beta^s C_{t+s} Y_{t+s} MC_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{-\psi-\frac{\gamma\psi}{1-\gamma}}\right]\\
&= c_t^{-1} Y_t MC_t + \beta\theta \mathbb{E}_t \Pi_{t+1}^{\psi+\frac{\gamma\psi}{1-\gamma}} AUX_{1,t+1}\\
&= c_t^{-1} Y_t MC_t + \beta\theta \mathbb{E}_t \Pi_{t+1}^{\frac{\psi}{1-\gamma}} AUX_{1,t+1}
\end{aligned}$$

and

$$\begin{aligned}
AUX_{2,t} &= \sum_{s=0}^{\infty}\theta^s \mathbb{E}_t\left[\beta^s C_{t+s}^{-1}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi} Y_{t+s}\right]\\
&= c_t^{-1} Y_t + \mathbb{E}_t \sum_{s=1}^{\infty}\theta^s\left[\beta^s C_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi} Y_{t+s}\right]\\
&= c_t^{-1} Y_t + \mathbb{E}_t\left(\frac{P_t}{P_{t+1}}\right)^{1-\psi}\sum_{s=1}^{\infty}\theta^s\left[\beta^s C_{t+s}\left(\frac{P_t}{P_{t+s}}\right)^{1-\psi} Y_{t+s}\right]\\
&= c_t^{-1} Y_t + \beta\theta \mathbb{E}_t \Pi_{t+1}^{\psi-1} AUX_{2,t+1}.
\end{aligned}$$

Appendix D: Welfare Analysis

The aggregate welfare function depends on households' preferences over consumption, housing, labor and public spending; the argument G_t represents government spending and is determined by the government in each period so that the representative consumer takes it as exogenously given. Thus social welfare is given by:

$$U_t = \frac{c^s}{Y}\left(\log c_t^s\right) + \frac{c^b}{Y}\left(\log c_t^b + \chi_H \log H_t^b - \frac{\left(N_t\right)^{1+\varsigma}}{1+\varsigma}\right) + \frac{g}{Y}\left(\log g_t\right) \tag{D.1}$$

where we attach weight coefficients equal to the steady state value of consumption over output and government spending over output. All derivations are calculated at the steady state values c^s, c^b, N, g and the variables signed with a "$\sim$" denote second-order approximations in terms of log-deviations:

$$\tilde{X} = X_t - X \simeq X\left(\hat{X}_t + \frac{1}{2}\hat{X}_t^2\right) \tag{D.2}$$

where $\hat{X}$ is the log-deviation from steady state for a generic variable X_t.

D.1. Deriving the second order approximation

Since the utility is additively separable between consumption, labor, housing then we can consider the second-order approximations to each term in (D.1) separately.

- The second-order approximation to saver's consumption is given by:

$$\begin{aligned}\log c_t^s &\approx U_{c^s}\widetilde{c}_t^s + \frac{U_{c^s c^s}\left(\widetilde{c}_t^s\right)^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \frac{1}{c^s}c^s\left(\widehat{c}_t^s + \frac{1}{2}\left(\widehat{c}_t^s\right)^2\right) - \frac{1}{\left(c^s\right)^2}\frac{\left(c^s\right)^2\left(\widehat{c}_t^s\right)^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \widehat{c}_t^s + \mathcal{O}\left(\|a\|^3\right)\end{aligned} \tag{D.3}$$

where $O\left(\|a\|^3\right)$ collects all the terms of third order or higher, in the bound $\|a\|$ on the amplitude of the relevant shocks.

- The second-order approximation to borrower's consumption is given by:

$$\begin{aligned}\log c_t^b &\approx U_{c^b}\widetilde{c}_t^b + \frac{U_{c^b c^b}\left(\widetilde{c}_t^b\right)^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \frac{1}{c^b}c^b\left(\widehat{c}_t^b + \frac{1}{2}\left(\widehat{c}_t^b\right)^2\right) - \frac{1}{\left(c^b\right)^2}\frac{\left(c^b\right)^2\left(\widehat{c}_t^b\right)^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \widehat{c}_t^b + \mathcal{O}\left(\|a\|^3\right)\end{aligned} \tag{D.4}$$

