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The effect of macroprudential policy on endogenous credit cycles

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Non-Technical Summary

The financial sector played a key role in triggering the recent crisis. Negative feedback loops between the financial sector and the real economy have further increased the persistence and amplitude of the downturn. A further implication was that microprudential and macroeconomic policy alone were insufficient to prevent financial crises. Macroprudential policy tools have come to the fore as a possible mechanism to ensure macro-financial stability. However, the DSGE models frequently used for policy analysis in many institutions and central banks did not account for these linkages. Therefore, these models need to be updated if appropriate responses to key policy questions are to be analysed.

We enhance EIRE Mod, a DSGE model of the Irish real economy, with the inclusion of a financial sector. This extension allows us to examine macro-financial feedback loops through the lens of the housing market. We find that the model is capable of replicating some key stylised facts from the bursting of the Irish property bubble. We show that expectations of future favourable events may accelerate credit growth and potentially result in a more vulnerable economy susceptible to downward revisions to the original expectations. The model is specifically designed to analyse the effect of macroprudential policy, with the focus on banks capital requirements and the newly implemented counter-cyclical capital buffer. We find that time-varying capital buffers are particularly effective in insulating the economy from these risks. Adjusting the minimum capital requirement in response to the financial cycles can encourage banks to develop capital buffers during periods of economic expansion. Reducing these during downturns can enable banks to play a role in economic recovery.

The effect of macroprudential policy on endogenous credit cycles*

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Abstract

The financial sector played a key role in triggering the recent crisis. Negative feedback loops between the financial sector and the real economy have further increased the persistence and amplitude of the downturn. We examine such macro-financial linkages through the lens of the housing market. We develop a model capable of replicating some key stylised facts from the bursting of the Irish property bubble. We show that expectations of future favourable events may accelerate credit growth and potentially result in a more vulnerable economy susceptible to downward revisions to the original expectations. We find that macro-prudential policy, in particular counter-cyclical capital requirements and larger capital buffers, can play a role in insulating the economy from these risks.

JEL classification: E44, E51, G10, G28.
Keywords: DSGE, macro-prudential policy, macro-financial linkages, capital requirements, Ireland.

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1 Introduction

DSGE models have become a powerful tool for policy analysis in many institutions and central banks. They provide a suitable framework to identify sources of macroeconomic fluctuations, assess and forecast the effect of policy changes and perform counter-factual experiments. In the aftermath of the recent financial crisis, however, some weaknesses in standard DSGE models have come to light. First, the crisis has called attention to the close interaction between financial and credit markets and the real economy. The financial sector played a key role in both triggering and propagating the crisis through macro-financial linkages.[1] Macro-financial feedback loops can increase the persistence and the amplitude of macroeconomic fluctuations. Therefore, a good understanding of business cycle dynamics requires enriching DSGE models with a properly designed financial sector. Second, before the crisis, real shocks were the main source of economic fluctuations. In such a framework, monetary policy represented the most powerful tool for achieving macroeconomic stability. In the aftermath of the crisis, it has become evident that new policy instruments, such as those in the macro-prudential space, may be needed to cope with an economic environment in which credit and the financial sector play such an important role. In light of such concerns, the models used by central banks need to be updated so as to include a financial sector and be able to assess the role of macro-prudential policies.

These concerns are particularly acute in a country like Ireland, where the bursting of a housing bubble has resulted in negative feedback loops between the financial sector and the real economy, causing a large recession. Residential property prices increased significantly in the run-up to the financial crisis and dropped dramatically after 2007. In response to the rapid decrease in asset values, particularly housing, Irish banks have become increasingly risk-averse and have reduced lending in order to re-

[1] A recent strand of the literature (*e.g.* Brunnermeier, 2009; Thomas and Nuño, 2013) argue that a key role in triggering and propagating the recent financial turmoil has been played by the "shadow" banking sector. This includes all those financial intermediaries that are engaged in maturity transformation, but have no access to central bank liquidity or public sector credit guarantees, and that are not subject to regulatory capital requirements. In this analysis, however, we concentrate on the traditional commercial banking sector.

build their balance sheets and conform to regulatory pressures (Figure 1). Due to both demand and supply factors, many households and firms have undertaken a wide-scale deleveraging (Figure 2) in order to pay-down some of the debt accrued during the bubble period (Holton and McCann, 2012; Gerlach-Kristen and Merola, 2013). A side-effect of credit tightening and deleveraging has been a large reduction in consumption and business investment, with the fiscal consolidation undertaken by the government further depressing domestic demand.

The reduction in domestic demand has coincided with higher unemployment and lower wages and disposable income (Figure 3). Lower disposable incomes and a greater risk of unemployment, combined with devalued collateral, have in turn led to an increase in non-performing loans (Figure 4), further damaging bank balance sheets. Due to a combination of higher credit risk and the need to repair their balance sheets, banks have responded by tightening credit standards (Figure 5). Such tightening took the form of both a reduction in lending volume (quantity), and higher interest rate spreads demanded on successful loan applications (price). Therefore, the spread charged on loans have been at an elevated level throughout the post-crisis period (Figure 6). Given this vicious cycle, the health of the banking sector and its ability to support the real economy with credit at sustainable rates has been identified as the largest uncertainty in Ireland's post-crisis adjustment (Central Bank of Ireland, 2013).

We develop a model to examine the macro-financial feedback loops which arise over the financial cycle, and seek to explain macroeconomic fluctuations resulting from these interactions. The model is also capable of undertaking analysis of alternative macro-prudential policies. We calibrate the model for Ireland and aim to replicate some of the key stylised facts, discussed above, from the recent housing boom and bust. This paper also examines whether macro-prudential policy is a successful instrument in increasing the resilience and moderating exuberance in the supply of credit from the financial system. We conduct simulations in order to illustrate the policy analysis capabilities of the model. These are designed to highlight the macro-financial feedback loops present in the model. Initially, we examine two scenarios, which provide insights into the motivations banks have for relaxing their credit standards before the crisis and becoming less risk-averse. In the first, we examine the role that over-optimistic expectations for future house prices play in the accumulation of credit risk. In the second, we examine the implications of lower cost of funds to banks and the resulting capital inflows. Both scenarios are able to reproduce the accumulation of imbalances and over-lending that have characterised the boom phase in Ireland, as well as the collapse in house prices and the large contraction in credit and economic activity experienced during the crisis. We then assess the impact that alternative macro-prudential policy tools can play in mitigating the build-up of these risks during "bad booms" driven by euphoria and over-optimistic expectations. In particular, we consider the implication of pro-active (or counter-cyclical) macro-prudential policies and larger capital buffers.

The paper is structured as follows. Section 2 provides an overview of the conceptual framework behind the model, while Section 3 describes the model's equations in detail. The calibration of the model is discussed in 4, with the results of the simulations described in Section 5. The final section summarises and concludes.

2 Theoretical framework

We enhance Eire Mod, a DSGE model of the Irish real economy (Clancy and Merola, 2014), with the inclusion of a financial sector. We adapt the banking sector framework developed by Beneš *et al.* (2014a, 2014b), which is based on three existing finance theories: loan portfolio value by Vasicek (2002), incentive-based capital regulation by Milne (2002) and costly bank capital adjustment by Estrella (2004). The incorporation of these theories allows for valuable insights and extends related works in several important aspects.

The paper relates to the literature on the banking system and collateral constraints. However, most of this literature (*e.g.* Iacoviello, 2005; Iacoviello and Neri, 2010; Gerali *et al.*, 2010) omits the possibility of default, either because households can not obtain loans if the value of the collateral decreases below a give threshold or because banking activity is limited to collecting deposits and supplying loans. A first valuable insight of the model is the presence of endogenous default, which is a key feature for the analysis of regulatory policies[2].

Moreover, following Beneš *et al.* (2014a, 2014b), we distinguish two component of endogenous risk: a fully-diversifiable and a non-diversifiable component. The non-diversifiable aggregate component of the endogenous risk generates non-linearities, which amplifies the response of the economy to tail-risk events. In most existing models, if lending risk exists, it is idiosyncratic and thus fully-diversifiable, or introduced through *ad-hoc* exogenous shocks (*e.g.* Bernanke *et al.*, 1999; Carlstrom and Fuerst, 1997). However, in reality, a systemic risk component also exists. For instance, even if banks appear to be solid individually, the banking system as a whole may be vulnerable. Banks are exposed to one another and can inflict losses directly on one another[3]. The greater the exposure to systematic risk, the greater the threat to the financial system as a whole, as an individual institution is likely to incur losses at the same time as the others, making it more difficult to absorb them[4]. Therefore, the presence of a systemic risk component amplifies the response of the economy to tail-risk events (non-linearities) and makes the model suitable to replicate Irish episodes during the housing crash. The presence of non-linearities explains the faster build-up of risk during boom periods, which has no visible consequences in normal or good times where there are very few defaulting loans. However, it can have dramatic consequences when the situation worsens. This supports the intuition that, under some circumstances, banking crises may be the effect of credit booms gone wrong (Schularick and Taylor, 2012). This latter stylised fact is not captured by traditional models, which have mainly focused on modelling the propagation and the amplification of adverse shocks.

[2]Without being exhaustive, other papers including endogenous default are Goodhart *et al.*, 2005 and De Walque *et al.*, 2010. For a discussion on the need to integrate default in DSGE models, see the column ”Default and DSGE models” by Goodhart and Tsomocos, VoxEu November 26^{th} 2009.

[3]Banks can also suffer substantial losses indirectly if they have shared exposures outside of the banking system. This was clearly evident during the financial crisis. When a bank is forced to sell off assets quickly, they fall in value. This weakens the balance sheets of other banks holding the same type of assets.

[4]For a discussion on the distinction between systematic and idiosyncratic risk, see Acharya (2009), Borio and Drehmann (2009) and Wagner (2008, 2010).

A second original aspect distinguishes this framework from traditional models focusing only on the demand side of credit (*e.g.* Carlstrom and Fuerst, 1997, Kiyotaki and Moore, 1997; Bernanke *et al.*, 1999). This framework instead contains endogenous feedback loops between the financial sector and the real economy from shocks to both the demand and supply of credit. From the demand side, access to credit depends on the prices of assets used as collateral, as in traditional models with credit frictions and collateral constraints (*e.g.* Kiyotaki and Moore, 1997; Christiano, Gust and Roldos, 2004; Iacoviello, 2005; Iacoviello and Neri, 2010). If asset prices fall below a given threshold, some loans become non-performing and banks can incur losses on the defaulted portion of these loans. In addition, the framework adopted in this paper embed macro-financial linkages arising from the supply side of credit in the traditional models mentioned above. In particular, banks face costs from violating minimum capital adequacy regulations, and therefore respond to negative shocks by raising their lending rate in order to rebuild their balance sheets and fulfill capital requirements[5]. This credit restriction adversely affects the real economy and impedes the recovery from a negative shock.

In addition, the framework includes a non-price bank lending channel, which captures the fact that banks use instruments other than interest rates to manage credit risk (Strahan, 1999). This is particularly true when non-diversifable risk exists on a banks' loan portfolio (Arnold *et al.*, 2010). As a result, the observed lending rates do not fully reflect the availability of credit, a commonly used definition of credit rationing[6] (Jeffe and Russell, 1976). By restricting the quantity of loans extended rather than increasing lending spreads to the full extent, banks earnings are negatively affected. It therefore takes longer for banks to recapitalise following a negative shock. This additional channel is particularly relevant in the case of binding political economy constraints, with (either actual or perceived) excessive rate hikes by publically bailed-out banks likely

[5]For a similar analysis, see, among others, Markovic (2006) and De Walque *et al.* (2010).

