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HOUSING SECTOR AND OPTIMAL MACROPRUDENTIAL POLICY IN AN ESTIMATED DSGE MODEL FOR LUXEMBOURG

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Housing sector and optimal macroprudential policy in an estimated DSGE model for Luxembourg*

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Abstract

This study investigates the optimal macroprudential policies for Luxembourg using an estimated closed-economy DSGE model. The model features a monopolistically competitive banking sector, a collateral constraint and an explicit differentiation between the flow and the stock of household mortgage debt. Based on a welfare-oriented approach and in a context of easy monetary policy environment, we first find that the non-joint optimal loan-to-value (LTV) and risk weighted capital requirement (RW) ratios for Luxembourg seem to be 90% and 30%, respectively, while the joint optimal ratios are found to be 100% and 10% respectively. Our results from the combination of instruments suggest that the policy scenario that provides better stabilization effects on mortgage credits isn't necessarily the one that is welfare improving. In other words, we find a complementarity between LTV and RW in terms of welfare, while their optimal combination diminishes the stabilization effects on mortgage debt and house prices. However, the time-varying and endogenous rules for LTV and RW improve the social welfare and better stabilizes mortgage loans and house prices compared to their static exogenous ratios. We further find that the optimal interactions between LTV and RW ratios in our modelling framework exhibit a convex shape. It should be recalled that the results are conditional on the model's specific assumptions.

JEL-Classification: E32, E44, R38.

Keywords: LTV, Risk weights, optimal macroprudential policy, combination of macroprudential instruments.

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Résumé non technique

La crise financière de 2008 a mis en évidence la nécessité de renouveler l'approche de la surveillance et de la régulation du système financier en la complétant par une perspective macroprudentielle en vue de promouvoir la stabilité financière. C'est ainsi que de nombreux pays, notamment européens, se sont récemment dotés de cadres opérationnels pour la mise en place des instruments macroprudentiels dédiés à la politique macroprudentielle. En 2015, le comité de risque systémique (CRS) a été créé pour coordonner l'implémentation de la politique macroprudentielle au Luxembourg.

Les mesures macroprudentielles déjà implémentées par les autorités luxembourgeoises comprennent le seuil plancher (fixé à 15 %) de la pondération moyenne du risque (Risk weight, RW) lié au secteur des biens immobiliers résidentiels par les établissements de crédit utilisant l'approche fondée sur les notations internes (IRB) et le coussin contracyclique (calibré à 0.25 % à partir du premier trimestre 2019).
Cependant, le marché des biens immobiliers résidentiels au Luxembourg continue d'être caractérisé par une forte croissance des prix qui, combinée avec un niveau élevé et croissant d'endettement des ménages (atteignant 181,5 % du revenu disponible au troisième trimestre 2018) pourrait être une source de risque systémique pour la stabilité financière sans la mise en place de mesures additionnelles.
Les instruments macroprudentiels basés sur l'emprunteur (borrower based measures), comme le ratio prêt-valeur (LTV), pourraient aider à remédier à ces vulnérabilités financières susceptibles d'avoir des effets néfastes sur l'économie réelle. Ces outils macroprudentiels agissant du côté de la demande de crédits relatifs aux biens immobiliers à usage résidentiel ne sont pas actuellement disponibles dans la boite à outils macroprudentielle du Luxembourg, même si un projet de loi relatif à l'introduction de ces instruments a été soumis au Parlement luxembourgeois en décembre 2017. L'implémentation effective de cette classe d'instruments macroprudentiels vise à contenir les risques liés à la dette des ménages et aux prix des biens immobiliers résidentiels.

En attendant l'adoption du projet de loi sur ces instruments par le Parlement, cette étude tente de déterminer le niveau optimal du ratio LTV ainsi que les paramètres optimaux d'une potentielle règle endogène de cet instrument macroprudentiel agissant sur la demande de prêts immobiliers. Ce travail s'inscrit également dans l'optique d'une recherche de la combinaison optimale entre un instrument macroprudentiel basé sur l'emprunteur (LTV) et un autre basé sur le prêteur (RW) dont le ratio et la règle optimaux sont aussi déterminés.
Dans cet objectif, nous construisons un modèle d'équilibre général stochastique et dynamique (DSGE) d'économie fermée contenant le secteur des biens immobiliers résidentiels, la dynamique de la dette des ménages distinguant le flux de prêts immobiliers du stock de dette, le secteur bancaire à concurrence monopolistique ainsi qu'une contrainte d'endettement (ou de collatéral)

des ménages. Le modèle est estimé sur la base des données luxembourgeoises en utilisant l'estimation bayésienne.

Les résultats de l'étude se résument comme suit[1]. D'abord, en se basant sur l'analyse du bien-être et dans un contexte de baisse du taux d'intérêt, les ratios optimaux non-joints de LTV et du RW obtenus pour le Luxembourg s'élèvent respectivement à 90 % et 30 % tandis que les ratios optimaux joints se situeraient respectivement à 100 % et 10 %. La combinaison des deux ratios (LTV et RW) améliore le bien-être social comparativement à l'implémentation du seul ratio LTV, suggérant ainsi une complémentarité entre ces deux instruments en termes de bien-être. Cependant, l'application du seul ratio optimal de LTV génère plus d'effets stabilisants sur la dette immobilière et les prix de l'immobilier résidentiel que la combinaison des deux instruments. En particulier, lorsque l'instrument LTV est appliqué seul et de manière exogène, nous trouvons que, dans un contexte d'assouplissement monétaire, son niveau optimal est très contraignant (à 20 %) pour être réaliste. Cela conduit à une perte de bien-être relativement à la combinaison avec le plancher du RW, tandis que ce niveau trop restrictif du ratio LTV stabilise la dette des ménages et le prix de l'immobilier en comparaison avec l'implémentation des deux instruments LTV et RW à la fois. Néanmoins, il apparaît dans nos résultats que les règles endogènes et variables dans le temps pour les ratios LTV et RW améliorent le bien-être social et stabilisent mieux la dette des ménages et le prix des biens immobiliers à usage résidentiel, comparativement aux ratios exogènes et statiques de ces instruments. Finalement, nous trouvons que les combinaisons optimales entre les ratios LTV et RW dessinent une forme convexe. Il est à rappeler que les résultats obtenus sont conditionnés au cadre spécifique du modèle développé (structure et hypothèses).

[1]Il est important de noter que le cadre spécifique de notre modèle, conduisant aux résultats, ne tient pas compte de l'ensemble des caractéristiques du marché de l'immobilier résidentiel au Luxembourg, notamment les contraintes sur l'offre des biens immobiliers résidentiels, les incitations fiscales telle que la déductibilité dégressive des taux d'intérêt pour les emprunts immobiliers et l'excès de demande liée à la croissance de la population résidente.

1. Introduction

The recent great recession revealed how the real estate sector can be a source of financial vulnerabilities for banks and the whole financial system and how these vulnerabilities could affect the real sector. Since then, a consensus has emerged among academics and policy makers on the need to dedicate specific instruments to financial stability tasks, called macroprudential tools, since traditional measures falling into the monetary policy framework failed to safeguard the financial system. These instruments have been embedded in a new regulatory framework defined as the macroprudential regulation.

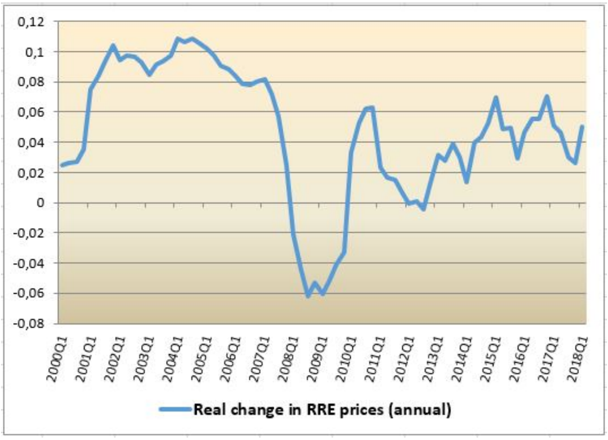
The purpose of this kind of regulation is to avoid the transmission of financial vulnerabilities to the broader economy. Several countries, in particular in the EU, have implemented macroprudential tools in order to promote financial stability. In this vein, a macroprudential policy framework has been established in Luxembourg with the implementation and operationalisation of the *Comité du Risque Systémique* (CRS) in 2015. The CRS is in charge of coordinating the implementation of macroprudential policy in Luxembourg.

Macroprudential measures implemented by authorities in Luxembourg include the (15%) risk weight floor on IRB banks' exposures to the residential real estate (RRE) sector and the countercyclical capital buffer (calibrated at 0.25%). Macroprudential measures such as the loan-to-value (LTV) ratio and other demand side instruments are currently not available in the national policy toolkit, although a draft law to implement these instruments was submitted to the Luxembourg parliament in December 2017.

In September 2016, the ESRB issued a warning that the vulnerabilities in the RRE sector coupled with household indebtedness could be a source of systemic risk to financial stability. In fact, high prices currently characterize the Luxembourg residential real estate market as illustrated by the upward trend in the real house price growth rate shown in Figure 1 below. This ongoing increase in RRE prices is driven by both excess of demand for housing and supply limitations. The persistent low interest rate environment, in combination with high dwelling prices, has fuelled the increase in household indebtedness levels.

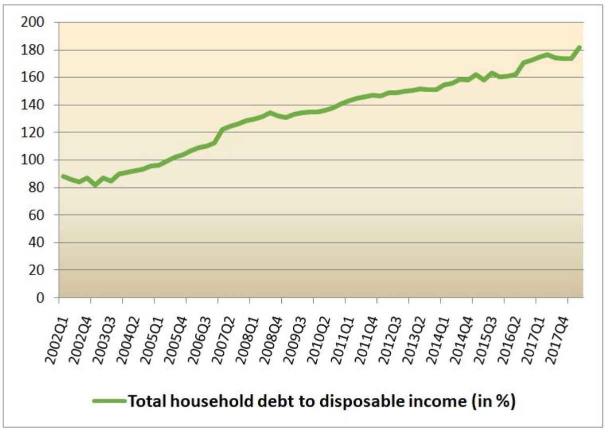
Luxembourg households' debt is at a high level, even compared to other European countries, and amounted to 181.5% of disposable income in 2018Q3 and continues to increase. Figure 2 below depicts a marked trend in the ratio of domestic households' total debt to disposable income. This increase in indebtedness combined with rising RRE prices poses risks to financial stability in the form of household debt sustainability and housing affordability. In particular, around 70% of outstanding mortgage credit is in the form of variable rate loans, exposing households to possible interest rate risk in the event of a significant and unexpected increase in the interest rate. In the absence of demand-side policy actions, these vulnerabilities could have adverse effects for the real economy. Borrower-based measures such as LTV limits could help to address these vulnerabilities. In addition to the existing capital based measures already implemented, the national authorities have drafted a legal framework for borrower-based measures to address risks related to household indebtedness in the RRE sector. Although the legal project for these instruments was transmitted to the Luxembourg Parliament in December 2017, it has not yet been formally adopted. Nevertheless, there is a need to assess the optimal levels of these instruments and they should be activated as soon as they are available in the national toolbox.

Figure 1: Real house price growth



Data source: Statec.