- The second-order approximation to real estate holdings is given by:

$$\begin{aligned}\chi_H \log H_t^b &\approx \chi_H U_H \widetilde{H}_t^b + \frac{\chi_H U_{HH}\left(\widetilde{H}_t^b\right)^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \frac{\chi_H}{H^b}H^b\left(\hat{H}_t^b + \frac{1}{2}\left(\hat{H}_t^b\right)^2\right) - \frac{\chi_H}{\left(H^b\right)^2}\frac{\left(H^b\right)^2\left(\hat{H}_t^b\right)^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \chi_H \hat{H}_t^b + \mathcal{O}\left(\|a\|^3\right)\end{aligned} \tag{D.5}$$

- The second-order approximation to labor is given by:

$$\frac{N_t^{1+\varsigma}}{1+\varsigma} \approx U_N N \tilde{N}_t + U_{NN} N^2 \frac{\tilde{N}_t^2}{2} + O\left(\|a\|^3\right) \tag{D.6}$$

Given that $U_{NN} = \varsigma N U_N$ with $U_N = N^\varsigma$ we can rewrite the above relationship as follows:

$$\begin{aligned}\frac{N_t^{1+\varsigma}}{1+\varsigma} &\approx U_N N\left(\hat{N}_t + \frac{1}{2}\left(1+\varsigma\right)\left(\widehat{N}_t\right)^2\right) + \mathcal{O}\left(\|a\|^3\right) \\ &\approx N^{\varsigma+1}\left(\hat{N}_t + \frac{1}{2}\left(1+\varsigma\right)\left(\widehat{N}_t\right)^2\right) + \mathcal{O}\left(\|a\|^3\right)\end{aligned} \tag{D.7}$$

Finally using the labor market clearing when the economy remains in a neighborhood of an efficient steady state (i.e. where $MC = 1$) yields $N^{\varsigma}c^b = (1-\gamma)\frac{Y}{N}$ from which we get $N^{\varsigma+1} = \frac{(1-\gamma)Y}{c^b}$. Substituting this into the above relationship gives:

$$\frac{N_t^{1+\varsigma}}{1+\varsigma} = \frac{(1-\gamma)Y}{c^b}\left(\hat{N}_t + \frac{1}{2}(1+\varsigma)\left(\widehat{N}_t\right)^2\right) + \mathcal{O}\left(\|a\|^3\right) \tag{D.8}$$

- The second-order approximation to government spending is given by:

$$\begin{aligned}\log g_t &\approx U_g \widetilde{g}_t + \frac{U_{gg}\widetilde{g}_t^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \frac{1}{g} g\left(\hat{G}_t + \frac{1}{2}\widehat{g}_t^2\right) - \frac{1}{g^2}\frac{g^2\widehat{g}_t^2}{2} + \mathcal{O}\left(\|a\|^3\right) \\ &\approx \widehat{g}_t + \mathcal{O}\left(\|a\|^3\right)\end{aligned} \tag{D.9}$$

D.2. Simplifying the Social Welfare Function

We now add equations (D.3), (D.4), (D.5), (D.8) in order to get a second-order approximation to the welfare function (D.1):

$$U_t - U \simeq \frac{c^s}{Y}\widehat{c}_t^s + \frac{c^b}{Y}\left(\widehat{c}_t^b + \chi_H \hat{H}_t^b\right) - (1-\gamma)\left(\hat{N}_t + \frac{1}{2}(1+\varsigma)\left(\hat{N}_t\right)^2\right) + \frac{g}{Y}\widehat{g}_t + \mathcal{O}\left(\|a\|^3\right) \tag{D.10}$$

(i) From the second order approximation of the housing market clearing condition we have $\left(\widehat{H}_t + \frac{1}{2}\left(\hat{H}_t^b\right)^2\right) = 0$ which implies that $\widehat{H}_t = -\frac{1}{2}\left(\hat{H}_t^b\right)^2$ so that (D.10) can be rewritten as follows:

$$U_t - U \simeq \frac{c^s}{Y}\widehat{c}_t^s + \frac{c^b}{Y}\widehat{c}_t^b - \frac{1}{2}\frac{c^b}{Y}\chi_H\left(\hat{H}_t^b\right)^2 - (1-\gamma)\left(\hat{N}_t + \frac{1}{2}(1+\varsigma)\left(\hat{N}_t\right)^2\right) + \frac{g}{Y}\widehat{g}_t + \mathcal{O}\left(\|a\|^3\right) \tag{D.11}$$