[6]In the modelling framework this feature is not derived from strict first principles, and is instead modelled as an *ad-hoc* mechanism. There is, however, a large literature which considers the optimality of credit rationing (see, for example, Jeffe and Modigliani, 1969; Stigltiz and Weiss, 1981; Besanko and Thankor, 1987).

to be an infeasible solution to banks' balance sheet problems.

A third novelty of the approach is that the regulatory capital requirement is not modelled as an ever-binding inequality, as in Angeloni and Faia (2009) or van den Heuvel (2008). Instead, banks are optimisers and choose their capital buffers according to an incentive-based mechanism under uncertainty. Therefore, capital buffers endogenously change over the time in response to financial cycles. The build-up of capital buffers strengthens the resilience of the financial system to negative shocks.

As in Beneš *et al.* (2014a, 2014b), we assume that banks do not act simply as intermediaries, lending out deposits placed by savers. As stated in Disyatat (2011) and in Borio (2012), "the banking system does not simply transfer real resources, more or less efficiently, from one sector to another; it generates (nominal) purchasing power. Deposits are not endowments that precede loan formation; it is loans that create deposits"[7]. However, in practice, banks cannot create money without limits for a number of reasons. First, monetary policy, by setting the interest rate, affects the price of new lending and how much households and firms may want to borrow. Second, households who receive the money created by new lending may take actions that quickly destroy money created by banks, for instance by using it to repay their existing debt. Finally, banks face limits on lending imposed by prudential regulation, which acts as a constraint on banks' activity in order to mitigate the build-up of risk and maintain the resilience of the financial system[8]. In this paper, we focus on this last aspect.

We adapt the Beneš *et al.* (2014a, 2014b) model in a number of ways. First, the model is modified and calibrated to represent a specific country, Ireland, which suffered a particularly sharp economic downturn as a result of difficulties in it's financial sector. In particular, the core of the model is expanded to represent a small open economy in a monetary union. As such, monetary policy is exogenous and cannot be used to stabilise the economy in response to shocks. This adds to the importance of assessing the usefulness of macro-prudential policy as an instrument to smooth fluctuations in

[7] See Borio (2012), pp. 11.

[8] For a detailed discussion on this mechanism of money creation in the banking system, see the Bank of England (2014).

the economy. Moreover, the model framework is re-designed to capture some specific features of the trade structure of the Irish economy, in particular the high degree of openness and the large share of import context of exports.

Second, the link between the real economy and the financial sector is now viewed through the lens of the housing market, instead of a generic asset. A bank's willingness to extend such loans depends on their expectations for future house prices, which are provided by households as collateral. As the existing housing assets of potential customers is offered as collateral, such expectations impact on lending spreads charged by the banks to cover the risk of the loans defaulting. A greater (lower) perceived risk of house price decreases can influence household demand for loans by raising (reducing) credit standards.

Finally, in Beneš *et al.* (2014a, 2014b) loan default is entirely related to the value of the collateralising asset. However, in Ireland, a key determinant of mortgage performance is the borrowers ability to pay (McCarthy, 2014). Even in regions in which there are non-recourse loans, which have come to be associated with behaviour consistent with "strategic default" of mortgage loans, survey evidence suggests the vast majority of borrowers regard not paying debts when one can afford to do so as morally wrong (Honohan, 2013). Therefore, while the existence of negative equity greatly increases the probability of default in non-recourse jurisdictions, it does not in those with full recourse (Ghent and Kudlyak, 2010). The incorporation of disposable income in to the cut-off point for loan defaults therefore brings the model closer to the Irish reality.

3 The model

We consider a small open economy within a monetary union. Agents in the economy are households, banks, domestic firms producing non-tradable goods, importers retailing foreign goods domestically and exporters selling domestic goods abroad. In the following description of the model, variables not indexed by time denote steady-state values.

3.1 Households

Households gain utility from consumption C_t, housing services H_t[9], deposits demanded for saving reasons D_t^S and disutility from labour N_t. They maximise their lifetime utility according to:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\chi) \log(C_t - \chi C_{t-1}) + \theta \log H_t - \frac{1}{1+\eta} N_t^{1+\eta} + \zeta \frac{1}{1-\iota} \left(\frac{D_t^S}{P_t^D} \right)^{1-\iota} \right] \tag{1}$$

where χ is the degree of habit persistence in consumption, $(1-\chi)$ is a scale factor which guarantees that the marginal utility of consumption in the steady state is independent from the habit parameter, β is the household discount factor, η is the labour supply elasticity and the parameters θ and ζ measure the households' preference for housing and deposits respectively. $P_t^D = (P_t)^{1-\omega^D} (P_t^H)^{\omega^D}$ is a composite price index, where P_t^H is the house price and P_t is the CPI price level. Another share of deposits D_t^T are demanded for transactions, that is for purchasing consumption goods C_t at price P_t, investment goods I_t at price P_t^I and housing H_t at price P_t^H, so that:

$$D_t^T = \gamma^C \left(P_t C_t + P_t^I I_t \right) + \gamma^H P_t^H H_t \tag{2}$$

where γ^C and γ^H are the shares of deposits motivated by the need for consumption, investment and housing transactions respectively. Total deposits D_t are the sum of deposits held for saving D_t^S and deposits held to facilitate transactions D_t^T:

$$D_t = D_t^S + D_t^T \tag{3}$$

[9]We assume that the housing stock is fixed. Therefore, we focus on the demand rather than the supply side of the housing market.

Households maximise their utility subject to two types of constraints. The first is a budget constraint:

$$P_tC_t + P_t^I I_t + \sum_{i=1}^{n} P_t^H H_{i,t} + E_t - \sum_{i=1}^{n} L_{i,t} + D_t^S \left[1 - \frac{1}{2}\xi^D \left(\Omega_t^D\right)^2\right]$$
$$= W_t N_t \left[1 - \frac{1}{2}\xi^W \left(\Omega_t^W\right)^2\right] + R_t^K K_{t-1} + \sum_{i=1}^{n} P_t^H H_{i,t-1} + R_t^E E_{t-1} - \sum_{i=1}^{n} R_t^L L_{i,t-1} + R_t D_{t-1}^S$$
$$+ P_t^N Y_t^N \left[\frac{1}{2}\xi^N \left(\Omega_t^N\right)^2\right] + P_t^M M_t \left[\frac{1}{2}\xi^M \left(\Omega_t^M\right)^2\right] + P_t^X X_t \left[\frac{1}{2}\xi^X \left(\Omega_t^X\right)^2\right] + E_t \left[\frac{1}{2}\xi^E \left(\Omega_t^E\right)^2\right] + \Pi_t - T_t \tag{4}$$

where $\sum_{i=1}^{n} P_t^H H_{i,t} = P_t^H H_t$ is the total value of housing wealth held by individual members. W_t is the wage rate, K_t denotes claims on physical capital[10], R_t^K is the return on physical capital, and I_t is the investment good which is purchased at price P_t^I. The term $\sum_{i=1}^{n} L_{i,t} = L_t$ denotes the total amount borrowed in bank loans on which households pay the aggregate[11] gross interest rate R_t^L, defined as $\sum_{i=1}^{n} \frac{R_{i,t}^L L_{i,t-1}}{L_{i,t-1}}$, while receiving the interest rate R_t on deposits D_t. Households transfer equity E_t to banks on which they receive a return of R_t^E[12]. The term $\Omega_t^D = \log \frac{D_t^S}{D_{t-1}^S}$ denotes deposit adjustment costs as households do not like sudden changes in their deposits [13]. The budget constraint also contains net pay-offs received from firms and banks. These are discussed in later sections. Finally, households pay lump-sum taxes T_t to the government and own the firms and receive their profits in the form of dividends Π_t.

The budget constraint requires that households' deposit holdings, transfers of bank capital and purchase of consumption and investment goods, physical capital and additional housing must be covered by labour and capital income, bank loans (net of interest payments) and dividends from firms, net from lump-sum taxes T_t. Households' resources in the budget constraint are net of transfers of bank capital and ad-

[10] In the model we differentiate between physical capital, owned by households and rented by firms for productive purposes, and bank capital, owned and used by banks to support their lending activities. Further details on the latter are provided in the description of the banking sector.

[11] Individual lending and individual risk will be defined in more detail in Section 3.3.

[12] We assume that households delegate banking activity to banks and banks give households net transfers of equity, which households take as given.

[13] Similarly, De Walque *et al.* (2010) also impose a target on deposits through a quadratic disutility term, as households do not like deposits differing from their long-run optimal level.

justment costs, which are assumed to be private losses. Adjustment costs arise from price adjustment in the non-tradable sector, $\Omega_t^N = \log \frac{\pi_t^N}{\pi_{t-1}^N}$, and in the import sector, $\Omega_t^M = \log \frac{\pi_t^M}{\pi_{t-1}^M}$ and from quantity adjustment in the export sector, $\Omega_t^X = \log \frac{X_t}{X_{t-1}}$. The term $\Omega_t^E = \log \frac{E_t}{E_{t-1}}$ denotes bank capital adjustment costs, which are borne by households, as banks are assumed to be fully owned by domestic households. For simplicity, from now on we define $(\Omega_t)^2 = P_t^N Y_t^N \left[\frac{1}{2}\xi^N \left(\Omega_t^N\right)^2\right] + P_t^M M_t \left[\frac{1}{2}\xi^M \left(\Omega_t^M\right)^2\right] + P_t^X X_t \left[\frac{1}{2}\xi^X \left(\Omega_t^X\right)^2\right] + E_t \left[\frac{1}{2}\xi^E \left(\Omega_t^E\right)^2\right]$. In addition, households face wage inflation adjustment costs defined by $\Omega_t^W = \log \frac{\pi_t^W}{\pi_{t-1}^W}$.