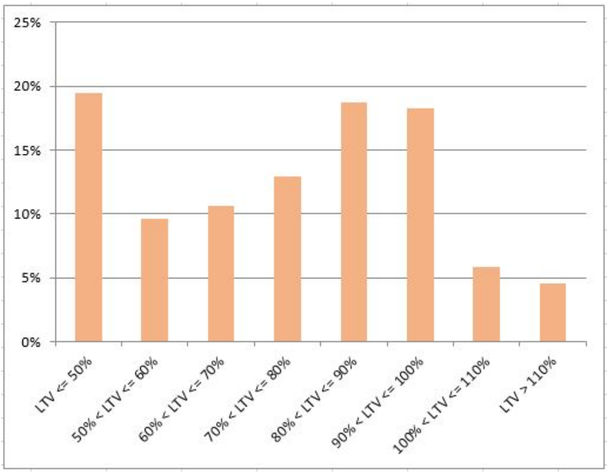
Figure 2: Total household debt to disposable income



Data source: Statec.

It is against this background that this work aims at addressing the following two interrelated questions: i) What would be the optimal loan-to-value (LTV) ratio/rule as a borrower-based macroprudential instrument for Luxembourg in a general equilibrium framework? This is an important policy issue as banks in Luxembourg currently apply various LTV ratios depending on their own assessment of household creditworthiness as illustrated in Figure 3.

Figure 3: Distribution of new loans by LTVs (aggregate sector, 2017)



Data source: CSSF.

ii) How important are the combinations of borrower and capital based macroprudential instruments and how can their optimal combinations be determined?
The first question above allows determining optimal levels of macroprudential instruments and characterizing their optimal rules for Luxembourg. The second question helps to shape the optimal interactions of macroprudential instruments.

To address these questions, this work proposes a framework for characterizing optimal macroprudential policies, assessing their optimal interactions and evaluating their implications for financial stability. To this end, we build a closed-economy DSGE model which features a housing sector and household debt dynamics. The model is estimated on Luxembourg data using Bayesian estimation techniques. Unlike what is widely done in the literature, we distinguish between the flow and the stock of household debt in the model. We also introduce a monopolistically competitive banking sector, which features the costs of regulatory capital requirements and a feedback loop channel between the real and the financial side of the economy.
With respect to macroprudential policies, we introduce borrower and capital based measures in order to determine their optimal ratios and interactions. We identify the optimal macroprudential ratios and rules for LTV and sectoral capital requirements, while adopting a broad definition of the sectoral capital requirement that we call the risk weighted capital requirement (RW). We subsequently discuss the effectiveness of the optimal combinations of instruments through their ability to stabilize financial cycle, house prices and household indebtedness in the presence of both interest rate and LTV shocks. Finally, a welfare comparison of alternative policies is conducted to draw meaningful conclusions on the potential costs of these policies for the real economy.

Our contribution is twofold. Based on a welfare analysis, we first identify the optimal LTV and RW ratios and characterize their optimal combination using an estimated DSGE model of

Luxembourg. Our second contribution, from the modelling perspective, consists in combining the distinction between the mortgage credit flow and stock with a stylised banking sector *à la* Gerali et al. (2010).

Our main findings can be summarized as follows[2]. First, the non-joint optimal ratios of LTV and RW leading to the maximum social welfare are respectively found to be 90% and 30% for Luxembourg in the context of an easy monetary policy environment. When solely a LTV measure is applied in the same context, it should be 20%, hence too tight to be realistic, leading admittedly to a welfare loss but bringing about stabilized debt relative to the use of both LTV and RW ratios. Second, we find that combining a borrower-based instrument, such as the LTV cap, with a capital-based one, as the RW ratio, welfare-dominates the use of LTV alone. This suggests that these two instruments can be considered as complements in terms of welfare improvement. Notably, a single LTV measure performs better than combining the two instruments in terms of mortgage debt and house prices stabilization effects. These results imply that the policy scenario that provides better stabilization effects on mortgage credit growth isn't necessarily the one that is welfare improving. More precisely, we find a complementarity between LTV and RW in terms of welfare, while their optimal combination deteriorates the stabilization effects on mortgage debt and house prices.
Nevertheless, the time-varying and endogenous rules for LTV and RW improves the social welfare and better stabilizes mortgage loans and the house prices compared to their static exogenous ratios. Finally, we find that the optimal interactions between LTV and RW ratios in our modelling framework exhibit a convex shape. In other words, when LTV increases, the corresponding optimal RW ratio is low and conversely, when the RW ratio increases, the corresponding optimal LTV ratio decreases.

The existing studies using the DSGE modelling approach for analysing the Luxembourg economy specifically are limited. Deák et al. (2011) built a DSGE model called LSM (Luxembourg Structural Model) which captures the main structural features of the Luxembourg economy in order to undertake various experiments. Marchiori and Pierrard (2017) proposed a general equilibrium model calibrated on the Luxembourg economy, which features overlapping generation dynamics and labour market frictions, with the purpose of assessing how global demand for financial services promote domestic growth in Luxembourg. These authors do not model housing and financial sectors and do not address the financial regulation issues in the context of their models.
This work is related to four strands of literature. First, it is related to numerous papers that model housing sector with borrowing constraints in a dynamic stochastic general equilibrium framework (e.g. Iacoviello (2005), Iacoviello and Neri (2010), Gerali et al. (2010), Mendi-

[2]Note that the modelling framework used to generate the results does not take into account all features of the residential real estate market in Luxembourg. In particular, the constraints on the residential real estate supply, public incentives, such as the tax deductibility of mortgage interest rate, are omitted from the model.

cino and Punzi (2014), Rubio and Carrasco-Gallego (2014), Guerrieri and Iacoviello (2017)). However, few works among the mentioned papers explicitly model the banking sector. Brzoza-Brzezina et al. (2017) use a small open economy model with a shortcut of the banking sector for studying the role of foreign currency loans in the monetary and macroprudential policies, but their model does not contain any friction in the banking sector nor a distinction between the mortgage credit flow and stock. Gerali et al. (2010) do consider frictions in the banking sector but they also do not differentiate between mortgage lending flow and stock. We try to fill this gap by considering a DSGE model in which banks are explicitly modelled in a monopoly competitive market and mortgage loan stocks and flows are explicitly differentiated in the model.
This study is also related to the growing body of literature on macroprudential policies. Several previous papers have explored the effectiveness of macroprudential policies using stochastic general equilibrium models. In particular, Lubello and Rouabah (2017) use a DSGE model with a shadow banking sector that is calibrated on Euro Area data to assess the role of the macroprudential policy in mitigating the effects of both real and financial shocks. However, their calibrated model does not account for the housing sector. Fève and Pierrard (2017) recently tackled macroprutdential regulation using an estimated DSGE model with shadow banking but without a housing sector. Overall, few studies have been interested in exploring the optimality of the macroprudential policies (Rubio and Carrasco-Gallego (2014), Mendicino and Punzi (2014), Punzi and Rabitsch (2018)). However, none of these studies focus on the interaction between macroprudential instruments. Most of these papers analyze optimal interactions between the monetary policy and the macroprudential policy using calibrated models rather than assessing the optimal interaction of macroprudential policies.
Our work fits into the literature on combinations of macroprudential instruments. This strand of literature is growing and most studies address the combination of borrower-based instruments using regression techniques (Kelly et al.(2018) and Albacete et al.(2018) among others). Some exceptions include Chen and Columba (2016), Grodecka(2017) and Greenwald (2018) who analysed the combination of borrower based instruments using the DSGE modelling approach. Fewer works investigate the combination between borrower and capital-based instruments using the DSGE modelling approach. In particular, Benes et al.(2016) use a DSGE model for studying the effectiveness of the countercyclical capital buffer and the LTV ratio without any optimality analysis.
Finally, the literature on the explicit distinction between credit flow and debt stock has a connection with our work. As far as we know, there exist only three papers in this case: Kydland et al. (2016), Grodecka(2017) and Alpanda and Zubairy (2017). These authors investigate household indebtedness or the effectiveness of macroprudential instruments by distinguishing mortgage credit flow from debt stock. However, they do not model the banking sector contrary to what we are doing in this study. Unlike these authors, we precisely emphasize the traditional feedback loop between the financial and real sector by incorporating the banking sector *à la*

Gerali et al. (2010) in our modelling approach.

The rest of the paper is organised as follows. Section 2 describes the model and Section 3 presents its estimation results. Section 4 describes the mocroprudential instruments and investigates an optimal macroprudential framework. Section 5 lays out main results and Section 6 concludes.

2. Model

We consider a closed-economy DSGE model with housing sector, a borrowing constraint and household debt[3]. Two groups of households populate the economy, each group having a unit mass: patient households and impatient households. Patient households are savers and have higher discount factors than those of impatient households who are borrowers ($\beta_P > \beta_I$). This heterogeneity in agents' discount factors generates positive fund flows in equilibrium: patient households make positive deposits and do not borrow, while impatient households borrow a positive amount of loans. Patient households consume, work and accumulate capital and housing. Impatient households consume, work and accumulate housing. As impatient households are considered to be borrowers, they are constrained by having to collateralize the value of their net worth (financial friction).

We introduce a monopolistically competitive banking sector *à la* Gerali et al.(2010). Banks intermediate the funds that flow from patient households to impatient households as they have different degrees of impatience. Banks issue loans to impatient households by collecting deposits from patient households and accumulating their own capital out of reinvested profits. A second financial friction is introduced in the model by assuming that banks are subject to a risk weighted capital requirement constraint that translates into an exogenous target for the leverage ratio, deviation from which imply a quadratic cost. Unlike Gerali et al. (2010), we introduce a distinction between the mortgage credit flow and stock following Kydland et al. (2016) and Alpanda and Zubairy (2017).

On the production side, monopolistically competitive intermediate-goods-producing firms produce heterogeneous intermediate goods using physical capital, bought from capital goods producers, and labour supplied by households against sticky wages *à la* Calvo (1983). The prices of intermediate goods are also set in a staggered fashion *à la* Calvo (1983). Final goods-producing firms, who bundle intermediate goods into final goods, capital and housing producers operate in perfectly competitive markets.

Finally, a passive government covers its expenditures and transfers to households by issuing bonds that are purchased by savers and a monetary authority follows a standard Taylor-type interest rate rule.

2.1. Households

There are two types of households in the economy, each of unit mass and indexed by I and P. Households derive utility from consumption $c_{z,t}$, housing services $h_{z,t}$ and hours worked,

[3]The assumption based on a closed economy model for Luxembourg is made by only focusing on domestic banks operating in the mortgage sector in Luxembourg as only 8% of mortgage loans from these banks in recent years are extended to non-residents. Moreover, the external trade balance would not matter for the dynamics of house stocks and prices.