(ii) From the second-order approximation of the aggregate resource constraint:

$$\left(\hat{Y}_t + \frac{1}{2}\hat{Y}_t^2\right) = \frac{c^s}{Y}\left(\widehat{c}_t^s + \frac{1}{2}\left(\widehat{c}_t^s\right)^2\right) + \frac{c^b}{Y}\left(\widehat{c}_t^b + \frac{1}{2}\left(\widehat{c}_t^b\right)^2\right) + \frac{g}{Y}\left(\widehat{g}_t + \frac{1}{2}\widehat{g}_t^2\right) + \mathcal{O}\left(\|a\|^3\right) \tag{D.12}$$

which implies

$$\frac{c^s}{Y}\widehat{c}_t^s + \frac{c^b}{Y}\widehat{c}_t^b + \frac{g}{Y}\widehat{g}_t = \left(\hat{Y}_t + \frac{1}{2}\hat{Y}_t^2\right) - \frac{1}{2}\left(\frac{c^s}{Y}\widehat{c}_t^s + \frac{c^b}{Y}\left(\widehat{c}_t^b\right)^2 + \frac{g}{Y}\widehat{g}_t^2\right) + \mathcal{O}\left(\|a\|^3\right) \tag{D.13}$$

(iii) To eliminate $\hat{N}_t$ which allows us to express the welfare function in terms of output, we use (C.1) to rewrite N_t in log-linear form:

$$(1-\gamma)\hat{N}_t = \hat{Y}_t - A_t + \widehat{S}_t \tag{D.14}$$

where $\widehat{S}_t \equiv (1-\gamma)\log\left[\int_0^1\left(\frac{P_{z,t}}{P_t}\right)^{-\frac{\psi}{1-\gamma}}dz\right]$ is the log-linear price dispersion in the intermediate sector with z denoting the price of good variety z.

Lemma 1 *In a neighborhood of a symmetric steady state and up to a second-order approximation* $\widehat{S}$ *is proportional to the cross-sectional variance of relative prices,* $\widehat{S}_t \equiv \frac{1}{2}\frac{\psi}{\varrho} var\left\{P_{z,t}\right\} + O\Big(\|a\|^3\Big)$ *where* $\varrho \equiv \frac{1-\gamma}{1+\gamma(\psi-1)}$

Lemma 2 $\sum_{t=0}^{\infty}\beta^t var\left\{P_{z,t}\right\} = \frac{\theta}{(1-\theta)(1-\beta\theta)}\sum_{t=0}^{\infty}\beta^t\pi_t^2$

Substituting (D.13) and (D.14) we can rewrite the welfare function (D.11) as follows:

$$U_t - U \simeq \left(\hat{Y}_t + \frac{1}{2}\hat{Y}_t^2\right) - \frac{1}{2}\left(\frac{c^s}{Y}\left(\widehat{c}_t^s\right)^2 + \frac{c^b}{Y}\left(\widehat{c}_t^b\right)^2 + \frac{g}{Y}\widehat{g}_t^2\right) - \frac{1}{2}\frac{c^b}{Y}\chi_H\left(\hat{H}_t^b\right)^2 + \\ - \left[\left(\hat{Y}_t - A_t + \widehat{S}_t\right) + \frac{1}{2}\left(\frac{1+\varsigma}{1-\gamma}\right)\left(\hat{Y}_t - A_t + \widehat{S}_t\right)^2\right] + \mathcal{O}\left(\|a\|^3\right) \tag{D.15}$$

By simplifying and using Lemma 1 and 2 in order to rewrite the terms involving the price dispersion as a function of inflation and knowing that $\eta \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\gamma}{1+\gamma(\psi-1)}$ and collecting the "$t.i.p$" (terms independent of policy) the above relationship can be rewritten as follows:

$$(U_t - U) \simeq \frac{1}{2}\left[\left(1 - \frac{1+\varsigma}{1-\gamma}\right)\hat{Y}_t^2 - \left(\frac{c^s}{Y}\left(\widehat{c}_t^s\right)^2 + \frac{c^b}{Y}\left(\widehat{c}_t^b\right)^2 + \frac{g}{Y}\widehat{g}_t^2\right) - \frac{c^b}{Y}\chi_H\left(\hat{H}_t^b\right)^2 - \frac{\psi}{\eta}\hat{\pi}^2\right] \\ + t.i.p. + \mathcal{O}\left(\|a\|^3\right) \tag{D.16}$$