The second constraint is a law of motion for capital. This states that the capital stock available at the beginning of period t, K_t, is equal to the capital stock available at the end of period *t-1*, net of capital stock depreciation δK_{t-1}, where $0 < \delta < 1$ is the capital depreciation rate, plus the amount of capital accumulated during period t, which is determined by the investment made during period t, I_t. Investment is subject to quadratic adjustment costs $\Omega_t^I = \frac{I_t}{I_{t-1}} - 1$. The capital accumulation equation is given by:

$$K_t = (1-\delta)K_{t-1} + I_t \left[1 - \frac{1}{2}\xi^I \left(\Omega_t^I\right)^2\right]. \tag{5}$$

Forming the Lagrangian, we can re-write the optimisation problem as:

$$
\begin{aligned}
\mathcal{L} = &\left((1-\chi)\log(C_t-\chi C_{t-1})+\theta\log H_t-\frac{1}{1+\eta}N_t^{1+\eta}+\zeta\frac{1}{1-\iota}\left(\frac{D_t^S}{P_t^D}\right)^{1-\iota}\right)\\
&+\Lambda_t\left(P_tC_t+P_t^II_t+\sum_{i=1}^{n}P_t^HH_{i,t}+E_t-\sum_{i=1}^{n}L_{i,t}+D_t^S\left[1-\frac{1}{2}\xi^D\left(\Omega_t^D\right)^2\right]-\Omega_t^2\right.\\
&\left.-W_tN_t\left[1-\frac{1}{2}\xi^W\left(\Omega_t^W\right)^2\right]-R_t^KK_{t-1}-\sum_{i=1}^{n}P_t^HH_{i,t-1}-R_t^EE_{t-1}+\sum_{i=1}^{n}R_t^LL_{i,t-1}-R_tD_{t-1}^S-\Pi_t+T_t\right)\\
&+\Xi_t\left((1-\delta)K_{t-1}+I_t\left[1-\frac{1}{2}\xi^I\left(\Omega_t^I\right)^2\right]-K_t\right)\\
&+\beta\left((1-\chi)\log(C_{t+1}-\chi C_t)+\theta\log H_{t+1}-\frac{1}{1+\eta}N_{t+1}^{1+\eta}+\zeta\frac{1}{1-\iota}\left(\frac{D_{t+1}^S}{P_{t+1}^D}\right)^{1-\iota}\right)+\\
&\beta\Lambda_{t+1}\left(P_{t+1}C_{t+1}+P_{t+1}^II_{t+1}+\sum_{i=1}^{n}P_{t+1}^HH_{i,t+1}+E_{t+1}-\sum_{i=1}^{n}L_{i,t+1}+D_{t+1}^S\left[1-\frac{1}{2}\xi^D\left(\Omega_{t+1}^D\right)^2\right]-\Omega_{t+1}^2\right.\\
&\left.-W_{t+1}N_{t+1}\left[1-\frac{1}{2}\xi^W\left(\Omega_{t+1}^W\right)^2\right]-R_{t+1}^KK_t-\sum_{i=1}^{n}P_{t+1}^HH_{i,t}-R_{t+1}^EE_t+\sum_{i=1}^{n}R_{t+1}^LL_{i,t}-R_{t+1}D_t^S-\Pi_{t+1}+T_{t+1}\right)\\
&+\beta\Xi_{t+1}\left[(1-\delta)K_t+I_{t+1}\left[1-\frac{1}{2}\xi^I\left(\Omega_{t+1}^I\right)^2\right]-K_{t+1}\right] \qquad (6)
\end{aligned}
$$

where Λ_t and Ξ_t are the multipliers associated with the budget and capital accumulation constraints respectively. The first order conditions for C_t, H_t, D_t^S, I_t, L_t and K_t respectively are:

$$\frac{1-\chi}{C_t-\chi C_{t-1}}=\Lambda_tP_t \qquad (7)$$

$$P_t^H=U_t^H\left[\frac{1}{\Lambda_t}\left(\frac{1}{H_t}+\beta\Lambda_{t+1}P_{t+1}^H\right)\right] \qquad (8)$$

$$\frac{\zeta}{\Lambda_t}\left(D_t^S\right)^{-\iota}\left(P_t^D\right)^{\iota-1}=1-\left(\beta R_t\frac{\Lambda_{t+1}}{\Lambda_t}\right)+\xi^D\Omega_t^D \qquad (9)$$

$$P_t^I=P_t^K\left[\left(1-\frac{1}{2}\xi^I(\Omega_t^I)^2\right)-\xi^I\Omega_t^I\right]+\beta\left[P_{t+1}^K\xi^I\Omega_{t+1}^I\left(\frac{I_{t+1}}{I_t}\right)^2\right] \qquad (10)$$

$$\Lambda_t=\beta\Lambda_{t+1}R_t^L \qquad (11)$$

$$P_t^K = \beta \frac{\Lambda_{t+1}}{\Lambda_t}(R_{t+1}^K + (1-\delta)P_{t+1}^K) \tag{12}$$

where U_t is an autoregressive exogenous housing demand shock process:

$$\log U_t^H = \rho^{U^H} \log U_{t-1}^H + \epsilon_t^{U^H}. \tag{13}$$

Moreover, each *i-th* household uses its monopoly power to set its wages so as to maximise the intertemporal objective function subject to both the budget constraint and a downward-sloping demand curve:

$$N_{i,t} = \frac{W_{i,t}}{W_t}^{-\frac{\epsilon^W}{\epsilon^W - 1}} N_t, \tag{14}$$

where ϵ^W is the elasticity of the demand and $\mu^W = \frac{\epsilon^W}{\epsilon^W - 1}$ is a mark-up over the marginal cost of labour. Households choose the optimal wage:

$$\frac{\mu N_t^\eta}{W_t \Lambda_t} = 1 + (\mu^W - 1)\xi^W \Omega_t^W - (\mu^W - 1)\xi^N \beta \Omega_{t+1}^W \tag{15}$$

where ξ^W is a wage adjustment cost parameter and Λ_t is the marginal utility of consumption.

3.2 Firms

There are three types of firms. While one locally produces non-tradable goods, another produces exports goods for sale on the international market. A final type imports foreign goods for sale on the domestic market. Firms producing domestic goods and firms importing foreign goods are assumed to face a small direct cost of adjusting their prices[14], modelled *à la* Rotemberg (1982). Firms producing export goods face quadratic adjustment costs if they want to change the level of their output. As a result, firms will only adjust prices gradually in response to a shock to demand or marginal cost (Devereux *et al.*, 2005; Merola, 2010).

[14] Adjustment costs for exporters are related to their output levels, as they are price takers.

3.2.1 Non-tradable good producers

Local producers combine domestic capital, K_{t-1}^N, and labour, N_t^N, using a Cobb-Douglas production function to assemble a non-tradable good:

$$Y_t^N = A_t^N \left(K_{t-1}^N\right)^{1-\gamma^N} \left(N_t^N\right)^{\gamma^N} \tag{16}$$

where γ^N measures labour share in the non-tradable sector and A_t^N is an exogenous technology term which follows an autoregressive process:

$$\log A_t^N = \rho^A \log A_{t-1}^N + \epsilon_t^A \tag{17}$$

with ρ^A the persistence of the process and ϵ_t^A a shock to non-tradable sector productivity. This shock is sector specific and is identical across all firms in the sector. The local producer optimises the present value of payoffs:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^N Y_t^N \left[1 - \frac{1}{2} \xi^N \left(\Omega_t^N\right)^2 \right] - W_t N_t^N - R_t^K K_{t-1}^N \right] \tag{18}$$

where ξ_t^N is an adjustment cost parameter associated with deviations in non-tradable good price inflation $\Omega_t^N = \log \frac{\pi_t^N}{\pi_{t-1}^N}$ and W_t and R_t^K are the cost of factor inputs. The optimal choice of labour and capital is:

$$\gamma^N MC_t^N Y_t^N = W_t N_t^N \tag{19}$$

$$(1-\gamma^N) MC_t^N Y_t^N = R_t^K K_{t-1}^N \tag{20}$$

where MC_t^N is the marginal cost of production in the non-tradable sector. Local firms face a downward-sloping demand curve for their output:

$$Y_{i,t}^N = \left(\frac{P_{i,t}^N}{P_t^N} \right)^{-\frac{\theta^N}{\theta^N - 1}} Y_t \tag{21}$$

where θ^N is the elasticity of demand for non-tradable goods. Local firms can use their degree of monopoly power to charge a mark-up over their marginal cost. The optimal price is set according to:

$$(\mu_t^N - 1)\xi^N \Omega_t^N = (\mu_t^N - 1)\xi^N \beta \mathbb{E}_t \Omega_{t+1}^N + \left(\frac{\mu_t^N MC_t^N}{P_t^N} - 1 \right) \tag{22}$$

where ξ^W is a cost parameter for deviations in non-tradable sector price inflation $\Omega_t^N = \log \frac{\pi_t^{P^N}}{\pi_{t-1}^{P^N}}$ and $\mu_t^N = \frac{\theta^N}{\theta^N - 1}$ measures the monopolistic mark-up in this sector, which follows an autoregressive process:

$$\mu_t^N = (1 - \rho^N)\mu_{t-1}^N + \rho^N \mu_{t-1}^N + \epsilon_t^N \tag{23}$$

where ρ^N is the persistence of the process and ϵ_t^N is a shock to the non-tradable price mark-up.

3.2.2 Importers

The import sector consists of firms that buy a homogeneous good in the world market, and use a branding technology to convert the imported goods into differentiated products, which are then sold to local households. It is assumed a set of monopolistic domestic importers purchase the foreign good at its marginal cost (expressed in domestic currency), $MC_t^M = P_t^{M\star} S_t$, where $P_t^{M\star}$ is the world import price expressed in foreign currency and S_t is the nominal exchange rate. For a small open economy, $P_t^{M\star}$ is taken as given. Import firms then use their market power to charge a mark-up μ_t^M over this price. These goods are then sold on the domestic market at price P_t^M:

$$\left(\frac{\mu_t^M MC_t^M}{P_t^M} \right) = 1 + (\mu_t^M - 1)\xi^M \Omega_t^M - (\mu_t^M - 1)\xi^M \beta \mathbb{E}_t \Omega_{t+1}^M \tag{24}$$

where ξ^M is a cost parameter for deviations in import sector price inflation $\Omega_t^M = \log \frac{\pi_t^{P^M}}{\pi_{t-1}^{P^M}}$ and $\mu^M = \frac{\theta^M}{\theta^M - 1}$ measures the monopolistic mark-up in this sector following an autoregressive process:

$$\mu_t^M = (1-\rho^M)\mu_{t-1}^M + \rho^M \mu_{t-1}^M + \epsilon_t^M \tag{25}$$

where ρ^M is the persistence of the process and ϵ_t^M is a shock to the import price mark-up. This local currency price stickiness allows for an incomplete exchange rate pass-through, and thus there is some delay between movements in the terms of trade and the adjustment of imported goods prices.

3.2.3 Tradable good producers

Competitive local exporters combine domestic labour and fixed capital $\overline{K}_{t-1}^X$ [15] using a Cobb-Douglas technology:

$$Z_t = A_t^X \left(\overline{K}_{t-1}^X\right)^{1-\gamma^X} \left(N_t^X\right)^{\gamma^X} \tag{26}$$

where γ^X measures labour intensity in the export sector and A_t^X is a sector specific exogenous technology term which follows an autoregressive process:

$$\log A_t^X = \rho^X \log A_{t-1}^X + \epsilon_t^X \tag{27}$$

with ρ^X the persistence of the process and ϵ_t^X a shock to export sector productivity. Re-exports X_t^M, which are goods purchased from abroad but not intended for sale in the domestic market, are combined with locally produced tradable goods Z_t to produce final export goods using a Leontief production function:

$$X_t = \min\left\{\frac{Z_t}{(1-\alpha)}, \frac{X_t^M}{\alpha}\right\}. \tag{28}$$

[15] The capital input decisions of tradable sector firms are not necessarily made domestically in small open economies with a large amount of Foreign Direct Investment (FDI) (for a detailed discussion, see Bradley and Fitzgerald, 1988 and 1990). Consistent with this, here export firms concentrate solely on the minimisation of labour costs and capital follows an autoregressive process $\log K_t^X = \rho^K \log K_{t-1}^X + \epsilon_t^K$, where ρ^K is the persistence of the process and ϵ_t^K is a shock to the export sector's capital stock. This shock could be considered as an influx of capital to the Irish tradable sector by the parent branch of a multinational corporation, for example.