$n_{z,t}$, so that the expected utility of the representative household i in each group is:

$$E_0 \sum_{s=0}^{\infty} \beta_z^t \Big[\mu_{c,t}(1-a) \ln \Big(c_{z,t}(i) - a c_{z,t-1} \Big) + \mu_{h,t} \chi_h \ln \Big(h_{z,t}(i) \Big) - \chi_n \frac{\Big(n_{z,t}(i) \Big)^{1+\phi}}{1+\phi} \Big] \tag{1}$$

where $z \in \{I, P\}$ denotes the two groups of households and β_z is the discount factor (with $\beta_P > \beta_I$). a is the external habit parameter, χ_h and χ_n are the relative weight in the utility function. ϕ denotes the inverse of the Frisch-elasticity of labour supply. $\mu_{c,t}$ and $\mu_{h,t}$ are the preference shocks affecting consumption and housing demands, respectively, and follow the AR(1) processes as below:

$$\ln(\mu_{c,t}) = \rho_c \ln(\mu_{c,t-1}) + \epsilon_{c,t} \tag{2}$$

$$\ln(\mu_{h,t}) = \rho_h \ln(\mu_{h,t-1}) + \epsilon_{h,t} \tag{3}$$

2.1.1. Patient households

The representative patient household i maximizes the expected utility function (1) subject to the following budget constraint (in real terms)

$$\begin{aligned} c_{P,t}(i) + q_{h,t} \Big[h_{P,t}(i) - (1-\delta_h) h_{P,t-1}(i) \Big] + q_{k,t} \Big[k_t(i) - (1-\delta_k) k_{t-1}(i) \Big] + d_t(i) + b_t(i) = \\ w_{P,t}(i) n_{P,t}(i) + r_{k,t} k_{t-1}(i) + (1 + r_{t-1}) \Big[\frac{d_{t-1}(i) + b_{t-1}(i)}{\Pi_t} \Big] + tr_{P,t} + \Lambda_t \end{aligned} \tag{4}$$

where $h_{P,t}$ and k_t are accumulated housing and physical capital with $q_{h,t}$ and $q_{k,t}$ their respective real prices. The stock of housing and physical capital depreciate at rates δ_h and δ_k, respectively. d_t defines real deposits made in the period and b_t is the real amount of one-period government bonds purchased by patient households, on which they earn a gross nominal interest rate of $(1 + r_t)$. $\Pi_t \equiv P_t / P_{t-1}$ defines the gross inflation rate with P_t as consumption goods prices. $r_{k,t}$ denotes the rental rate of physical capital received from the intermediate goods producing firms, while $w_{P,t}$ stands for the real wage. Patient households receive lump-sum transfers from government, $tr_{P,t}$, and dividends from monopolistically competitive firms and banks, Λ_t.
The first order conditions derived from the patient households' problem are[4]:

$$U^c_{P,t}(i) = \beta_P E_t \Big[U^c_{P,t+1}(i) \frac{(1 + r_t)}{\Pi_{t+1}} \Big] \tag{5}$$

$$U^c_{P,t}(i) q_{k,t} = \beta_P E_t \Big[U^c_{P,t+1}(i) \Big(r_{k,t+1} + q_{k,t+1}(1 - \delta_k) \Big) \Big] \tag{6}$$

$$U^c_{P,t}(i) q_{h,t} = U^h_{P,t}(i) + \beta_P (1 - \delta_h) E_t \Big(U^c_{P,t+1}(i) q_{h,t+1} \Big) \tag{7}$$

[4] The optimal condition related to wage setting is provided in Subsection 2.1.3.

where $U^c_{P,t}$ and $U^h_{P,t}$ are respectively the household marginal utilities with respect to consumption and housing.

2.1.2. Impatient households

The representative impatient household i also maximizes the expected utility function (1) subject to the following budget constraint

$$c_{I,t}(i) + q_{h,t}\Big[h_{I,t}(i) - (1-\delta_h)h_{I,t-1}(i)\Big] + (r_{M,t-1}+\kappa)\frac{de_{t-1}(i)}{\Pi_t} = \\ w_{I,t}(i)n_{I,t}(i) + l_t(i) + tr_{I,t} \quad (8)$$

and the following collateral constraint

$$l_t(i) \leq m_{h,t}\left[\frac{(1-\delta_h)E_t q_{h,t+1}h_{I,t}(i)\Pi_{t+1}}{(1+r_{L,t})} - (1-\kappa)\frac{de_{t-1}(i)}{\Pi_t}\right]\mu_{m,t} \quad (9)$$

where $h_{I,t}$ is housing accumulated by impatient households. The latter don't accumulate any physical capital and borrow l_t from banks at a gross nominal interest rate of $(1+r_{L,t})$. They earn $w_{I,t}$ as wages and receive lump-sum transfers, $tr_{I,t}$, from government as for patient households. $m_{h,t}$ denotes the loan-to-value (LTV) on total mortgage loans and is set by the macroprudential authority. The collateral constraint (9) means impatient households cannot borrow more than a fraction of the expected value of their net wealth (the expected value of the housing stock minus the real value of non-amortized debt)[5]. $\mu_{m,t}$ defines an exogenous LTV shock which follows an autoregressive process AR(1).
$(r_{M,t-1}+\kappa)\frac{de_{t-1}(i)}{\Pi_t}$ is impatient households (borrowers) mortgage payments, defined as the sum of interest and principal payments. $r_{M,t}$ denotes the effective interest rate on all mortgage outstanding and κ is the amortization rate determining the principal payments out of the stock of debt.
Therefore, the stock of mortgage debt evolves according to:

$$de_t(i) = (1-\kappa)\frac{de_{t-1}(i)}{\Pi_t} + l_t(i) \quad (10)$$

New and refinanced loans are both subject to the period interest rate $r_{L,t}$ set by the banks. Following Alpanda and Zubairy (2017), the effective interest rate is assumed to be:

$$r_{M,t} = (1-\zeta)\left(1-\frac{l_t}{de_t}\right)r_{M,t-1} + \left[\left(\frac{l_t}{de_t}\right) + \zeta\left(1-\frac{l_t}{de_t}\right)\right]r_{L,t} \quad (11)$$

[5]As in Iacoviello (2005), we assume that the shocks are small enough that the collateral constraint always binds.

where the fraction of existing loans that are refinanced each period is ζ.
If $\zeta = 1$, all mortgage loans are refinanced and the effective rate equals the new loan rate ($r_{M,t} = r_{L,t}$), while when $\zeta = 0$ the model features no refinanced loans. Furthermore, note that if $\kappa = 1$ the model does not differentiate debt stock and loans ($l_t(i) = de_t(i)$) and we have one-period debt as common in the literature and the effective interest rate would again simply equal the banking new loan rate ($r_{M,t} = r_{L,t}$).
The first order necessary conditions from impatient households' maximization problem are:

$$U^c_{I,t}(i)q_{h,t} = U^h_{I,t}(i) + \beta_I(1-\delta_h)E_t\Big(U^c_{I,t+1}(i)q_{h,t+1}\Big) + \mu_t m_{h,t}\mu_{m,t}(1-\delta_h)\frac{E_t(q_{h,t+1}\Pi_{t+1})}{(1+r_{L,t})} \tag{12}$$

$$\mu_t = \Theta_{d,t} + \Theta_{r,t}r_{L,t} - 1 \tag{13}$$

$$\Theta_{r,t} = \beta_I \frac{U^c_{I,t+1}(i)}{U^c_{I,t}(i)}\left[\frac{(1-\zeta)(1-\kappa)\Theta_{r,t+1} - 1}{\Pi_{t+1}}\right] \tag{14}$$

$$\Theta_{d,t} + \Theta_{r,t}r_{M,t} = \beta_I \frac{U^c_{I,t+1}(i)}{U^c_{I,t}(i)} \left[\frac{-r_{M,t} - \kappa - \mu_{t+1}(1-\kappa)\mu_{m,t+1}m_{h,t} + (1-\kappa)\left[\Theta_{d,t+1} + \Theta_{r,t+1}((1-\zeta)r_{M,t} + \zeta r_{L,t+1})\right]}{\Pi_{t+1}}\right] \tag{15}$$

where μ_t denotes the Lagrange multiplier on the collateral constraint, $\Theta_{d,t}$ is the Lagrange multiplier with respect to the law of motion of debt and $\Theta_{r,t}$ defines the Lagrange multiplier on the effective interest rate evolution. These Lagrange multipliers are defined relative to the Lagrange multiplier on the budget constraint.

2.1.3. Wage setting

In order to introduce wage stickiness in the model, we assume that labour services are heterogeneous across households within each group, which gives to households some pricing power in setting their own wages. These differentiated labour services are aggregated into a homogeneous labour service (using a CES aggregator) by perfectly competitive labour intermediaries (called unions or labour packers), who in turn rent these labour services to goods producers [6]. Therefore, the profit maximization of the unions provides the following demand curve facing each household i of each type $z \in \{I, P\}$:

$$n_{z,t}(i) = \left(\frac{w_{z,t}(i)}{w_{z,t}}\right)^{-\epsilon_w} n^d_{z,t} \tag{16}$$

[6] Note that there two unions for the two groups of households.

where $n^d_{z,t}$ is the aggregate demand for homogeneous labour services with $w_{z,t}$ as the aggregate real wage and $\epsilon_w > 1$ denotes the elasticity of substitution between the differentiated labour services.

Following Calvo (1983), we assume that households are not freely able to adjust their wage each period. In particular, each period a randomly selected fraction of households, $1-\theta$, is given the opportunity to optimally adjust their nominal wage and θ of households cannot adjust their nominal wage.

In the period t, the real wage of each updating household i is $w^*_{z,t}$ and let's define the one of each non-updating household i as $w_{z,t-1}(i)\Pi_t^{-1}$. By considering the problem of a household who can update its wage in period t, the probability that nominal wage it chooses today will still be relevant in $t+s$ is θ^s and the corresponding real wage is $w_{z,t}(i)\Pi^{-1}_{t,t+s}$ (where $\Pi_{t,t+s} \equiv P_{t+s}/P_t$). Plugging the labour demand in the part of households' maximization problem related to the choice of labour and solving the latter yields the following optimal common real wage for all updating households of type $z \in \{I, P\}$:

$$w^{*1+\epsilon_w\phi}_{z,t} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{E_t \sum\limits_{s=0}^{\infty} \Big(\beta_z\theta\Big)^s \chi_n w^{\epsilon_w(1+\phi)}_{z,t+s} \Big(\Pi_{t,t+s}\Big)^{\epsilon_w(1+\phi)} \Big(n^d_{z,t}\Big)^{1+\phi}}{E_t \sum\limits_{s=0}^{\infty} \Big(\beta_z\theta\Big)^s \lambda_{z,t+s} w^{\epsilon_w}_{z,t+s} \Big(\Pi_{t,t+s}\Big)^{\epsilon_w - 1} n^d_{z,t}} \tag{17}$$

The aggregate real wage in the economy is then:

$$w^{1-\epsilon_w}_{z,t} = (1-\theta) w^{*1-\epsilon_w}_{z,t} + \theta \Pi_t^{\epsilon_w - 1} w^{1-\epsilon_w}_{z,t-1} \tag{18}$$

2.2. Banking sector

The banking sector is built up of a continuum of banks $j \in [0, 1]$. Following Gerali et al. (2010) and Gambacorta and Signoretti (2014), we assume that each bank j is composed of two segments: a wholesale branch and a retail branch.