The welfare function (D.16) can be also expressed in terms of aggregate welfare losses using the following purely quadratic loss function:

$$\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t(U_t - U) = -\frac{1}{2}\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t L_t + t.i.p + \mathcal{O}\left(\|a\|^3\right) \tag{D.17}$$
$$\text{with } L_t = \varphi_Y\sigma_Y^2 + \varphi_{c^s}\sigma_{c^s}^2 + \varphi_{c^b}\sigma_{c^b}^2 + \varphi_g\sigma_g^2 + \varphi_{H^b}\sigma_{H^b}^2 + \varphi_\pi\sigma_\pi^2$$

where the weight coefficients are given by $\varphi_Y \equiv \frac{\varsigma+\gamma}{1-\gamma}$, $\varphi_{c^s} \equiv \frac{c^s}{Y}$, $\varphi_{c^b} \equiv \frac{c^b}{Y}$, $\varphi_{H^b} \equiv \frac{c^b}{Y}\chi_H$,

$\varphi_g \equiv \frac{g}{Y}$ and $\varphi_\pi \equiv \frac{\psi}{\eta}$ with $\eta \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}\frac{1-\gamma}{1+\gamma(\psi-1)}$.

Appendix E: Estimation: Data

For the estimated version of the model, we use U.S. quarterly data from 1975Q1 to 2011Q4 (database of the U.S. Federal Reserve Bank of St. Louis). The time series we implemented are the following:

- PCEC: Personal Consumption Expenditures (billions of dollars, SA annual rate).
- A191RI1Q225SBEA: Gross Domestic Product: Implicit Price Deflator (percent, SA annual rate).
- HHMSDODNS: Households and Nonprofit Organizations; Home Mortgages; Liability, Level (billions of dollars, SA).
- USSTHPI: All-Transactions House Price Index for the United States, Index 1980:Q1=100, Quarterly, (index, NSA).
- AWHI: Index of Aggregate Weekly Hours: Production and Nonsupervisory Employees: Total Private Industries (index, SA).
- PCECTPI: Personal Consumption Expenditures: Chain-type Price Index (index, SA).
- GDPDEF: Gross Domestic Product: Implicit Price Deflator (index, SA).
- CNP16OV: Civilian Noninstitutional Population (thousands of persons, NSA).
- FEDFUNDS: Effective Federal Funds Rate, (percent, NSA).

The final series to be used in the model are then constructed as follows:

Real personal consumption expenditures per capita

$$C_{obs,t} = \frac{PCEC_t}{PCECTPI_t \times CNP16OV_t} \tag{E.1}$$

Inflation

$$\pi_{obs,t} = \frac{A191RI1Q225SBEA_t}{4} \tag{E.2}$$

Real home mortgage loan liabilities per capita

$$L_{obs,t} = \frac{HHMSDODNS_t}{GDPDEF_t \times CNP16OV_t} \tag{E.3}$$

Real house prices

$$q_{obs,t} = \frac{USSTHPI_t}{GDPDEF_t} \tag{E.4}$$

Aggregate weekly hours per capita

$$L_{obs,t} = \frac{AWHI_t}{CNP16OV_t} \tag{E.5}$$

Policy interest rate (gross)

$$R^M_{obs,t} = \frac{FEDFUNDS_t}{400} \tag{E.6}$$

All the series but $R^M_{obs,t}$ and $\pi_{obs,t}$ are normalized relative to 1975Q1, then log-transformed, and lastly detrended by series-specific one-sided HP filters, with a smoothing parameter set to 100,000. Inflation is demeaned. Figure 1 displays graphical representations of the series.