The large size of the multinational sector in Ireland makes this import content of exports channel very relevant for policy analysis[16]. By considering the international fragmentation of the tradable goods production process, this features can account for the reliance of exports in Ireland on imported components. For any given level of output, the inputs in the final export good X_t are combined in proportions fixed by the parameter α:

$$Z_t = (1 - \alpha) X_t \tag{29}$$

$$X_t^M = \alpha X_t. \tag{30}$$

The assumption of a fixed proportions is justified by the fact that changes in relative prices should not overly influence the use of imported intermediate goods in the production of the final export good. In a small open economy such as Ireland the imported component is often not produced within the country, and so is irreplaceable from domestic sources. With capital fixed, domestic firms producing the tradable good Z_t minimise their costs:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^X X_t - W_t N_t^X - R_t^K \overline{K}_{t-1}^X \right]. \tag{31}$$

This optimisation choice only considers the domestic component, as the imported component is set to a fixed proportion of the final export good. The optimal choice of labour in this sector is derived from:

$$\gamma^X MC_t^Z Z_t = W_t N_t^X. \tag{32}$$

The exporters marginal cost of production is:

$$MC_t^X = (1 - \alpha) MC_t^Z + \alpha P_t^M \tag{33}$$

[16]See Hummels *et al*. (2001) for an estimate of the importance of this channel in a panel of OECD and emerging market countries, including Ireland.

where MC_t^Z is the marginal cost of locally-produced export goods used in the final export good production process, while P_t^M is the price of imported goods defined previously. After substituting the total production cost into the exporters' pay-offs, we can derive the following first-order condition for the optimal level of exports:

$$\frac{P_t^X}{MC_t^X} = 1 + \xi^X \Omega_t^X - \beta \mathbb{E}_t \Omega_{t+1}^X \tag{34}$$

where ξ^X is a cost parameter associated with changing the level of export output $\Omega_t^X = \log \frac{X_t}{X_{t-1}}$.

3.3 The financial sector

Banks' assets consist of loans, which are financed through banks' liabilities, namely deposits and capital (*i.e.* equity). Banks choose loans, deposits and capital to maximise the pay-off to shareholders. For simplicity, the model distinguishes between two branches of banks and treats them separately. The lending branch of banks offer loan contracts to individuals (households). Banks can incur losses on non-performing loans (NPLs) when the value of a collateralising asset (supplied by households to secure a loan) and disposable income drops significantly. The asset-liability management branch of banks decide how much capital is needed to support a portfolio of loans given certain risk characteristics. The presence of this latter branch in the model allows for an assessment of the effect of macro-prudential policy (*e.g.* capital regulation and deposit insurance). Capital regulation limits the bank's optimal choice of capital, by requiring that the ex-post value of bank capital is a certain proportion of the ex-post realisable value of the bank's loan portfolio. If the bank falls short of regulatory capital, it pays a penalty, which is proportional to its ex-post value of assets (*i.e.* performing loans).

The rationale for imposing minimum capital adequacy regulations on banks stems from banks' incentive to take on large amounts of lending risk and to minimise their own equity base. The moral hazard problem exposes depositors to a significant risk of capital losses. There are several solutions for introducing discipline in the banking system. A first solution would be to sign deposit contracts which reflect that risk. However, this solution requires depositors to engage in costly monitoring, and also may trigger bank runs when adverse information about individual banks is revealed. A second solution is to create some form of deposit insurance. However, as deposit insurance schemes can not insure against systemic crises, it has to be accompanied by further macro-prudential measures. A third solution is to impose direct capital adequacy regulations that penalise banks for maintaining an insufficient equity buffer.

In this model, we focus on the latter policy option. We first define the notion of individual credit risk. Then, following Vasicek (2002), we turn to the loan portfolio as a whole to compute the portfolio default ratio. Finally, following Milne (2002), we introduce capital regulation as an incentive-based mechanism.

3.3.1 A definition of credit risk

Banks make one-period loans to a large number of households[17]. To access credit, each *i-th* household provides his housing wealth[18] and wage income as collateral. A generic *i-th* household repays his loan if the actual value of the composite wealth (composed of his housing and income) accepted as collateral is above a cut-off value:

$$\psi\left[\phi H_{i,t-1} P_{i,t}^{H} + (1-\phi) W_t N_{i,t}\right] > R_{i,t}^{L} L_{i,t} \tag{35}$$

where $L_{i,t}$ is the individual exposure on which the *i-th* household pays the non-contingent[19] lending rate $R_{i,t}^{L}$, which will be defined later. The parameter ψ is the share of composite wealth accepted as collateral. The loan-to-value ratio on housing wealth for the *i-th*

[17] We assume that the number of loans is large enough so that banks are able to fully diversify away the idiosyncratic risk.

[18] We further assume that all households own some housing stock, and therefore abstract from the issue of first-time buyers.

[19] Non-contingent means that the lending rate is fixed at time *i-th* and thus will not change in response to outcomes observed at time $t+1$.

household is defined as $LTV_{i,t} = \frac{L_{i,t}}{H_{i,t-1}P^H_{i,t}}$. We define the default cut-off value as:

$$\overline{F_{i,t}} = \frac{R^L_{i,t} L_{i,t}}{\psi}. \tag{36}$$

The actual individual expected composite wealth can be decomposed into three components:

$$F_{i,t+1} = \mathbb{E}_t \left(F_{t+1}\right) \exp\left(u^a_{i,t+1}\right) \exp\left(u^b_{t+1}\right) \tag{37}$$

where $\mathbb{E}_t \left(F_{t+1}\right)$ is the expected aggregate average market price of composite wealth, $\exp\left(u^a_{i,t+1}\right)$ is the idiosyncratic risk related to the *i-th* loan and $\exp(u^b_{t+1})$ is the systemic risk component. Equation (37) states that uncertainty over house prices includes both an idiosyncratic (microeconomic) and a systemic (macroeconomic) component. At time *t+1*, if the value of composite housing and income wealth $F_{i,t+1}$ used as collateral for the *i-th* loan drops substantially below the threshold $\overline{F_{i,t}}$, banks cannot recover the full amount of the loan (*i.e.* it becomes non-performing). The cut-off value for household wealth, below which the loan becomes non-performing, is defined as $F_{i,t+1} < \overline{F_{i,t}} = \frac{R^L_{i,t} L_{i,t}}{\psi}$. Therefore, to evaluate the individual probability of default we introduce a Bernoulli random variable J^i_{t+1} describing the performance of the *i-th* individual loan:

$$J^i_{t+1} = \begin{cases} 0 & \text{loan performs, if } (F_{i,t+1}) > \overline{F_{i,t}}, \\ 1 & \text{loan defaults, if } (F_{i,t+1}) < \overline{F_{i,t}}. \end{cases} \tag{38}$$

Turning from individual loans to the bank's portfolio, we denote the representative portfolio L_t as the sum of individual exposures L^i_t, so that $L_t = \sum_{i=1}^n L^i_t$. In addition to assuming there are a large number of loans, we also assume that all loans have the same probability of default. We define the ex-ante (*i.e.* unconditional) distribution of the non-performing loans (hereafter, NPLs) as a proportion of the banks' portfolio. The cut-off value determines the ex-ante probability of default, which is defined as the c.d.f of a standard normal distribution evaluated at the cut-off household wealth:

$$\mathbb{E}_t(J_{t+1}) = Pr(J_{t+1} = 1) = J^{ex-ante}_t = \varkappa + (1-\varkappa)\Phi\left[\frac{\log \overline{F_t} - \log \mathbb{E}_t(F_{t+1})}{\sigma_a + \sigma_b}\right] \tag{39}$$

where Φ is the c.d.f of a standard normal distribution and σ_a and σ_b denote the uncertainty related to the idiosyncratic and systemic components of the risk factor respectively[20]. We assume that a share $\varkappa$ of loans might become non-performing even if economic conditions are favourable. The ex-ante probability of default depends on expected household wealth and both the idiosyncratic and systemic components of risk.

The ex-post (*i.e.* conditional) probability of default depends on realised household wealth and only the systemic risk σ_b, and it can be interpreted as the share of NPLs:

$$\mathbb{E}_t(J_{t+1}|F_{t+1}) = Pr(J_{t+1} = 1|F_{t+1}) = J_t^{ex-post} = \varkappa + (1-\varkappa)\Phi\left[\frac{\log \overline{F_{t-1}} - \log F_{t+1}}{\sigma_b}\right]. \quad (40)$$

3.3.2 Bank lending and credit risk management

The banks' portfolio consists of a large number of one-period loans L_t extended to households, each at a lending rate R_t^L. At time t, banks' loans are financed by (domestic and foreign) deposits D_t[21] and equity liabilities E_t (*i.e.* bank capital). Bank loans are

[20]Equation (39) is derived from the threshold condition, which can be re-written as:

$$\frac{R_{i,t}^L L_{i,t}}{\psi} > \mathbb{E}_t(F_{t+1}) \exp\left(u_{i,t+1}^a\right) \exp\left(u_{t+1}^b\right)$$

where the idiosyncratic and aggregate risks are assumed to be distributed normally and independent of each other $u_{t+1}^a \sim \mathcal{N}(0, \varsigma\sqrt{1-\rho})$ and $u_{i,t+1}^b \sim \mathcal{N}(log\mathbb{E}_t\left[(F_{t+1})\right], \varsigma\sqrt{\rho})$. The standard deviations of the two risk factors $\sigma_a = \varsigma\sqrt{\rho}$ and $\sigma_b = \varsigma\sqrt{1-\rho}$ are treated parametrically, where ς is the variance of the aggregate risk factor and ρ is the coefficient of correlation between idiosyncratic and aggregate risks. The presence of autocorrelation between individual risk factors, $\rho > 0$, implies that at least a portion of risk on banks' balance sheets is not fully-diversifiable. As ex-ante households are identical, in a symmetric equilibrium the cut-off value is the same for all loans. Taking the log and rearranging, we obtain:

$$\log\left(\frac{R_t^L L_t}{\psi}\right) - \log \mathbb{E}_t\left(F_{t+1}\right) > u_{t+1}^a + u_{t+1}^b,$$

$$\log \overline{F_t} - \log \mathbb{E}_t\left(F_{t+1}\right) > u_{t+1}^a + u_{t+1}^b.$$

[21]We do not formally differentiate between domestic and foreign deposits. In the steady state, the domestic and foreign interest rates are equal. As these interest rates represent the banks' cost of (deposit) liabilities, banks have no preference between them. However, if there is a shock to interest rates, the presence of a debt elastic risk premia (see section 3.5) can cause a gap between domestic and foreign cost of liabilities to develop. This will alter banks' preferences, who adjust the composition of their balance sheets accordingly.

risky because, depending on developments in the collateral (housing) market and the real economy (wage income), some loans may become non-performing at the time of repayment. Whenever a loan becomes non-performing, the bank is able to recover only a portion $1-\nu$ of the total amount of outstanding loans. To avoid a situation where banks take excessive risk and hold an inadequate amount of equity in reserve, banks are subject to minimum capital requirements. Each bank should therefore hold capital in proportion to its risk exposure.