The perfectly competitive wholesale segment collects deposits $d_t(j)$ from patient households paying a net interest rate r_t set by the central bank and issues loans $l_t(j)$ on which it earns the wholesale loan net rate $r^{\varpi}_{l,t}$. Furthermore, the bank has own funds $k_{b,t}(j)$, which are accumulated out of reinvested profits so that:

$$\Pi_t k_{b,t}(j) = (1-\delta_b) k_{b,t-1}(j) + \Lambda_{b,t-1}(j) \tag{19}$$

where $\Lambda_{b,t}(j)$ and δ_b are respectively profits made by the two branches and the fraction of bank capital consumed in each period in banking activity.

As in Gerali et al. (2010), we assume that the bank has a target τ_t for their capital-to-assets ratio (i.e., the inverse of leverage ratio) and pays a quadratic cost whenever it deviates from that target. The target can be interpreted as an exogenous regulatory constraint that imposes

the amount of own resources to hold. The existence of a cost for deviating from τ_t implies that bank leverage affects credit conditions in the economy.
Wholesale bank j's problem is therefore to maximize its profits subject to the following balance sheet constraint:

$$\max_{l_t(j),d_t(j)} r^{\varpi}_{l,t} l_t(j) - r_t d_t(j) - \frac{\chi}{2}\left(\frac{k_{b,t}(j)}{l_t(j)} - \tau_t\right)^2 k_{b,t}(j) \tag{20}$$

$$\text{s.t.} \quad l_t(j) = d_t(j) + k_{b,t}(j) \tag{21}$$

In the above equation, bank profits are the loan interest payments minus both deposit interest payments and the quadratic cost that bank is assumed to pay for deviating from its target leverage. The first order condition is given by:

$$r^{\varpi}_{l,t} = r_t - \chi\left(\frac{k_{b,t(j)}}{l_t(j)} - \tau_t\right)\left(\frac{k_{b,t}(j)}{l_t(j)}\right)^2 \tag{22}$$

This defines the cost of loans as the policy rate plus an endogenous spread related to the degree of bank leverage, with elasticity equal to χ.
The retail loan branch operates under monopolistic competition. This segment obtains wholesale loans from the wholesale segment at rate $r^{\varpi}_{l,t}$, differentiates them at no cost and resells them to final borrowers (i.e., impatient households) at rate $r_{L,t}$. As in Gambacorta and Signoretti (2014), we assume that the retail loan rate $r_{L,t}$ is set in the process by simply applying a constant mark-up m_b on the wholesale loan rate so that:

$$r_{L,t} = r_t - \chi\left(\frac{k_{b,t}(j)}{l_t(j)} - \tau_t\right)\left(\frac{k_{b,t}(j)}{l_t(j)}\right)^2 + m_b \tag{23}$$

Banks' total profit then evolves as follows:

$$\Lambda_{b,t}(j) = r_{L,t} l_t(j) - r_t d_t(j) - \frac{\chi}{2}\left(\frac{k_{b,t}(j)}{l_t(j)} - \tau_t\right)^2 k_{b,t}(j) \tag{24}$$

2.3. Capital and housing producers

2.3.1. Capital producers

In each period, perfectly competitive capital investment-goods producers purchase last-period undepreciated capital at price $q_{k,t}$ from patient households and $i_{k,t}$ capital investment goods from final-goods firms at a relative price of 1, and produce the new capital goods increasing the effective installed capital, which is then sold back to patient households at $q_{k,t}$. This transformation process is subject to adjustment costs in the change in investment and is described by the following law of motion for capital:

$$k_t = (1-\delta_k)k_{t-1} + \mu_{ik,t}\left[1 - \frac{\zeta_k}{2}\left(\frac{i_{k,t}}{i_{k,t-1}} - 1\right)^2\right] i_{k,t} \tag{25}$$

where ζ_k is the adjustment cost parameter and $\mu_{ik,t}$ denotes a capital-investment efficiency shock defined as an autoregressive process AR(1).
Capital producers choose $i_{k,t}$ so as to maximize:

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \lambda_{P,t} \left[q_{k,t} \left(i_{k,t} - \frac{\zeta_k}{2} \left(\frac{i_{k,t}}{i_{k,t-1}} - 1 \right)^2 i_{k,t} \right) - i_{k,t} \right] \tag{26}$$

where $\lambda_{P,t}$ represents the marginal utility for patient households.
The first order condition of firms provides $q_{k,t}$ as:

$$\begin{aligned} q_{k,t}\left[1 - \frac{\zeta_k}{2}\left(\frac{i_{k,t}}{i_{k,t-1}} - 1\right)^2 - \zeta_k\left(\frac{i_{k,t}}{i_{k,t-1}} - 1\right)\left(\frac{i_{k,t}}{i_{k,t-1}}\right)\right] \\ + \beta_P E_t\left[\frac{\lambda_{P,t+1}}{\lambda_{P,t}} \zeta_k q_{k,t+1} \frac{\mu_{ik,t+1}}{\mu_{ik,t}} \left(\frac{i_{k,t+1}}{i_{k,t}} - 1\right)\left(\frac{i_{k,t+1}}{i_{k,t}}\right)^2\right] = 1 \end{aligned} \tag{27}$$

2.3.2. Housing producers

We assume that residential investment producers act in a way that is analogous to the one of capital producers. They purchase the total investment goods $i_{h,t}$ from final-goods firms at a relative price 1, combine this with the existing housing stock and produce new housing stock that can be purchased by households at the installed price $q_{h,t}$. This process is subject to adjustment costs and evolves according to:

$$h_t = (1-\delta_h)h_{t-1} + \mu_{ih,t}\left[1 - \frac{\zeta_h}{2}\left(\frac{i_{h,t}}{i_{h,t-1}} - 1\right)^2\right] i_{h,t} \tag{28}$$

where ζ_h is the adjustment cost parameter and $\mu_{ih,t}$ denotes a housing-investment efficiency shock defined as an autoregressive process AR(1).
The maximization of housing producers' problem gives:

$$\begin{aligned} q_{h,t}\left[1 - \frac{\zeta_h}{2}\left(\frac{i_{h,t}}{i_{h,t-1}} - 1\right)^2 - \zeta_h\left(\frac{i_{h,t}}{i_{h,t-1}} - 1\right)\left(\frac{i_{h,t}}{i_{h,t-1}}\right)\right] \\ + \beta_P E_t\left[\frac{\lambda_{P,t+1}}{\lambda_{P,t}} \zeta_h q_{h,t+1} \frac{\mu_{ih,t+1}}{\mu_{ih,t}} \left(\frac{i_{h,t+1}}{i_{h,t}} - 1\right)\left(\frac{i_{h,t+1}}{i_{h,t}}\right)^2\right] = 1 \end{aligned} \tag{29}$$

2.4. Goods production

2.4.1. Final goods

Perfectly competitive final-goods producers purchased differentiated intermediate goods $j \in [0,1]$ that are bundled into final goods via the Dixit-Stiglitz aggregator:

$$y_t = \Big(\int_0^1 y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \Big)^{\frac{\epsilon}{\epsilon-1}} \tag{30}$$

where $\epsilon > 1$ is the elasticity of substitution among varieties of intermediate goods. Profit maximization by the final goods firm yields a downward-sloping demand curve for each intermediate good:

$$y_t(j) = \left(\frac{p_t(j)}{p_t} \right)^{-\epsilon} y_t \tag{31}$$

where $p_t(j)$ is the price of the intermediate good j and p_t denotes the aggregate price of final goods defined as:

$$p_t = \Big(\int_0^1 p_t(j)^{1-\epsilon} dj \Big)^{\frac{1}{1-\epsilon}} \tag{32}$$

2.4.2. Intermediate goods

A continuum of monopolistically competitive intermediate-goods producers $j \in [0,1]$ produce each intermediate good j according to the following production function:

$$y_t(j) = \mu_{y,t} \Big(k_{t-1}(j) \Big)^{\alpha} \Big[\Big(n^d_{I,t}(j) \Big)^{\eta} \Big(n^d_{P,t}(j) \Big)^{1-\eta} \Big]^{1-\alpha} \tag{33}$$

where α is the share of capital in overall production, and η denotes the share of impatient households in the labour input. $n^d_{P,t}(j)$ and $n^d_{I,t}(j)$ represent labour supplied by patient and impatient households. $\mu_{y,t}$ is the sector-wide total factor productivity which follows an AR(1)process, as

$$\ln(\mu_{y,t}) = \rho_y \ln(\mu_{y,t-1}) + \epsilon_{y,t} \tag{34}$$

Solving the cost minimization problem of firms and assuming a perfect symmetry across firms yields real aggregate ratios for factors and the real marginal cost as follow:

$$\frac{r_{k,t}}{w_{I,t}} = \left(\frac{\alpha}{1-\alpha} \right) \left(\frac{1}{\eta} \right) \frac{n^d_{I,t}}{k_{t-1}} \tag{35}$$

$$\frac{w_{I,t}}{w_{P,t}} = \left(\frac{\eta}{1-\eta} \right) \frac{n^d_{P,t}}{n^d_{I,t}} \tag{36}$$

$$mc_t = \left(\frac{1}{\alpha}\right)^{\alpha} \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(r_{k,t}\right)^{\alpha} \left(\frac{w_{I,t}}{\eta}\right)^{\eta(1-\alpha)} \left(\frac{w_{P,t}}{1-\eta}\right)^{(1-\eta)(1-\alpha)} \frac{1}{\mu_{y,t}} \tag{37}$$

Price rigidities are introduced in the model following the New Keynesian literature. Firms are subject to Calvo price-setting. As in Calvo (1983), each period there is a fixed probability of $1-\psi$ that a firm j can adjust its price at $p_t^*(j)$. If it cannot adjust, it set the price from the previous period $p_{t-1}(j)$. The dynamic problem of profit maximization of the firm that adjust its price in period t is:

$$\max_{p_t^*(j)} E_t \left\{ \sum_{s=0}^{\infty} \left(\beta_P \psi\right)^s \frac{\lambda_{P,t+s}}{\lambda_{P,t}} \left[\frac{p_t^*(j)}{p_{t+s}} \left(\frac{p_t^*(j)}{p_{t+s}}\right)^{-\epsilon} y_{t+s} - mc_{t+s} \left(\frac{p_t^*(j)}{p_{t+s}}\right)^{-\epsilon} y_{t+s} \right] \right\} \tag{38}$$

The first order condition provide the optimal price as:

$$p_t^*(j) = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta_P \psi)^s \lambda_{P,t+s} mc_{t+s} p_{t+s}^{\epsilon} y_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta_P \psi)^s \lambda_{P,t+s} p_{t+s}^{\epsilon-1} y_{t+s}} \tag{39}$$

The aggregate price level is given by:

$$p_t^{1-\epsilon} = (1-\psi)(p_t^*)^{1-\epsilon} + \psi p_{t-1}^{1-\epsilon} \tag{40}$$

2.5. Government and monetary policy

The government finances its exogenous consumption (g_t) and transfers to households (tr_t) by issuing debt (b_t). Accordingly, the government budget constraint is:

$$b_t - (1 + r_{t-1}) \frac{b_{t-1}}{\Pi_t} = g_t + tr_t \tag{41}$$

where g_t follows an AR(1) process and the aggregate transfers (tr_t) are distributed to patient and impatient households in the inverse proportion to their labour shares so as $\eta tr_{I,t} = (1-\eta) tr_{p,t}$. The central bank sets the monetary policy according to the following Taylor-type rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_1} \left[\left(\frac{\Pi_{t+1}}{\Pi}\right)^{\gamma_2} \left(\frac{y_t}{y}\right)^{\gamma_3} \right]^{1-\gamma_1} \mu_{r,t} \tag{42}$$

where $R_t = (1 + r_t)$ and $\Pi_t = (1 + \pi_t)$ are gross interest and inflation rates, respectively. γ_1 denotes the interest rate smoothing parameter and γ_2 and γ_3 are respectively inflation and output responses coefficients to interest rate changes. The variables without subscript $''t''$ are the steady state values of variables with subscript $''t''$. $\mu_{r,t}$ represents a monetary policy shock following an AR(1) process as:

$$\ln(\mu_{r,t}) = \rho_r \ln(\mu_{r,t-1}) + \epsilon_{r,t} \tag{43}$$

2.6. Market clearing conditions

The market clearing condition in goods market is given by:

$$y_t = c_t + q_{k,t}\left[k_t - (1-\delta_k)k_{t-1}\right] + q_{h,t}\left[h_t - (1-\delta_h)h_{t-1}\right] + g_t + \delta_b \frac{k_{b,t-1}}{\Pi_t} \tag{44}$$

where $c_t = c_{P,t} + c_{I,t}$ is aggregate consumption and $h_t = h_{P,t} + h_{I,t}$ denotes aggregate housing stock. In equilibrium, bond holding is zero ($b_t = 0$). The model's equilibrium is defined as a set of prices and allocations such that households maximize the discounted present value of utility, banks maximize the discount present value of profits, and all firms maximize the discounted present value of profits subject to their constraints, and all markets clear.