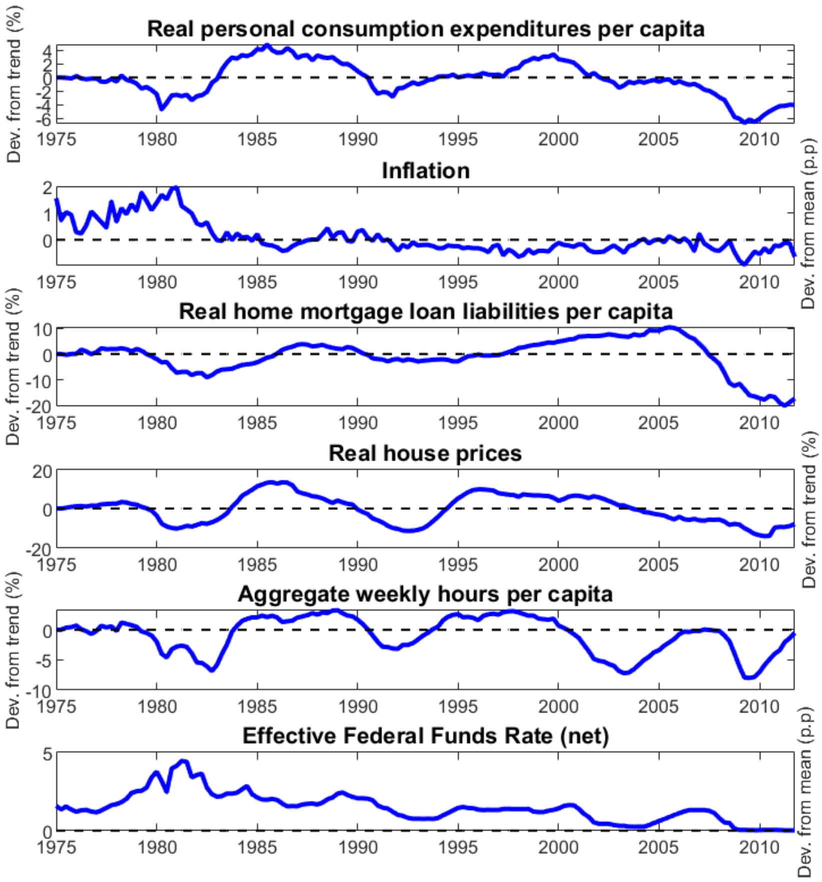

Figure E.1: Data

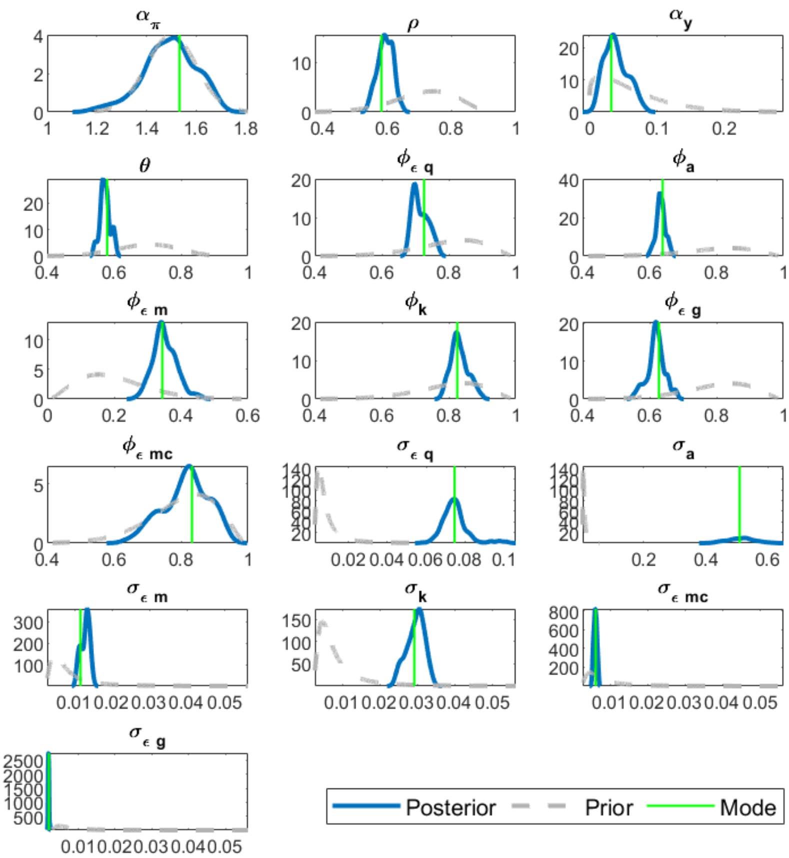

Figure E.2: Priors and Posteriors

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