The asset-liability management branch of the bank chooses the size of it's balance sheet, *i.e.* the volume of loans, deposits and the optimal bank capital reserves required to support a portfolio of loans with given risk characteristics, observed ex-post. Banks maximise the expected pay-off to shareholders, corrected to account for both the risk and the expected value of the regulatory penalty:

$$\max \mathbb{E}_t \hat{\beta} \frac{\Lambda_{t+1}}{\Lambda_t} \left[R_t^L (1 - \nu J_t^{ex-ante}) L_t - R_t D_t - \upsilon \left(\frac{L_t}{E_t} - \overline{g}_{min} \right) L_t \right] + \left[E_t - \frac{1}{2} \xi^E \left(\Omega_t^E \right)^2 E_t \right] \quad (41)$$

where $R_t^L(1-\nu J_t^{ex-ante})$ is the bank lending rate corrected for risk and ν can be interpreted as the loss-given-default (hereafter, LGD). The term $\upsilon\left(\frac{L_t}{E_t}-\overline{g}_{min}\right)$ represents the penalty for deviating from the regulatory minimum capital requirement $\overline{g}_{min}$. The penalty function $\upsilon(\bullet)$ is introduced to prevent the bank from going below the regulatory capital minimum during times of large credit expansion (such as during a boom). It is modelled as an exponential function in the deviation from the minimum regulatory capital $\overline{g}_{min}$. This feature allows for asymmetric reactions as the capital buffer gets drawn down and the bank increases it's leverage. It is therefore an essential component of the non-linearities embedded in the model, with bank behaviour adjusting more rapidly when regulatory requirements are in danger of being breached. Macro-prudential policy can set the minimum capital requirement either as a constant $\overline{g}_{min}$ or as a time-varying target g_t which responds asymmetrically to market conditions, thereby mirroring the asymmetry of financial cycle. In this latter case, macro-prudential policies are pro-active and the capital requirement becomes:

$$g_t = \min\left[\overline{g}_{max}, \max\left[\overline{g}_{min}, \phi_{g1}g_{t-1} + (1-\phi_{g1})\phi_{g2}\left(\log\frac{L_t}{Y_t} - \log\frac{L}{Y}\right)\right]\right] \tag{42}$$

where $\frac{L_t}{Y_t}$ is the loans-to-GDP ratio.[22] The deviation from the steady-state level, $\frac{L}{Y}$, represents a measure of credit expansion (see Angelini *et al.*, 2011). However, banks may want to keep an additional buffer over and above this minimum regulatory capital $\overline{g}_{min}$, without going beyond $\overline{g}_{max}$, which is the capital required after the full legislated counter-cyclical capital buffer available to financial regulators has been utilised. We set the discount factor for banks $\hat{\beta} < \beta$, and so impatient banks will demand a higher future return to forego using their resources in the current period. Less patient banks also display a propensity to overlend. Therefore, they can use this higher return to accumulate a greater capital buffer than the regulatory minimum. Macro-prudential policy can discipline bankers and penalise banks for maintaining an insufficient equity buffer, either by setting a lower reference level for the loan-to-equity ratio or by increasing the penalty in the case of deviations from the regulatory level. The first order condition for L_t states that:

$$\tilde{R}_t = R_t^L(1-\nu J_t^{ex-ante}) = R_t + \upsilon\left(\frac{L_t}{E_t} - g_t\right) \tag{43}$$

where the term on the right-hand side is the marginal cost of lending $\tilde{R}_t = R_t + \upsilon\left(\frac{L_t}{E_t} - g_t\right)$. This equation states that the marginal cost of lending $\tilde{R}_t$ can be set as a spread over the deposit rate R_t. This spread is determined by the cost of regulatory penalty and compensates the bank for their greater risk of breaching the minimum capital requirement at higher leverage levels. The f.o.c. for equity E_t, after some algebra, is given by:

$$\mathbb{E}_t\hat{\beta}\frac{\Lambda_{t+1}}{\Lambda_t}R_t^E = 1 + \xi^E\Omega_t^E \tag{44}$$

[22]When the minimum capital requirement is set as a time-varying target, g_t replaces $\overline{g}_{min}$ in the banks' maximisation problem (Equation 41).

where:

$$R_t^E = R_{t-1} + (R_{t-1}^L - \tilde{R}_{t-1})\frac{L_{t-1}}{E_{t-1}}. \tag{45}$$

To adjust the loan-to-equity ratio towards the regulatory level, banks face two options: (i) cut back lending, either by increasing interest rates (*i.e.* increasing the lending spread) or by reducing the quantity of credit or (ii) issue new equity. Whenever banks deviate from the regulatory level g_t, they pay a cost $\upsilon\left(\frac{L_t}{E_t} - g_t\right)$. By requiring banks to pay a penalty if they violate the capital requirement, this framework closely resembles the current Basel regime. In other words, banks' choice of capital is modelled as an incentive-based mechanism which changes their behaviour. Hence, while in most of the existing models capital requirements are an ever-binding constraint (*e.g.* Angeloni and Faia, 2009; van den Heuvel, 2008), in this framework capital buffers change over the time in response to financial cycles. Incentives to create capital buffers arise because equity from households is costly and not always available and hence banks decide to maintain a cushion to avoid capital shortfall. Once the asset-liability management branch determines $\tilde{R}_t$, it gives the lending branch instructions to offer each household-borrower an individual lending supply curve defined by all possible combinations of R_t^L and L_t that is consistent with $\tilde{R}_t$. Lending branches fix the ex-post lending rate and the relative spread as follows:

$$\left(R_t^L\right)^{ex-post} - R_t = \tau\left(R_t^L - R_t\right) + (1-\tau)(\overline{R}^L - \overline{R}) \tag{46}$$

where τ determines to what extent credit tightening is implemented via increased lending rates and $1-\tau$ is the degree of credit rationing. This second component represents the non-price bank lending channel, whereby banks are unable to fully enact desired changes in their lending rates. This feature replicates the presence of tracker mortgages[23] on Irish banks' loan portfolios. The difference $R_t^L - R_t$ represents the lending spread, with their steady-state counterparts represented by $\overline{R}^L$ and $\overline{R}$. This lending spread, which is over and above the spread needed to cover capital regulation costs, is

[23]These variable rate mortgages have a fixed margin above the ECB base rate. Therefore, movements in the lending rate of these mortgages are outside of the banks control.

linked to the probability of default and hence to individual households' risk.

3.4 Policy authorities

As Ireland is part of the EMU, monetary policy is assumed to be exogenous, as interest rates are set by the European Central Bank. Moreover, Ireland is too small to affect macroeconomic aggregates in the euro area. Therefore, instead of a Taylor rule, we assume that a fixed exchange rate is maintained (i.e. the nominal exchange rate equals one). It is further assumed that the small size of Ireland means that foreign inflation is also exogenously given. The fiscal authority is stylised, and is primarily included in order to obtain a more accurate calibration of key steady-state ratios. Government spending is specified as a fraction of steady-state nominal output $\bar{Y}$:

$$G_t = g\bar{Y} \tag{47}$$

and is assumed to consist entirely of domestically produced non-tradable goods. A balanced budget is ensured in every period by a lump-sum tax (transfer) Θ_t that offsets any fiscal deficit (surplus):

$$P_t^N G_t = T_t. \tag{48}$$

3.5 Rest of the world and closing conditions

The domestic interest rate R_t is assumed to be tied to the euro area interest rate, $R_t^\star$, through an uncovered interest parity (UIP) condition:

$$R_t = R_t^\star \frac{\mathbb{E}_t S_{t+1}}{S_t} + \theta^B \left(\log \frac{B_t}{P_t} - \log \frac{B}{P} \right). \tag{49}$$

where the term $\theta^B(\bullet)$ is a debt elastic risk premium used to close the model, as in Schmitt-Grohe and Uribe (2003), and θ^B is a parameter governing how quickly debt returns to its steady-state level $\frac{B}{P}$. Furthermore, $R_t^\star$ can be subject to exogenous shocks

U_t^F, described by the following autoregressive process:

$$\log U_t^F = \rho^{U^F} \log U_{t-1}^F + \epsilon_t^{U^F}. \tag{50}$$

Domestic and foreign deposits are paid their corresponding interest rates. Therefore, if the euro area interest rate is shocked, a gap can develop between the banking sector's cost of liabilities for domestic and foreign liabilities due to the presence of the debt elastic risk premium. The balance of payments equation for the country as a whole is obtained by combining the households' budget constraint with the definition of banks and firms' profits:

$$B_t = B_{t-1} - R_{t-1} - (P_t^X X_t - P_t^M M_t) + \left(R_{t-1}^L\right)^{ex-post} L_{t-1} \nu J_t^{ex-post} \tag{51}$$

where the term $\left(R_{t-1}^L\right)^{ex-post} L_{t-1} \nu J_t^{ex-post}$ measures the total cost of loan defaults, which is assumed to be a social loss[24].

The final consumption good C_t and investment good I_t are an aggregate of locally produced non-tradables and imports, bundled in fixed proportions[25]:

$$C_t = \omega^C C_t^M + \left(1 - \omega^C\right) C_t^N \tag{52}$$

$$I_t = \omega^I I_t^M + \left(1 - \omega^I\right) I_t^N \tag{53}$$

where ω^C and ω^I are the share of imports in final consumption and investment goods respectively. Real prices of the consumption and investment goods are derived by imposing the following conditions:

$$P_t C_t = P_t^N C_t^N + P_t^M C_t^M \tag{54}$$

[24] Alternatively, we can assume that the cost of bank losses is borne by the government or some other agent.

[25] We assume a fixed share of domestic and import goods in total demand of consumption and investment goods, given that Ireland is characterised by a low degree of substitution between imported goods and domestically produced goods.

$$P_t I_t = P_t^N I_t^N + P_t^M I_t^M. \tag{55}$$

In equilibrium, the final goods market clears when demand from households and the foreign economy is matched by the production of final goods firms. The bond market is in equilibrium when the positions of the export and importing firms equals the households' choice of bond holdings. The following represents the clearing conditions for the final non-tradable good, import, labour and capital markets respectively:

$$Y_t^N = C_t^N + I_t^N + G_t \tag{56}$$

$$M_t = C_t^M + I_t^M + X_t^M \tag{57}$$

$$N_t = N_t^N + N_t^X \tag{58}$$

$$K_t = K_t^N + \overline{K}_t^X \tag{59}$$

where capital in the export sector is fixed. Given that all households choose identical allocations in equilibrium, the aggregate quantity is expressed in domestic per capita terms. The economy's aggregate resource constraint is therefore:

$$Y_t = P_t^N C_t^N + P_t^M C_t^M + P_t^N I_t^N + P_t^M I_t^M + P_t^N G_t + P_t^X X_t - P_t^M M_t. \tag{60}$$

4 Calibration

The model is developed so as to allow for the specific nature of the Irish economy to be modelled within the context of the EMU. Of particular importance will be correctly capturing the small size and highly open nature of the Irish economy. The calibration process involves the specification of values for steady-state (long-run) ratios and model parameters which govern the model's dynamic adjustment to shocks. This section contains a discussion of some of the key choices and data sources. The values of steady-state ratios and parameters used to calibrate the model found are provided in Tables 1-2. Key steady-state ratios are targeted in order to resemble the underlying structure of the Irish economy. However, given the large fluctuations in the Irish economy over the previous four decades, the elicitation of appropriate steady-state values is difficult. The data chosen are the long-run (1980-2010) averages from the national accounts statistics, as gathered from the ESRI model database. This dataset allows for the longest possible time horizon to be used, while omitting the large structural changes to the economy which took place prior to this period.

We assume that the economy starts out in a steady state with zero consumption growth. Thus, the interest rate must equal the rate of time preference. The nominal output shares of government expenditures (13%) and investment (11%) are based on the respective domestic demand shares of public consumption and gross capital formation. The total share of exports is set using the same data source[26]. The modelling framework sets the share of consumption (75%) equal to the residual of the sum of the remaining output shares.

However, data averaged over the very long-run may not be as useful in capturing Ireland's international trade relations. Therefore, the imported intermediate inputs in exports is set at 50%, in line with OECD estimates using input-output (I/O) tables for the period 1995-2010. The share of imports in the aggregate consumption (29%) and investment (48%) baskets are based on the latest available (2008) final use breakdown of imports from the Central Statistics Office I/O tables. These latter features ensure that the model captures the highly open nature of the Irish economy. The factor-intensity parameters are important in determining the dynamics of the model. As only labour is mobile between the non-tradable and export sectors, the impact of productivity and terms of trade shocks will depend on the differing labour intensity of these sectors.