3. Estimation

We estimate the model using Bayesian methods and Luxembourg data. We estimate the structural parameters that mainly affect the model dynamics and calibrate the parameters that either determine the steady state so as to match key statistics in the data or are non-identifiable. In the section that follows, we first discuss the calibrated parameters, priors and data, and we then report the parameter estimates.

3.1. Calibration and priors

Table 1 reports the values of the calibrated parameters. Time is measured in quarters. The parameters are set in such a way that the model matches the data for Luxembourg. The steady-state gross inflation, Π, is set to 1.005, corresponding to the average long-run annual inflation rate of 2% in Luxembourg. We set the discount factor of patient households, β_P, at 0.999 in order to match the average annual Euribor rate of 2.1% in our sample (1999-2017). As for the discount factor of impatient households, β_I, we set it at 0.995 implying the average annual spread between the Euribor rate and loan rates on new mortgage contracts in Luxembourg of 190 bps.

The capital share in output, α, is calibrated at 0.3, corresponding to the share of labour income over GDP of 0.7 as per Luxembourg data. The capital depreciation rates in the residential (δ_h) and non-residential (δ_k) sectors are set respectively at 0.005 and 0.01 corresponding to residential and non-residential investments over their respective stock of capital in the data. The relative weight of housing in the utility function, χ_h, is calibrated such that the ratio of housing over consumption in the steady state is 0.043.

Setting the weight of labour in utility, χ_n,to 7 allows us to match the share of working time

of 1/3. The steady-state LTV ratio, m_h, is set at 0.7 consistent with the average data. The steady state value of capital-to -mortgage loan ratio (τ) is calibrated as 0.25 as provided by the Luxembourg end-period data (2017).
We calibrate the amortization rate for mortgage loans, κ, at 0.0165, which implies that the average duration of mortgage loans in the model is 20 years[7]. This value is consistent with Luxembourg data. Given this value and the ratio of debt to loan in the data, we infer that the share of loans that is refinanced in the model,ζ, is about 0.02, by assuming that the refinancing share of the first loan applications in data is small (10%) as there are no available Luxembourg data on this parameter.
Some steady state ratios are required for solving the models. Bank's capital-to-GDP ratio is set at 3% according to the end-period data. Public debt-to-GDP and spending-to-GDP ratios are respectively 23% and 20% as per the average data in the sample.
Parameters for which data are not available to calibrate are set following the literature. We calibrate the share of impatient households' income in labour income, η, at 0.7, following Alpanda and Zubairy (2017) and the fact that the BCL survey of Luxembourg households (HFCS, 2014) reports a small share of income of wealthier households (top deciles) over the total income declared.

All other parameters are estimated. The prior distributions are reported in Table 2. Our choices of prior distributions follow the literature and some theoretical restrictions. In particular, a Beta distribution is chosen for the parameters restricted to the interval [0, 1], Gamma and Normal distributions are chosen for the parameters which are assumed to be positive and an Inverse-Gamma distribution is used for the standard deviation of shocks. The prior means and standard errors are closely chosen from the literature. More precisely, we pick a mean value of 0.85 for both Calvo parameters of price (ψ) and wage stickiness (θ), implying a frequency of price adjustment of 6 quarters. This value is close to the one estimated in Iacoviello and Neri (2010). The mean of the habit formation degree in consumption, a, is set at 0.4, close to the value in Iacovellio (2015) and Iacoviello and Neri (2010). The mean of parameters governing the adjustment cost in housing (ζ_h), capital (ζ_k) and banking (χ) are picked respectively as 2, 2 and 1. The mean of elasticities of substitution between differentiated goods, ϵ, and differentiated labour, ϵ_w , are both set to 6, which implies a value of the steady-state markup of 20%, following Gerali et al. (2010). We allow the monetary policy rule to have a mean of the smoothing parameter of about 0.8, a mean of the response to inflation of about 2.2, and the mean of the response to output of about 0.04. A mean of 0.5 is chosen for autoregressive coefficients of shocks.

[7]Following Alpanda and Zubairy (2017), we approximate the duration by 2 times the half-life of the loan.

Table 1: Calibrated parameters

Description	Parameter	Value
Discount factor of patient households	β_P	0.999
Discount factor of impatient households	β_I	0.995
Capital share in output	α	0.3
Residential capital depreciation rate	δ_h	0.005
Non-residential capital depreciation rate	δ_k	0.01
Weight of housing in the utility	χ_h	0.3
Weight of labour in utility	χ_n	7
LTV ratio	m_h	0.7
Capital-to-asset ratio	τ	0.25
Amortization rate	κ	0.0165
Share of refinanced loans	ζ	0.02
Capital-to-GDP ratio	$\frac{k_b}{Y}$	0.03
Public debt-to-GDP ratio	$\frac{b}{Y}$	0.23
Public spending-to-GDP ratio	$\frac{G}{Y}$	0.2
Share of impatients in labour income	η	0.7

3.2. Data

We use the following 8 observable series for the estimation: real private consumption, real house price index, real residential investment, real non-residential investment, domestic households' mortgage debt stock, total hours worked, CPI inflation rate, and the Euribor interest rate (6 months). The real residential investment in data is defined by the dwellings gross fixed capital formation and the gross fixed capital formation excluding dwellings denotes the real non-residential investment. Data series are collected quarterly and the sample period is 1999Q-2017Q4. Series with seasonal patterns are seasonally adjusted by the Census X-12 procedure and those with trend are HP-filtered in order to make them stationary, while both interest and inflation rate are demeaned.

3.3. Posterior estimates

The posterior distributions of the parameters are obtained using the Metropolis-Hastings algorithm with 2 chains of 200 000 draws. The acceptance rate by chain was 0.25. Convergence was assessed by the convergence statistics proposed by Brooks and Gelman (1998).
Table 2 reports the mean and the 5th and 95th percentiles of the posterior distributions of the estimated parameters. Clearly, it appears that data are quite informative about most of the parameters and the parameter estimates are in line with the literature. The posterior mean of the habit formation in consumption is found reasonable to be 0.51, which is close to the estimates from Iacoviello (2015) and Guerrieri and Iacoviello (2017). The Calvo price and wage

parameter estimates are found to be 0.65 and 0.34 respectively, suggesting that price and wage stickiness are somewhat low. In addition, prices seem to be two times more sticky than wages, which is not surprising given the dynamic and the flexibility in labour market in Luxembourg. The estimates for the adjustment cost parameters are quite low, implying that housing and capital can be traded easily between households. The monetary policy is reasonably persistent with a mean equal to 0.67 and the mean estimates for the reaction coefficients to inflation and output are 2.45 and 0.047, respectively.

Table 2: Estimated parameters

		Prior distribution			**Posterior distribution**	
Parameter	Description	Distribution	Mean	SD	**Mean**	**95% interval**
a	Habit in consumption	Beta	0.4	0.02	0.5077	[0.4782 0.5296]
ϕ	Inverse of Frisch elasticity	Gamma	1	0.15	1.1585	[0.8368 1.4704]
θ	Calvo wage stickiness	Beta	0.85	0.1	0.3370	[0.2426 0.4370]
ψ	Calvo price stickiness	Beta	0.85	0.1	0.6577	[0.6109 0.7039]
ϵ_w	Labour substitution elasticity	Gamma	6	1.5	4.1131	[2.0805 6.2955]
ϵ	Goods substitution elasticity	Gamma	6	1.5	5.6797	[3.9188 7.6730]
ζ_k	Capital investment adj. cost	Gamma	2	1.5	0.2165	[0.1531 0.2841]
ζ_h	Housing investment adj. cost	Gamma	2	1.5	0.2870	[0.2009 0.3831]
χ	Bank leverage deviation cost	Normal	1	0.1	0.6582	[0.4818 0.8565]
γ_1	Taylor rule smoothing coeff.	Beta	0.8	0.1	0.6758	[0.5943 0.7496]
γ_2	Taylor rule coeff. on inflation	Normal	2.2	0.15	2.4582	[2.2154 2.7015]
γ_3	Taylor rule coeff. on output	Normal	0.04	0.01	0.0476	[0.0293 0.0668]
ρ_c	AR consumption pref. shock	Beta	0.5	0.15	0.5765	[0.3888 0.7535]
ρ_h	AR housing pref. shock	Beta	0.5	0.15	0.7006	[0.6324 0.7696]
ρ_y	AR productivity shock	Beta	0.5	0.15	0.2162	[0.1054 0.3303]
ρ_r	AR monetary policy shock	Beta	0.5	0.15	0.1606	[0.0612 0.2651]
ρ_q	AR LTV shock	Beta	0.5	0.15	0.0684	[0.0187 0.1233]
ρ_k	AR capital invest. shock	Beta	0.5	0.15	0.4109	[0.3402 0.4806]
ρ_{hi}	AR housing invest. shock	Beta	0.5	0.15	0.9802	[0.9634 0.9947]
ρ_g	AR gov. spending shock	Beta	0.5	0.15	0.8618	[0.8179 0.9035]
σ_c	SD consumption pref. shock	Inv. gamma	0.001	0.1	0.1277	[0.0958 0.1635]
σ_h	SD housing pref. shock	Inv. gamma	0.001	0.1	0.9404	[0.6940 1.2005]
σ_y	SD productivity shock	Inv. gamma	0.001	0.1	0.0855	[0.0647 0.1075]
σ_r	SD monetary policy shock	Inv. gamma	0.001	0.1	0.0058	[0.0045 0.0071]
σ_q	SD LTV shock	Inv. gamma	0.001	0.1	0.2952	[0.2447 0.3475]
σ_k	SD capital invest. shock	Inv. gamma	0.001	0.01	0.5055	[0.3880 0.6258]
σ_{hi}	SD housing invest. shock	Inv. gamma	0.001	0.1	2.0861	[1.6924 2.5122]
σ_g	SD gov. spending shock	Inv. gamma	0.001	0.1	0.7573	[0.5868 0.9233]

4. Macroprudential instruments and the optimal policy framework

In this section, we discuss the instruments and the objectives of the macroprudential authority. We consider two macroprudential instruments: loan-to-value (LTV) and the sectoral capital requirement[8]. This includes all capital requirements that target or weigh on the mortgage sector, gathering the regulatory risk weights, the share of countercyclical capital requirements affecting mortgage loans and other broad capital based measures on banks, etc...[9]. For simplicity, we interpret this broad sectoral capital requirement as the most commonly risk weights (RW) on mortgage loans with the additional assumption that all risks born by the bank stem from the mortgage sector. We choose these instruments because of their direct impacts on house demand and prices and the policy need to assess the combinations of borrower and capital-based instruments. Therefore, our instruments capture the two key aspects of the macroprudential policy namely the demand and supply sides of mortgage loans.