[26] In the steady state, the trade balance will simply cover net foreign interest payments. A larger trade surplus/deficit in the steady state would only be feasible with the inclusion of an international bond market which permitted the accumulation of net foreign assets/liabilities.

Several Irish studies (e.g. Bermingham, 2006) have found that the non-traded sector is more labour intensive than the export sector, and accordingly their shares in the production function are higher in the non-tradable (76%) than in the tradable sector (24%).

The model belongs to the New Open Economy Macroeconomics synthesis[27], and as such uses real and nominal rigidities in order to match the sluggish reaction of prices and wages found in macroeconomic data. However, data on these features is limited in Ireland. Therefore, the matching process involved identifying values common in the literature and recursively updating them when the impulse response functions did not correspond to well-known macroeconomic theory. For example, the investment adjustment costs and habit formation parameter are adjusted in order to replicate the well-known (see, for example, King and Rebelo, 1999) respectively higher and lower variability of investment and consumption over the course of the business cycle.

Druant *et al.* (2009) identified a relatively high degree of frictions in the Irish goods and labour market, implying a lower level of competition. However, Keeney *et al.* (2010) and Keeney and Lawless (2010) note that this may be due to the boom in Ireland during the period in which the survey used by Druant *et al.* (2009) took place. Keeney and Lawless (2010) find that, despite the lack of wage decreases during the period, Irish firms had the least issue with regulations of all euro area countries surveyed. This finding, coupled with evidence of wage decreases since the onset of the financial crisis, suggests greater flexibility in the labour market. In light of such offsetting evidence for goods and labour market flexibility, it was decided to keep price and wage markups at standard values found in the literature.

For the banking sector, the minimum capital adequacy ratio is fixed at 8%, in line with the proposals in Basel III. As detailed in the previous section, banks optimally choose to hold an additional buffer on top of this. For instance, if the minimum capital requirement $\overline{g}_{min}$ is a constant and it is set equal to 8%, then banks can set their optimal amount of capital $\overline{g}_{max}$ up to 10.5% and the capital buffer is 2.5%. In the baseline

[27]See Lane (2001) for an early survey of this literature.

scenario, we assume that the macro-prudential rule does not respond to the credit expansion (*i.e.* $\phi_{g1} = \phi_{g2} = 0$). However, we also consider the implications of a pro-active macro-prudential rule (*i.e.* $\phi_{g1} = 0.8$ and $\phi_{g2} = 1.2$) in the simulation exercises.

A fixed proportion of loans $\varkappa$ default in each period, irrespective of developments in the real economy. This share is calibrated to be 0.5%. The loss given default ν is set at 0.5 (*i.e.* only 50% of the value of a defaulted loan can be recovered by the bank). Idiosyncratic and systemic risks are treated parametrically and are set equal to 0.05 and 0.10 respectively. The loan-to-value ratio is determined endogenously and it is equal to 74%. This value is consistent with the increasing proportion of loan-to-value ratios on mortgage loans in Ireland between 2004 and 2008 (see Honohan, 2009; Kennedy and McIndoe Calder, 2011). If a negative shock erodes banks' capital, they must recapitalise to meet the minimum regulatory requirements. In order to do so, banks are faced with the choice of either increasing the lending spread or restricting the supply of new loans. The degree to which banks can pass on desired changes in the lending spread, $1 - \tau$, is treated as a parameter and set to be 0.5 (i.e. banks can pass on 50% of their desired lending spread increases).

In order to provide values for parameters for which there is no empirical evidence, we calibrate them consistently with the steady-state ratios and the interest rate margins observed in Irish data. While the balance sheet ratios can be calculated from official statistics, the interest margins are purely illustrative. They should therefore not be taken as an attempt to calibrate the average lending rate spread charged by Irish banks. The interest rate on deposits, which is equal to the policy rate, is set at 3%. We calibrate the markup on the deposit rate, designed to compensate the banks' high leverage risk, at 2%. Therefore, the marginal cost of lending $\tilde{R}_t$, which indicates as the minimum return on loans necessary to ensure capital requirements are met, is set at 5%. The retail lending rate, which consumers internalise in their loan demand decisions, is calibrated to be 8%. All interest rates are quoted in annual terms. The weights of housing and deposits in the utility function, θ and ζ, are calculated using the annual ratio of housing stock (200%) and deposits to GDP (87%) respectively. These figures are based on Quarterly National Accounts data from 2002 - 2012. The banks discount factor is consistent with the equity-to-loans ratio, $e = 10\%$. This is the inverse of the $\frac{L_t}{E_t}$ term in the banks' maximisation problem. The elasticity of labour supply η is set at 0.5, a common value in the literature (*e.g.* Devereux *et al.*, 2005).

5 Simulation exercises

In this section, we highlight the macro-financial feedback loops present in this framework and illustrate the policy analysis capabilities of the model by performing various simulations[28]. In most DSGE models with financial/banking sectors, recessions are the result of large financial shocks, namely shocks that either push up the cost of loans or decrease the demand for credit (*e.g.* Gerali *et al.*, 2010). These adverse financial-type shocks might be amplified and propagated by financial frictions (*e.g.* Jermann and Quadrini, 2012; Gertler and Karadi, 2011). On the contrary, in the modelling framework adopted here, credit crunches are not necessarily triggered by financial-type shocks. To simulate a credit crunch, we consider both a real shock (*i.e.* an increase in housing demand) and a financial shock (*i.e.* a decrease in the cost of banks' foreign liabilities). In this respect, the model is close to Boissay *et al.* (2013).

First, we examine the transmission of house price shocks to the financial sector and the real economy. We explicitly consider the role that expectations[29] for future house prices play in the endogenous accumulation of credit risk. By setting a shock that agents in the model expect to occur in the future, we can analyse the response of these agents in anticipation of these future changes. We can also assess the reaction of agents when the anticipated shock fails to materialise (*i.e.* the expectations were over-optimistic). By doing so, we distinguish between "good booms", based on solid economic fundamentals, and "bad booms" driven by irrational expectations or unsustainable changes in the economy.

[28]We use the IRIS toolbox add-on to Matlab (http://iristoolbox.codeplex.com/) to perform the simulations reported in this paper. All simulations are deterministic.

[29]There is a large literature suggesting that changes in expectations may be an important element driving economic fluctuations. See, for example, Beaudry and Portier (2006) for empirical evidence.

Second, we further demonstrate the transmission channels of the model by detailing the impact of a shock that originates inside the financial system (*i.e.* capital flows), rather than the real economy.

Finally, we consider the role that counter-cyclical macro-prudential policy can play in mitigating the build-up of credit risk in periods of ”bad booms”. We compare the performance of a time-varying minimum capital requirement to the baseline case where this target is constant, and assess its impact in terms of limiting the impact of negative shocks to the financial system and the real economy. We also assess whether increasing the scope of the regulatory authority to increase capital buffers is of further benefit.

5.1 Real economy shock: housing demand

When describing the housing boom-bust cycle, the literature distinguishes between two phases. During the boom, a large and increasing fraction of households receive positive signals about future fundamentals and believe that it is a good time to buy a house. During the bust, agents receive increasingly negative signals and change their expectations (see Burnside *et al.*, 2014; Piazzesi and Schneider, 2009). We set a positive expected 5% housing demand shock U_t^H to occur after three years (12 quarters). This shock is expected to be temporary but persistent. We consider two scenarios: one in which the increase in demand occurs as expected; the other in which these expectations are unfulfilled, and when the shock was supposed to occur housing demand remains unchanged. The results of these simulations are reported in Figure 7.

We initially focus on the period in which the expectations are still valid (i.e. they are still assumed by agents to be correct). This is represented by the shaded area of the plot. There is an immediate rise in house prices, as consumers want to purchase these assets before the expected increase in demand. With supply of housing fixed by assumption, demand side pressure leads to a large increase in house prices. As the threshold for non-performing loans is based partly on house prices, banks respond by decreasing their lending spreads to cover the (erroneously) expected lower default risk. The perceived decrease in default risk also manifests itself in an increase in lending, with the supply of loans increasing to keep pace with demand. The increased leverage on the banks' balance sheet means that they are now eroding some of their capital buffer. As they are now closer to the regulatory minimum capital adequacy ratio, banks increase the spread to cover the expected marginal costs of breaching this requirement. However, this increase is minimal in comparison to the decrease in the default risk spread and thus overall lending rates decrease. Higher housing asset prices and cheaper lending rates combine to loosen household's budget constraints, with debt levels increasing after taking on a greater amount of loans. There is a consequent increase in domestic demand, with output expanding to meet this demand. The higher demand for labour leads to an increase in both the wage rate and in hours worked. This increase in labour income further increases the default threshold, making loans even more likely to be repaid in full. Thus there is an endogenous build-up of credit with strong feedback loops between the financial sector and the real economy. Finally, exports decrease as external competitiveness is affected by the increase in factor input prices, driven by higher demand for these resources from the non-tradable sector.

We now focus on the period after the shock has materialised. We first describe what happens when the expectations for housing demand have proven to be correct (green line scenario). House prices follow a smooth adjustment path back to their steady state level. The share of NPLs and the spread covering default risk return converge to a permanently higher level than the initial steady-state. This is because the higher level of loans provided by the banks requires a permanently higher spread to cover the increased possibility of default. As the banks have reduced their capital buffer to extend these loans, the spread covering the risk of failing to meet the regulatory capital requirements remains elevated. The continued easing of credit conditions means that consumption, output and imports can smoothly return to their steady state levels. However, investment remains below its steady state for a prolonged period as household continue to bring forward consumption in light of favourable economic conditions. Due to the large accumulation of debt levels, exports need to remain above their steady state level in order to cover the increased debt repayments.

Conversely, when the expectations concerning housing prove to be over-optimistic (blue line scenario), house prices are now over-valued and fall accordingly. This lowers the threshold for non-performance of loans and causes banks to increase their spread covering default risk. The resulting increase in lending rates reduces demand for loans, with domestic demand also suffering as households begin to deleverage the large amount of debt accumulated during the boom period. Therefore, the transmission mechanism from the financial sector to the real sector is via two channels. On the one side, households start deleveraging and reallocating their savings. On the other side, banks tighten credit standards and start recapitilising. Our model reproduces the counter-cyclical equity observed in the model of Adrian and Boyarchenko (2013). Banks build up new equity only when forced during recession periods. This result contrasts with the assumptions in Brunnermeier and Sannikov (2012) and He and Krishnamurthy (2012, 2013) who feature pro-cyclical equity.

The decrease in output lowers the demand for labour, which reduces the wage income and puts further pressure on non-performing loans. This feedback loop between the real economy and the financial sector reinforces the banks decision to increase lending rates and results in a persistent downturn. The reduction in wages, however, boosts the external competitiveness of export sector firms. Accordingly, these firms increase their output and the resulting trade surplus enables the paying down of foreign debt.

5.2 Financial shock: capital flows

As pointed out in Lane (2014), the role of international flows during the boom in driving the rapid growth in the external debt of the banking system remains unclear. On the one hand, bank-intermediated debt inflows certainly contributed to the amplification of the property boom during 2003-2007. However, on the other hand, other types of international flows have played a stabilising role and partially offset the effect of bank-intermediated debt. In relation to crisis dynamics, much remains to be worked out in terms of modelling official flows (*i.e.* eurosystem funding of the banks, EU-IMF funding of the sovereign). In relation to the recovery phase, it is crucial to identify the most successful policy tools to re-build confidence among international investors. With free capital mobility and cross-border lending, national regulatory requirements may become a weaker instrument for moderating the credit cycle.