In general, macroprudential policies in standard DSGE models consist of exogenously setting macroprudential instruments at fixed values, which are not time varying as they are not affected by economic conditions. In this work, we first take into account these types of static ratios and we further extend the model by introducing the macroprudential policy rules for the two aforementioned tools. These rules can define how macrprudential policies could work in practice. When the LTV ratio is high, the borrowing constraint is less tight and impatient households (borrowers) will borrow as much as they are allowed to. Conversely, a low LTV ratio tightens the constraint and reduce the loans that borrowers can obtain from banks. Moreover, bank capital would have a key role in determining credit supply as it potentially generates a feedback loop between the real and the financial side of the economy. Higher risk weighted capital requirements constrain the banks to have more capital for given mortgage loans, which forces them to reduce their loans.

4.1. Macroprudential policy instruments

4.1.1. Static ratios

We start by looking at the policy case where both the instruments (LTV and RW) are exogenous and defined as fixed parameters. We then find the optimal values of these LTV and RW ratios. The optimality criteria will be defined later.

[8] Note that the current model allows for taking into account another macroprudential tool which is the amortization requirement. To make the analysis more tractable, we only focus on the two mentioned instruments in the current study and we plan to analyse the amortization requirement in the future work.

[9] We refer to as the shares of capital charges on banks that could weigh on mortgage lending, having in mind that all broad regulatory capital requirements might affect the mortgage sector.

4.1.2. Dynamic and endogenous rules

In this section, we assume that LTV and RW measures are not static but dynamic and endogenous in the sense that they depend on some endogenous variables of the model, as described below.

LTV rule

As in Kannan et al. (2012) and Rubio and Carrasco-Gallego (2014), we assume that a regulatory macroprudential policy for LTV (denoted as $m_{h,t}$) is time varying and a Taylor-type rule so that it reacts inversely to the credit-to-GDP gap, in the spirit of the Basel III regulation which aims at addressing episodes of excessive credit growth:

$$m_{h,t} = m_{h,op} - \phi_l \hat{\Delta}_t \tag{45}$$

Here $m_{h,op}$ is the optimal static level of LTV, $\hat{\Delta}_t$ denotes the mortgage loan-to-GDP gap and ϕ_l measures the responses of the LTV cap to the the gap. With this kind of rule, LTV would be set low in booms, restricting credit to the housing sector and therefore avoiding a mortgage boom stemming from economic upswings (and conversely for economic downturns).

Sectoral risk weighted rule

The risk weighted capital requirement rule (RW) is a time varying Taylor-type rule reacting to a key macroeconomic variable as in Angelini et al. (2012). We choose this variable to be the cyclical component of output. The risk weighted capital requirement (denoted by τ_t) is then set according to the following rule:

$$\tau_t = \tau_{op} + \chi_\tau \hat{y}_t \tag{46}$$

where τ_{op} measures the optimal static level of RW, $\hat{y}_t$ represents the cyclical component of output (i.e., a proxy for the output gap) and χ_τ denotes the response parameter of capital requirements to the business cycle. A positive value of χ_τ stands for a countercyclical policy: capital requirements increase during economic upswings (i.e., banks hold more capital for a given mortgage loan) and decrease in recessions. This capital requirement rule is in line with the countercyclical capital buffer introduced by Basel III.

4.2. An optimal macroprudential policy framework

An optimal policy analysis aims at identifying optimal values for the policy ratios or reaction parameters which could maximize the objective function of the macroprudential authority. Therefore, determining the optimal policy ratios requires defining the objective of the macroprudential/financial stability authority and then the optimality criteria.
It is challenging to model the objectives of macroprudential policies within a DSGE framework

since vulnerabilities in the financial system can arise wherever in various forms. Furthermore, there is no specific proxy or widely accepted definition of such policy objectives in the majority of macro models. Given the commonly accepted definition of the objective of the macroprudential authority, which is to safeguard the financial stability, some authors such as Rubio and Carrasco-Galego (2014) and Angelini et al. (2012) assume that there exists a loss function for the macroprudential authority. This loss function is considered to depend on a set of weighted variable volatilities and the authority minimizes it subject to the equilibrium conditions of the model. This approach is similar to the monetary economics approach in which the monetary policy authority minimizes its loss function.

However, using loss functions in a DSGE context is generally a short-cut approach of the social welfare analysis. The reason is that the loss function is derived from a second order approximation to the expected utility function of the representative household in the basic New Keynesian (NK) model in the absence of real and financial frictions (with only price stickiness)[10]. The authority's loss function therefore represents an average welfare loss and depends on the variability of some endogenous variables[11]. Moreover, the economic rationale behind the use of the welfare loss function as a policy objective function, which depends on the volatilities of variables, is that the volatility has an impact on the welfare of economic agents. For example, from a financial stability perspective, lower volatility of credit growth can smooth borrowers' consumption and therefore improves their welfare.

For these reasons, we use a welfare based approach in this work and the maximization of the social welfare as a proxy for the objective of the macroprudential authority. We therefore define the optimal macroprudential policy as the one that maximise the social welfare of the economy. Rather than using a weighted sum of volatilities as the macroprudential authority's loss function (like in Rubio and Carrasco-Galego (2014) and Angelini et al. (2012)), which is equivalent to the analytically derived welfare loss only in a basic NK model without real and financial frictions, we numerically compute the social welfare losses/gains since our model is far more complex than the basic NK model. We perform a grid search for values of macroprudential ratios and parameters of instruments that maximise the social welfare.

We compute the welfare loss/gain for each type of economic agent under each policy regime using optimal ratios and optimized parameters of rules. This provides an evaluation of the benefits of implementing different macroprudential policies. We follow Schmitt-Grohe and Uribe (2007) by computing the conditional welfare of agents using the second order approximation of the model (and rules).

The individual welfare for patients (savers) and impatients (borrowers) are respectively defined as:

[10]See for instance, Gali (2008), Gali and Monacelli (2005, 2008)

[11]The monetary policy authority's loss function depends for instance on the variability of both the output gap and the rate of inflation (See Gali (2008) for more details).

$$W_{P,t} = E_0 \sum_{s=0}^{\infty} \beta_P^t \left[\mu_{c,t}(1-a) \ln \Big(c_{P,t}(i) - a c_{P,t-1} \Big) + \mu_{h,t} \chi_h \ln \Big(h_{P,t}(i) \Big) - \chi_n \frac{\Big(n_{P,t}(i) \Big)^{1+\phi}}{1+\phi} \right] \tag{47}$$

$$W_{I,t} = E_0 \sum_{s=0}^{\infty} \beta_I^t \left[\mu_{c,t}(1-a) \ln \Big(c_{I,t}(i) - a c_{I,t-1} \Big) + \mu_{h,t} \chi_h \ln \Big(h_{I,t}(i) \Big) - \chi_n \frac{\Big(n_{I,t}(i) \Big)^{1+\phi}}{1+\phi} \right] \tag{48}$$

Following Rubio and Carrasco-Galego (2014), we define social welfare as a weighted sum of the individual welfare as follows:

$$W_t = (1-\beta_P) W_{P,t} + (1-\beta_I) W_{I,t} \tag{49}$$

To make the welfare results more intuitive, we define a welfare metric in terms of consumption equivalents. This consumption equivalent welfare measure is the constant fraction of steady-state consumption that households are willing to give away in order to obtain the benefits of the macroprudential policy. A positive value means a welfare gain, which is how much the consumer would be willing to pay to obtain a welfare improvement.
Formally, the welfare loss or gain is λ_w such as:

$$W_t(c_t, h_t, n_t) = W((1+\lambda_w)c, h, n) \tag{50}$$

where variables without subscript "t" denote their steady-state values,c_t, h_t and h_t are respectively aggregate consumption, housing services and labor[12].

5. Optimal values of LTV and RW and the dynamic of the model

In this section, we first present the optimal macroprudential ratios and optimal parameters for the rules along the lines of the concepts presented in the previous section. Afterwards, we discuss the dynamics of the model.
In this sense, we address an important policy question, among other things, of what would be the optimal ratios for LTV and RW and optimal parameters for the Taylor–type macroprudential rules in Luxembourg ? The results are discussed for an easy monetary policy environment and a LTV shock. A second order approximation of the model is used for solving the model and providing the following quantitative results[13].

[12] The similar welfare metric is used for computing the welfare loss/gain of individual agents.

[13] Second order approximation methods have a particular advantage of accounting for effects of volatility of variables on the mean levels. See among others Schmitt-Grohe and Uribe (2004).

5.1. Optimal LTV and RW ratios and optimized parameters of the policy rules

We start by computing volatilities and welfare losses/gains for the scenario in which LTV and RW are set to their average values based on data (i.e, the benchmark case). Afterwards, we report the results for a single instrument scenario (LTV alone), a two-instrument scenario (LTV and RW) and a scenario in which the model comprises the optimal rules for instruments. Table 3 shows the optimal ratios, optimal parameter values of policy rules, volatilities and the welfare gains/losses for different policy scenarios in a low interest rate environment. Note that when the two instruments are both used in the policy framework we assume that the set-up of the optimization exercise consists of searching for the optimal value of each ratio or rule's parameter while taking the other as given and set to its value based on the data. This is the non-joint optimization. The joint optimal values of the ratios from the joint optimization perspective are provided later.
When the two instruments are both used in the economy model (Column 3), the optimal static LTV ratio is found to be 90% while the optimal RW ratio is about 30%. These optimal levels imply a welfare gain for borrowers while savers face a welfare loss. Social welfare is therefore positive as a consequence of the welfare gain from the borrowers' side. The intuition is as follows: on one hand, increasing the LTV ratio has a direct effect on borrowers' welfare as the collateral constraint is loosened. However, up to a certain threshold, borrowers could be over-indebted as higher consumption levels imply higher interest rates (inflation being increased). This leads to higher repayments, which act to curb consumption and welfare levels.
On the other hand, higher interest rates imply higher returns on saving and as the savers' intertemporal optimization determines their consumption pattern, they reduce their consumption. This channel is reinforced by the increase in the inflation rate following the increase in loans to borrowers (higher LTV). These results are illustrated in Figure 4 below.

If the RW ratio is removed from the authority's macroprudential toolkit meaning that there are no capital requirements weighing on the banking sector, the scenario of a single LTV policy (Column 2) provides a tighter optimal value of 0.2 for the LTV ratio. This means the LTV ratio, used alone, may need to be tightened in an easy monetary policy environment, which can result in relatively low volatilities of credit and output while generating a welfare loss for the economy. Even if this scenario is less realistic in practice, it allows for assessing synergies and complementarities between LTV and RW measures in the context of the economy model.

Comparing the two-instrument policy scenario to the one with a single LTV policy, Table 3 (Benchmark Column and Column 3) shows that mortgage lending and output are less stabilized in the former than the latter case. However, the two-instrument policy implies a social welfare gain for the economy while the single LTV policy scenario provides a social welfare loss, suggesting that the two macroprudential instruments (LTV and RW) are complements in terms of welfare effects. The welfare gain of combination of the two instruments is around 1.21% in terms of consumption equivalents.

These results suggest that the policy scenario, among the two static scenarios, that provides a better stabilization of mortgage loans is not necessarily the one that is welfare improving. In particular, the implementation of both LTV and RW measures generates higher macro financial volatilities relative to a LTV only policy regime while the former case leads to higher welfare than the latter. This is explained by the fact the collateral channel effects stemming from an optimal tighter LTV worsens borrowers' welfare as they are more constrained to borrow and then to consume. The LTV ratio used in a single policy scenario should optimally be tight if facing a low interest rate environment, as it restricts and stabilises credit flows to borrowers and decreases or stabilizes their consumption and wealth effects from house acquisition on consumption fall. The presence of both the borrower - and capital-based instruments in the macroprudential toolkit, i.e., one (LTV) on the credit demand side and the other (RW) on the price side (i.e., loan rates), has a loosening effect on LTV along the values of the RW ratio. Figure 5 shows that the welfare characterisation is jointly dependent on LTV and RW with the welfare effects being somewhat convex. When the optimal RW ratio increases, the optimal ratio of LTV corresponding to the highest value of welfare is low and conversely, when the LTV increases the corresponding optimal RW decreases Therefore, the joint optimal value of LTV and RW are respectively 100% and 10% as illustrated by the elevated region (in blue) in Figure 5.

We finally compare the outcomes from the static LTV and RW ratios to those under their time varying rules. We find that introducing the macroprudential rules is welfare improving with an associated welfare gain of 0.43% compared to the case of the static ratios. Moreover, in terms of macro financial stabilization, mortgage lending and output are more stabilized under the policy rule scenario than under the static ratio scenario. The two-instrument rule provides better outcomes in terms of volatilities and welfare suggesting the interest of introducing such rules.

The results in terms of stabilisation of output and credit flows are consistent with the impulse response functions presented below.

Table 3: Optimal LTV and RW policies

	Benchmark	Optimal static policy		Optimal policy rules
		Single instrument	Two instruments	Two instruments
LTV	0.7	0.2	0.9	0.9
RW	0.2	-	0.3	0.3
ϕ_l	-	-	-	0.3
χ_τ	-	-	-	0.1
σ_l	17.7271	3.7614	16.4028	14.6057
σ_y	3.7178	3.3075	4.8729	4.6760
$\sigma_{(LTV+RW)}$	-	-	-	2.9762
Social welfare (losses/gains)	0.0002	-0.0032	0.0119	0.0162
Impatients (borrowers)	0.0409	-0.0005	0.1031	0.0863
Patients (savers)	-0.0390	-0.0060	-0.0717	-0.0494

Notes: Volatilities are expressed in %. The welfare metric used is the conditional welfare, computed conditionally on the initial state being the deterministic steady state of the model. The welfare losses/gains are expressed in terms of % of consumption equivalents. This is the same across policies. A second order approximation of the model is used for solving the model and providing those quantitative results.

Figure 4: Welfare losses/gains in function of LTV ratios

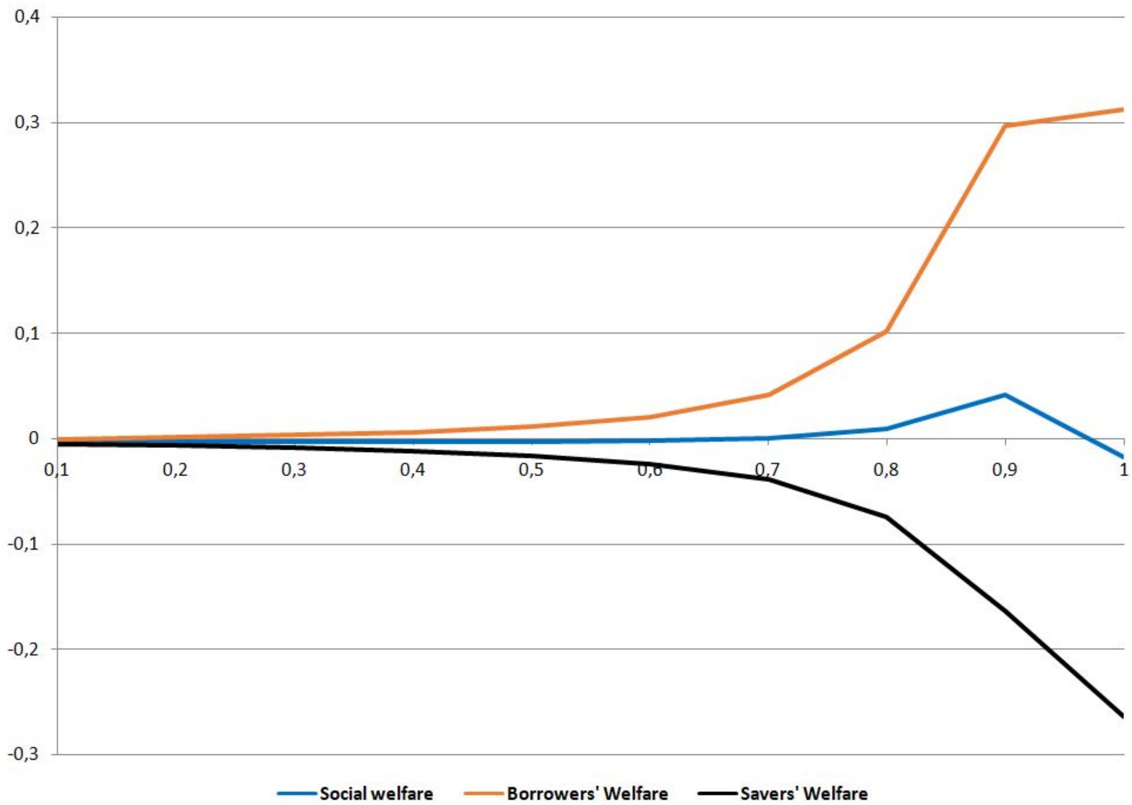
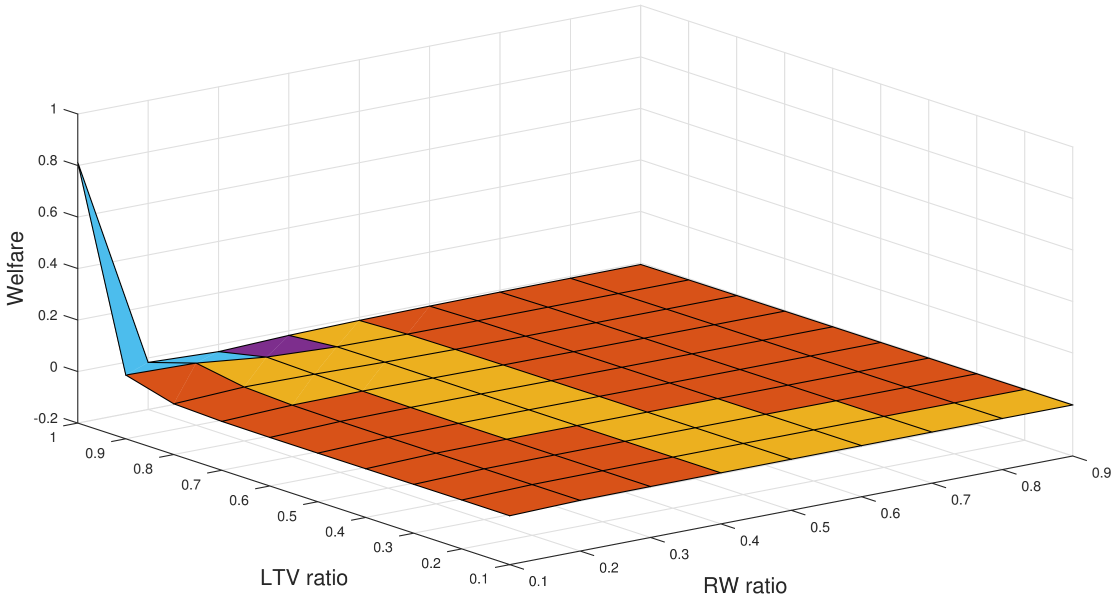


Figure 5: Welfare effects of interactions between LTV and RW ratios



5.2. Impulses responses

In order to understand the dynamics of the model and how the optimal LTV ratio interacts with the optimal RW, we simulate the impulse responses of the model using the optimal ratios and optimized parameters of the macroprudential rules we found in the previous section. We keep the model estimated parameters and supplement them with optimal ratios and policy rule parameters. We consider an easy monetary policy environment and a loosening LTV environment.