In order to further assess the transmission channels of the model, we simulate a scenario in which a shock emanates from the financial sector. We set a negative 1% shock to the cost of banks' foreign liabilities U_t^F, which occurs immediately. The presence of a debt elastic risk premia ensures that foreign deposits become relatively cheaper than those from domestic sources, and so banks adjust their balance sheets to accumulate more of the former. We assess two alternative paths: one in which this decrease in costs is permanent; the other in which the decrease is unexpectantly reversed. In this latter scenario, after 3 years (at $t = 13$) the cost of foreign banks' liabilities increases by 0.5% and stays permanently at this level. The first scenario results in the economy converging to a new steady state. The second scenario replicates the impact of a capital reversal or a sudden stop, with the economy returning back towards the original steady state. The results of these scenarios are reported in Figure 8. We focus first on the period in which the cost of foreign liabilities are reduced. This is represented by the shaded area of the plot and the impulse responses are the same for both scenarios during this period.

With the domestic interest rate, which serves as the deposit rate, tied to the external interest rate, the cost of domestic liabilities also decreases. In response to their reduced costs of liabilities, banks increase their lending as each loan is now more profitable. The expansion in credit fuels higher demand for housing assets and final goods, and requires an expansion in domestic output and imports to fulfil this extra demand. Higher asset prices and wage income levels reduce the amount of non-performing loans. This lower default risk further encourages banks to reduce their lending spreads and reinforce the increased demand for loans. The increase in leverage and reduction in the capital buffer forces banks to raise the spread used to ensure the minimum capital adequacy ratio is achieved. On aggregate, however, this is insufficient to offset the decrease in the default spread and so lending rates decrease. In the first scenario, represented by the green line, the reduction in the cost of liabilities is permanent. In this case, there is a smooth transition to a greater level of lending, and correspondingly, debt accumulation, in the steady state. However, the permanent increase in the volume of loans results in a greater number of non-performing loans in the steady state. This is because of the accumulation of risk due to the greater amount of lending. Accordingly, banks charge a higher spread to cover this increased default risk. A trade deficit can be financed due to the lower cost of servicing the foreign debt, and so domestic demand remains elevated with negative effects for the competitiveness of exporters.

In the alternative scenario, represented by the blue line, the reduction in the cost of liabilities is temporary and after 3 years is partially reversed. The convergence of costs back towards their original level encourages banks to reduce their lending. This contraction in credit availability leads to a drop in demand for housing assets (the price of which suffer from a sharp reduction) and final goods, as households begin to deleverage some of the foreign debt accumulated during the boom. The reduction in labour demand as output contracts pushes down wage income (from both lower wages and decreased hours worked). As a result of this, and the large decrease in house prices, the default threshold is lower and the share of non-performing loans increases. This adds to the downward pressure on lending, as banks try to recapitalise. The trade balance increases as lower competition for factor inputs improves the export sectors' external competitiveness. The corresponding trade surplus is essential in paying down the foreign debt accrued during the boom. The capital reversal is associated with a recession, as discussed in Calvo *et al.* (2004) and Bordo *et al.* (2010).

Our results are in line with those obtained in Jaimovih and Rebelo (2008) for news in a small open economy without the financial sector. However, in our set-up the reversal is not anticipated, and therefore labour supply, and labour income, decreases at time $t = 13$, when the reversal materialises.

5.3 Counter-cyclical capital regulation and increased conservation buffer

Due to the nature of their operations, banks often impose tighter financial conditions precisely at the time when the real economy would benefit from a more counter-cyclical lending policy (Borio, 2012). The principle of counter-cyclical lending implemented through a time-varying capital target is to address the so-called pro-cyclicality of the financial system and the real economy, which can cause financial instability. More counter-cyclical macro-prudential policies could limit pro-cyclicality by encouraging the accumulation of buffers and re-straining the build-up of credit during the expansion phase. These buffers could then be drawn down, although still adhering to the minimum regulatory requirement, as harder times materialise and financial strains threaten to emerge.

Ideally, policymakers should distinguish between "good booms", based on solid economic fundamentals, and "bad booms" driven by irrational expectations or unsustainable changes in the economy. Successfully differentiating between the two would allow tail risk in the financial system to be contained without eliminating the financial sector's contribution to economic growth. Therefore, macro-prudential tools should allow policymakers to lean against the wind during "bad booms" driven by euphoria and characterised by increasing leverage and rapidly rising asset prices. On the contrary, macro-prudential tools should be designed so as to allow policymakers to react more cautiously during "good booms" driven by a wave of new technologies for example (see Popov and Smets, 2011). We analyse the effect of a counter-cyclical capital requirement and compare the impact it has to that of the baseline simulation in which the capital requirement was constant. To implement this aspect of the model we allow the capital requirement to be time-varying (i.e. g_t rather than $\bar{g}_{min}$), as described in equation 42. For the sake of brevity, we focus our analysis only on the case of a positive 5% housing demand shock. The results are detailed in Figure 9.

We start by discussing the effects of pro-active capital regulation, represented by the green line. We see that pro-active capital regulation reacts to the house price boom by raising the capital requirement. The increased possibility of breaching this more stringent target forces banks to increase the spread used to cover this over-lending risk, $\tilde{R}_t - R_t$, to a much higher level than in the case of constant capital requirement. Higher lending rates reduce the demand for loans relative to the scenario assuming constant capital requirement, and thus help to limit the accumulation of debt and the boom in domestic demand and output. Higher lending rates also make lending more profitable, and allow banks to build up their capital buffers. Therefore, when the expectations over housing demand prove to be over-optimistic, the financial sector is much better placed to handle the shock. Although non-performing loans, and thus credit risk increase, they do so by less than in the simulation assuming constant capital requirement. This is because a lower amount of loans, which are now riskier as lower house prices and reduced wage income make default more likely, were extended during the boom phase. Banks do not need to recapitalise, as the extra spread charged to cover the increase costs of regulation have allowed them to develop a large buffer. As a result, the persistence of the crisis is much lower when counter-cyclical capital regulation is used, as banks balance sheets are much healthier and can therefore help support the recovery.

Up to now, we have assumed that the minimum capital requirement has been fixed (8%) and that banks keep a buffer over and above this to prevent against any regulatory capital breaching (and ensuing penalty). With a pro-active macro-prudential rule, we now discuss the effects of increasing the minimum capital requirement. This scenario is represented by the red line in Figure 9. Recently introduced legislation in Ireland allows the regulatory authorities to increase the minimum capital requirement by up to 2.5%. This extra capital is used to develop what is described as a ”conservation buffer”. Although it is possible in principle to extend minimum capital requirements beyond this amount, the need for approval at European level may discourage its potential use. At a very minimum it takes the decision out of the full control of domestic authorities. In the previous simulation, the upper bound of the buffer is reached very quickly, after which the regulatory authority has no ability to act further in this regard. Here we assess whether the use of a larger range for the counter-cyclical capital requirement (with the lower bound always fixed by Basel III) is of value in terms of minimising the output loss from boom and bust cycles. In this simulation, the results of which are described in Figure 9, we allow the minimum capital requirement to be increased by up to 4% (i.e. the minimum capital requirement can vary between 8% and 12%).

We can see that allowing the minimum capital requirement to be raised (and so extra buffers developed) during the boom phase helps the economy recover faster during the subsequent downturn. In response to rapidly increasing house prices and credit growth, the regulatory authority raises the minimum capital requirement above that permitted by current legislation. This additional capital requirement forces banks to raise the spread covering the expected cost of regulation even higher, and for a more extended period, than in the case assuming counter-cyclical capital requirements are limited to a 2.5% increase. The higher profits earned on loans extended allows the bank to build up a larger capital buffer. The increased price on these loans also limits the increase in demand for loans, and so diminishes the boom in the real economy. During the downturn, the share of non-performing loans is even lower than in the baseline. The reduced amount of losses on the banks' loan portfolio allows them to smooth the reduction in credit to the real economy. As a result, the impact of the house price crash is much less damaging, with the downturn also being far less persistent in this scenario.

Our results, therefore, replicate the phenomena of pro-cyclical equity observed in Brunnermeier and Sannikov (2012) and He and Krishnamurthy (2012, 2013). This procyclicality occurs as banks build up capital buffers during booms, rather than being forced by stress tests (for example) to issue new equity during recessions (see Adrian and Boyarchenko, 2012).

6 Conclusions

The influence of the financial sector in both triggering and propagating the recent crisis has meant that the DSGE models, commonly used in central banks and policy institutions, need to be updated to account for macro-financial linkages. We develop a DSGE model with a financial sector and we calibrate the model in order to replicate some key stylised facts from the Irish financial crisis. We use the model to simulate the fluctuations of key macroeconomic and financial variables in response to shocks to house price expectations and capital inflows. The model illustrates how expectations of future favourable events, such as a long-lasting increase in house prices and capital inflows, may accelerate credit growth, and potentially result in a more vulnerable economy susceptible to downward revisions to the original expectations.

We also consider the role that alternative macro-prudential policy instruments can play in mitigating the build-up of credit risk. We compare the performance of several policy measures in terms of limiting the impact of negative shocks to the financial system and real economy. We find that a pro-active macro-prudential rule responding to credit growth and higher minimum regulatory capital requirement help in smoothing economic fluctuations.

Although already suitable for policy analysis, there are still room for further extensions and improvements. First, in this paper, when analysing the effects of macro-prudential tools in mitigating credit and output volatility, we focus exclusively on capital target instruments (*i.e.* counter-cyclical macro-prudential rules and capital buffers). Therefore, the next step will be to also analyse the effects of borrowing target instruments (*i.e.* caps on loan-to-value and loan-to-income ratios).

Another step forward would imply the analysis of the legacy costs of a credit boom and bust. Banks balance sheets may have a large portfolio of non-performing loans for a large number of years following lax lending standards during an economic upturn. However, at present, all loans are modelling as lasting one-period. This has the effect of banks being able to clean up their balance sheets much quicker after a crash, and thus help support a recovery. However, computational limitations mean that this problem is wide-spread in the literature, and not unique to our study.

Utility based welfare analysis could also be undertaken to assess which policies produce the best outcomes from a societal perspective. Finally, further research should address the implications of banks' losses on public finances.