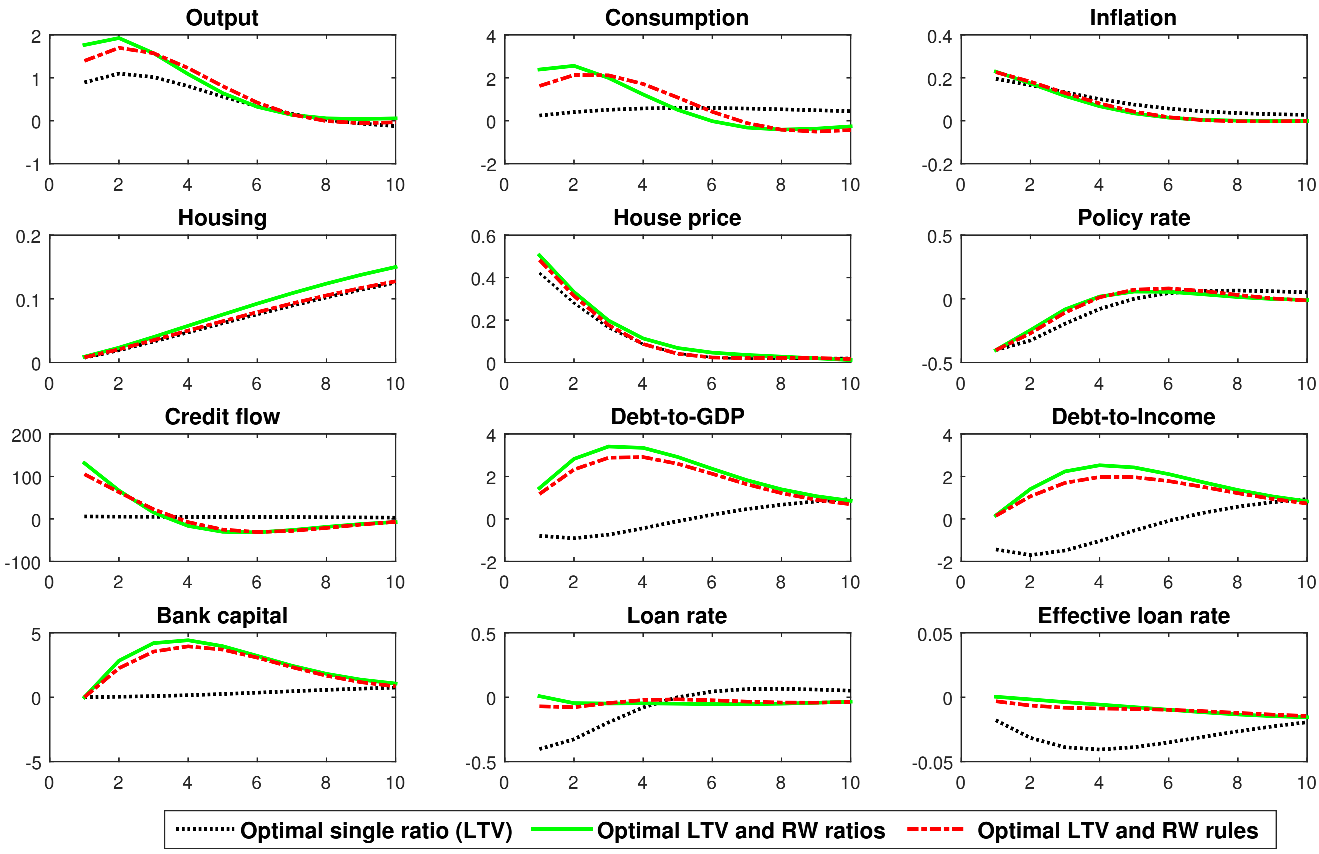
5.2.1. Effects of a monetary policy shock under optimal macroprudential policies

Figure 6 displays the expansionary effects of a 10 bps decrease in the monetary policy rate on the economy. This shock implies lower loan and effective borrowing rates. Consequently, mortgage loans increase along with overall mortgage debt stock, leading to an increase in the debt-to-GDP and debt-to-income ratios (except under the scenario with LTV ratio alone). The increase in mortgage loans supplied by banks positively impacts housing demand thereby increasing house prices. The rise in the house value generates an upswing of output and consumption. As the collateral constraint is binding with the LTV policy, the increase in mortgage loans is exacerbated following the increase in house value. The inflation rate goes up following the decline in the policy rate and subsequently due to the increase in total consumption. Bank capital increases as a consequence of higher profits stemming from an upswing of economic activity and housing loans.

Comparing the impulse responses under different policy scenarios provides some underlying economic intuitions for the results discussed so far. Figure 6 contrasts the optimal single ratio with the optimal two-instrument policy regime. As previously mentioned, mortgage credit flow is smoother under the single LTV policy case than the optimal two-instrument scenario. Therefore, debt-to –GDP and debt-to-income are decreasing in the wake of the expansionary interest rate shock under the former while they go up in the latter where loans are more volatile and increase more. This channel affects all other variables in the economy. Indeed, house prices increase less in the case of the single LTV ratio scenario than in the case of the two-instrument scenario. Output and consumption have hump-shape patterns. Output increases more in the two-instrument policy compared to the single policy case. This is explained by consumption pattern, which is subdued in the single policy regime due to a stronger mortgage loan restriction implied by a tight LTV ratio.

Overall, the differences between using LTV ratio alone and the two-instrument policy combination stem from the higher amount and volatility of loans in the latter policy scenario. As the optimal policy rules are not overly strict (i.e., non-aggressive coefficients for rules), Figure 6 shows that the paths of variables under that policy scenario are close to those of the case of two-static ratios with the exception of the more stabilized mortgage credit, debt-to-GDP, debt-to-income and house prices under the policy rules scenario.

Figure 6: Effects of an easy monetary policy



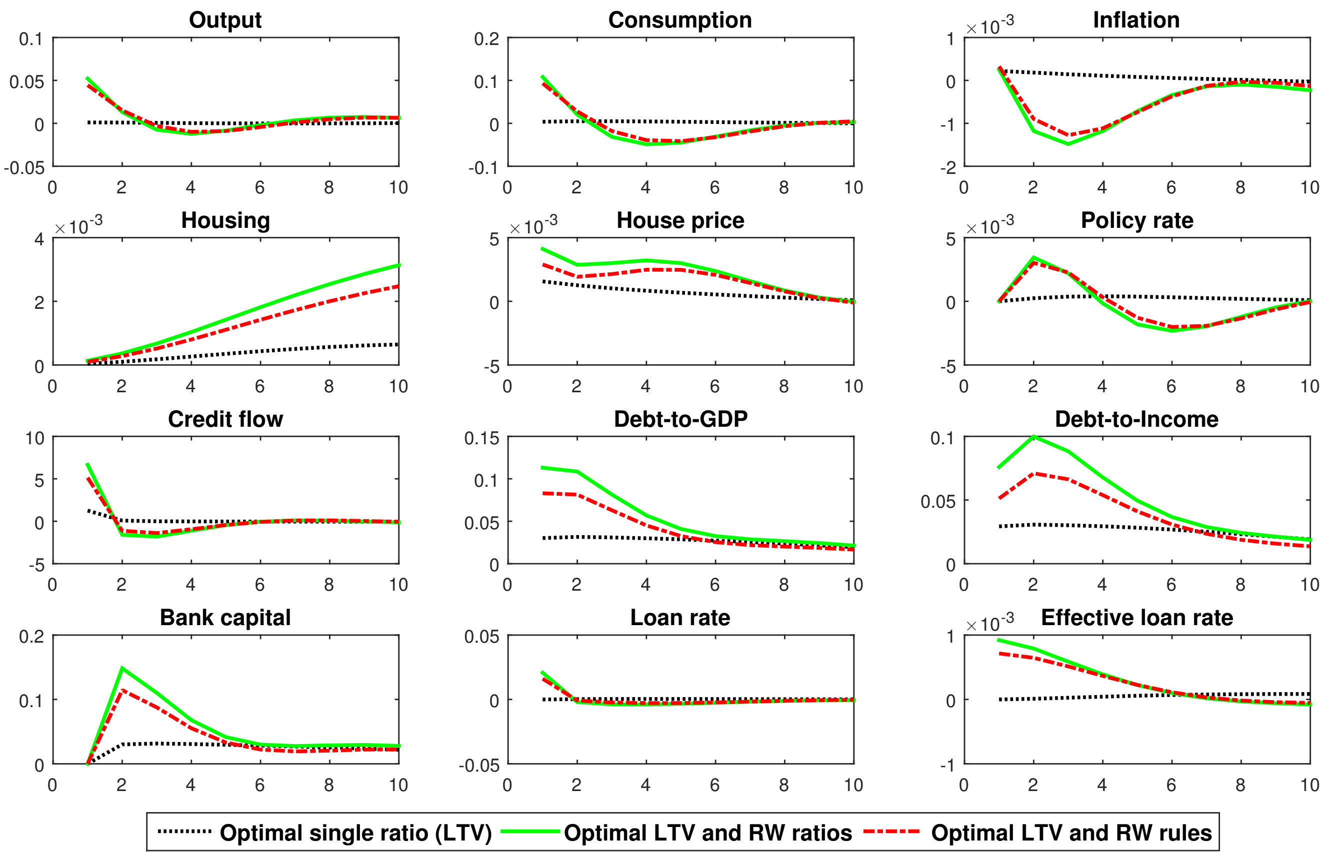
Notes: Time, measured in quarters, is on the horizontal axis. All variables are measured in % deviations from steady state, except inflation and the interest rates which are measured in annualized deviations from steady state.

5.2.2. Effects of a LTV shock under optimal macroprudential policies

Figure 7 displays the effects of a 100 bps increase in the regulatory LTV ratio (i.e., the loosening LTV) under different policy scenarios. This shock leads to expansionary effects and has a direct impact on the borrowing constraint of impatient households, loosening that constraint. This implies an increase in mortgage credit to households. As a consequence, debt stocks (debt-to-GDP and debt-to-income) and housing demand increases, leading to an increase in house prices. Consumption and output go up in the short term before going back to the steady state. Facing higher demand of loans stemming from higher housing demand, banks increase their loan rates. Due to the expansionary effects of easy credit standards on output, the policy rate increases in the short-term leading to a decline in the inflation rate and exacerbating the rise of loan rates.

The comparison of different policy scenarios on the basis of impulse responses does not change qualitatively their ranking compared to the previous results with the interest rate shock. Indeed, the single LTV ratio scenario has a better stabilization power of house prices, mortgage loan flow and stock, followed by the scenarios with the policy rules and the two ratios.

Figure 7: Effects of an increase in dynamic LTV



Notes: Time, measured in quarters, is on the horizontal axis. All variables are measured in % deviations from steady state, except inflation and the interest rates which are measured in annualized deviations from steady state.

6. Conclusions

In this work, we investigate the optimal macroprudential policies in Luxembourg. To address this question, we build a closed-economy DSGE model and estimate it on Luxembourg data using the Bayesian techniques. In comparison to the literature, our modelling approach brings together a monopolistically competitive banking sector, a collateral constraint and an explicit differentiation between the flow and the stock of household mortgage debt. We further contribute to the existing literature on this topic by identifying the optimal ratios and rules of the loan-to-value cap and the risk weighted capital requirement for Luxembourg. Specifically, we analyse the welfare effects of these instruments from a financial stability perspective and determine the optimal combination of a borrower and a capital-based macroprudential instruments for Luxembourg.

Based on a welfare analysis in a context of easy monetary policy environment, we first find that the non-joint optimal LTV and RW ratios for Luxembourg seem to be 90% and 30%, respectively, while the joint optimal ratios are found at 100% and 10% respectively. We also find that combining LTV and RW measures welfare-dominates the use of LTV alone suggesting a complementarity between these instruments in terms of welfare. We note that the latter policy performs better than the former with respect to mortgage debt and house prices stabilization effects. This result implies that the policy scenario that provides better stabilization effects on mortgage credits isn't necessarily the one that is welfare improving. In other words, LTV and RW measures can be considered as complements in terms of welfare, while their optimal combination diminishes the stabilization effects on mortgage debt and house prices. In particular, when LTV is applied alone in the context of an easy monetary policy environment, it is found to be too tight (i.e., 20%) to be realistic, leading to a welfare loss but helping to stabilize debt relative to the use of both LTV and RW ratios. In addition, the time-varying and endogenous LTV and RW rules improve overall social welfare and better stabilize the growth of mortgage loans and house prices relative to their static exogenous ratios. Finally, we find that the optimal interactions between LTV and RW ratios in our framework follow a convex shape. When LTV is increased, the corresponding optimal RW ratio is low and conversely when the RW ratio is increased, the corresponding optimal LTV ratio should be lowered.

In future work, we plan to extend the number and type of the macroprudential instruments in the analysis by including amortization requirements and/or introducing debt-to-income (DTI)/debt service-to-income (DSTI) constraints in the model. We also intend to explore the same topic investigated here in the context of a small open economy model.

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