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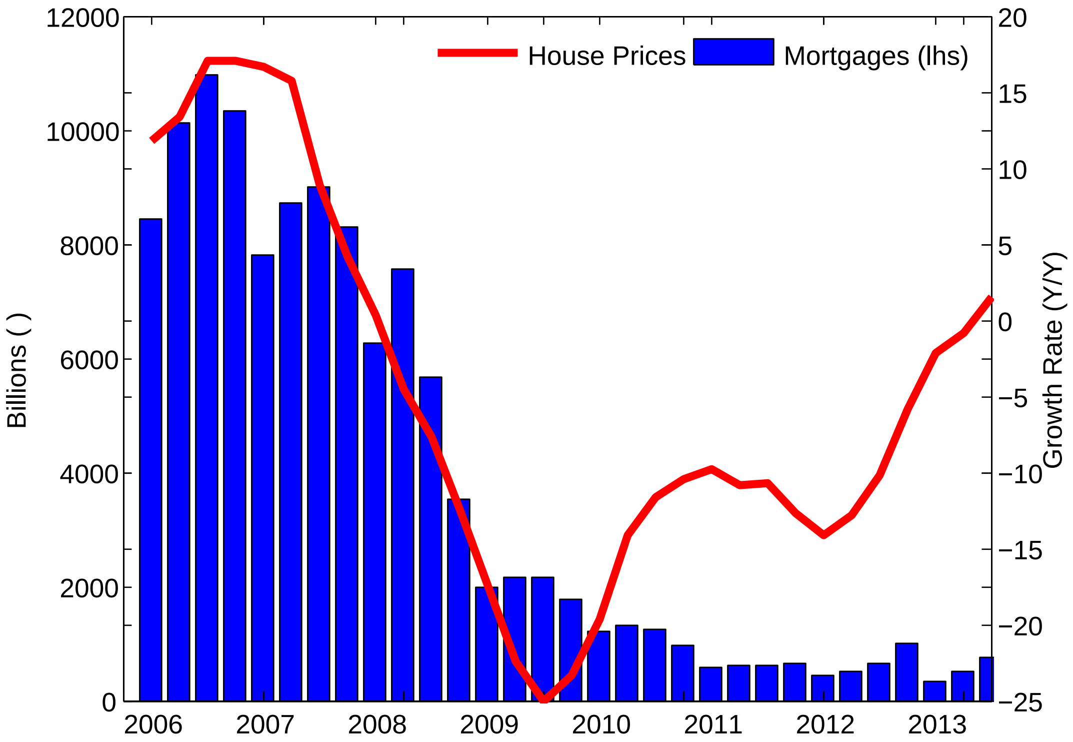
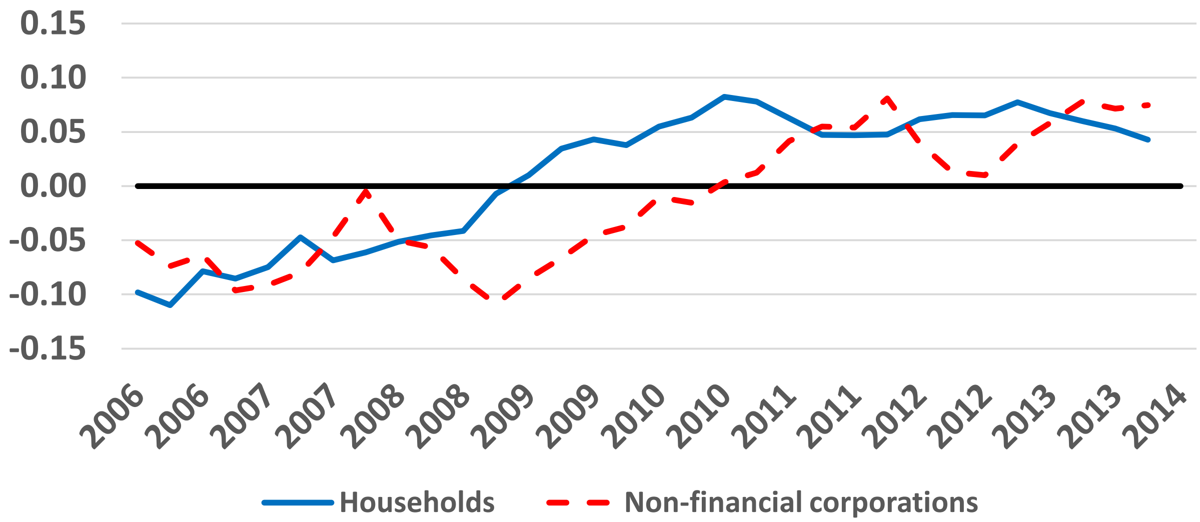
FIGURE 1. **House prices and mortgage credit**



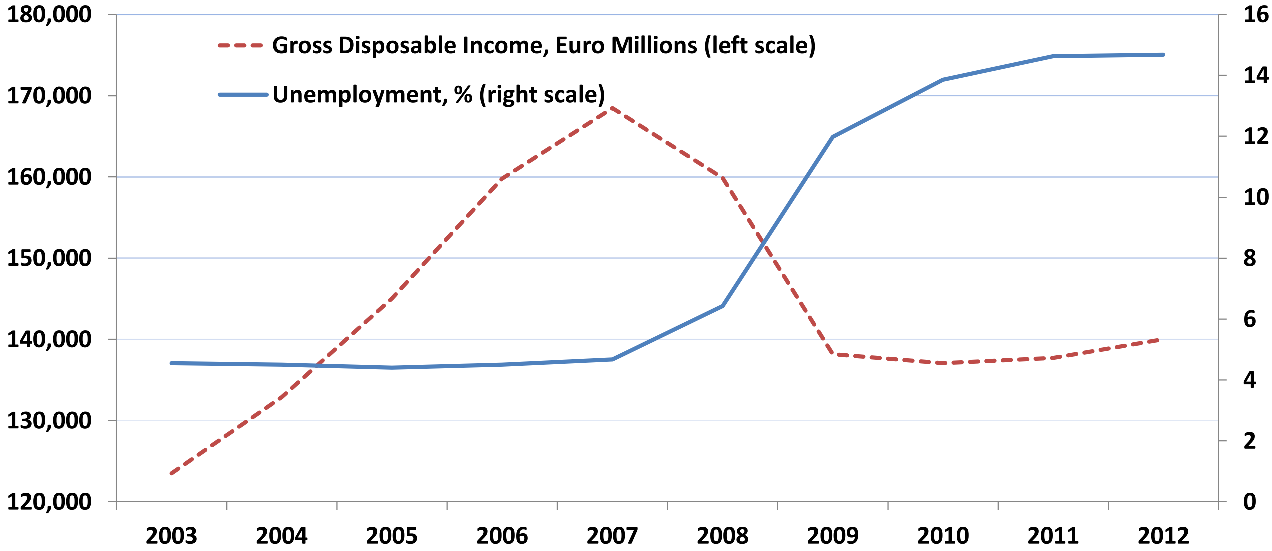
Notes: The house price series is the Central Statistics Office Property Price Index. See O'Hanlon (2011) for details on the construction of the index. Mortgage credit is represented by new mortgage drawdowns as reported by the Irish Banking Federation.

FIGURE 2. **Household and non-financial corporation deleveraging**



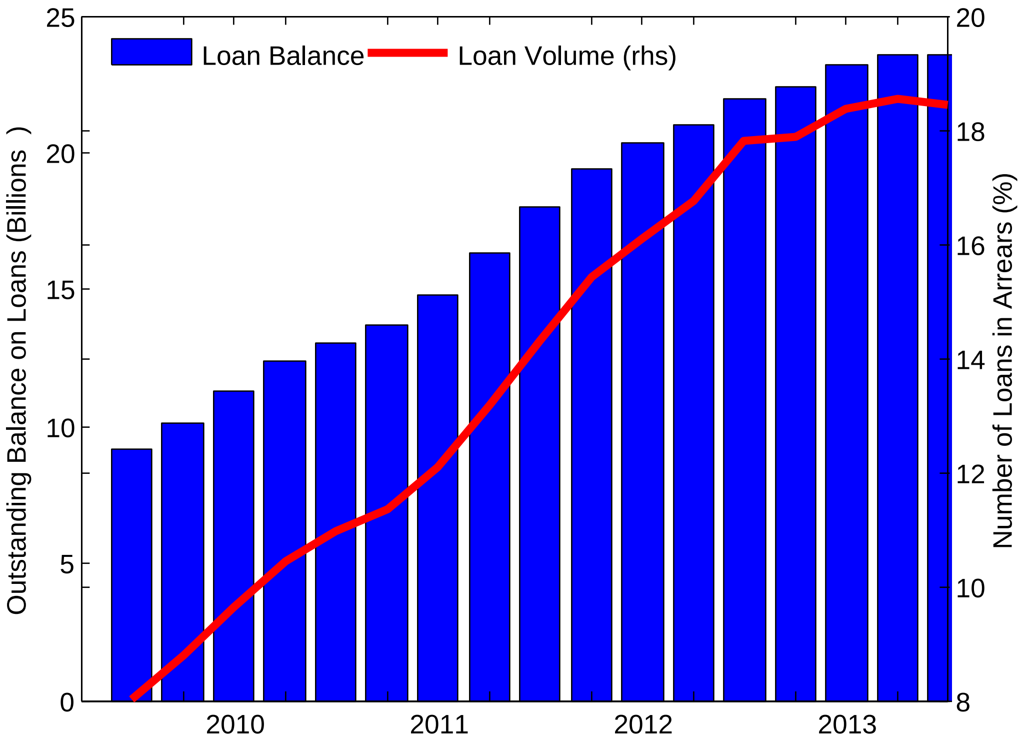
Notes: Sectoral deleveraging is represented by net lending/borrowing from the Central Bank of Ireland's Quarterly Financial Accounts. A positive (negative) number in any given period indicates that the sector in question is reducing (increasing) their liabilities. The figures are stated as a percentage of GDP.

FIGURE 3. **Unemployment and disposable income**



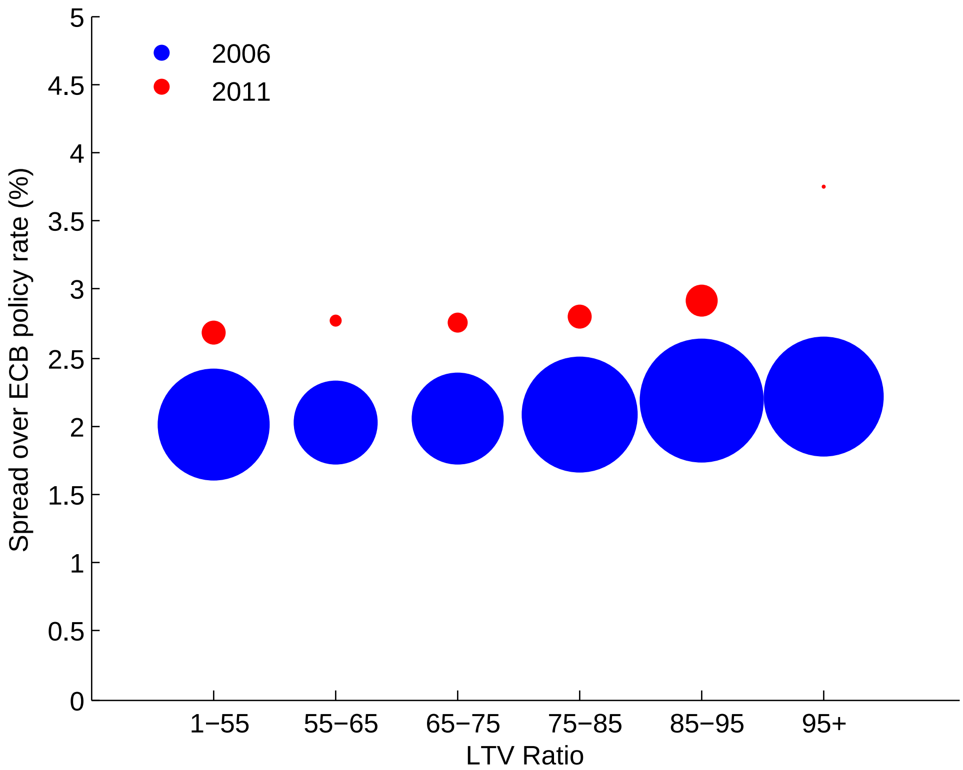
Notes: The unemployment rate is seasonally-adjusted and for both sexes. National gross disposable income is in millions of euros. Source: Central Statistical Office.

FIGURE 4. **Mortgage arrears**



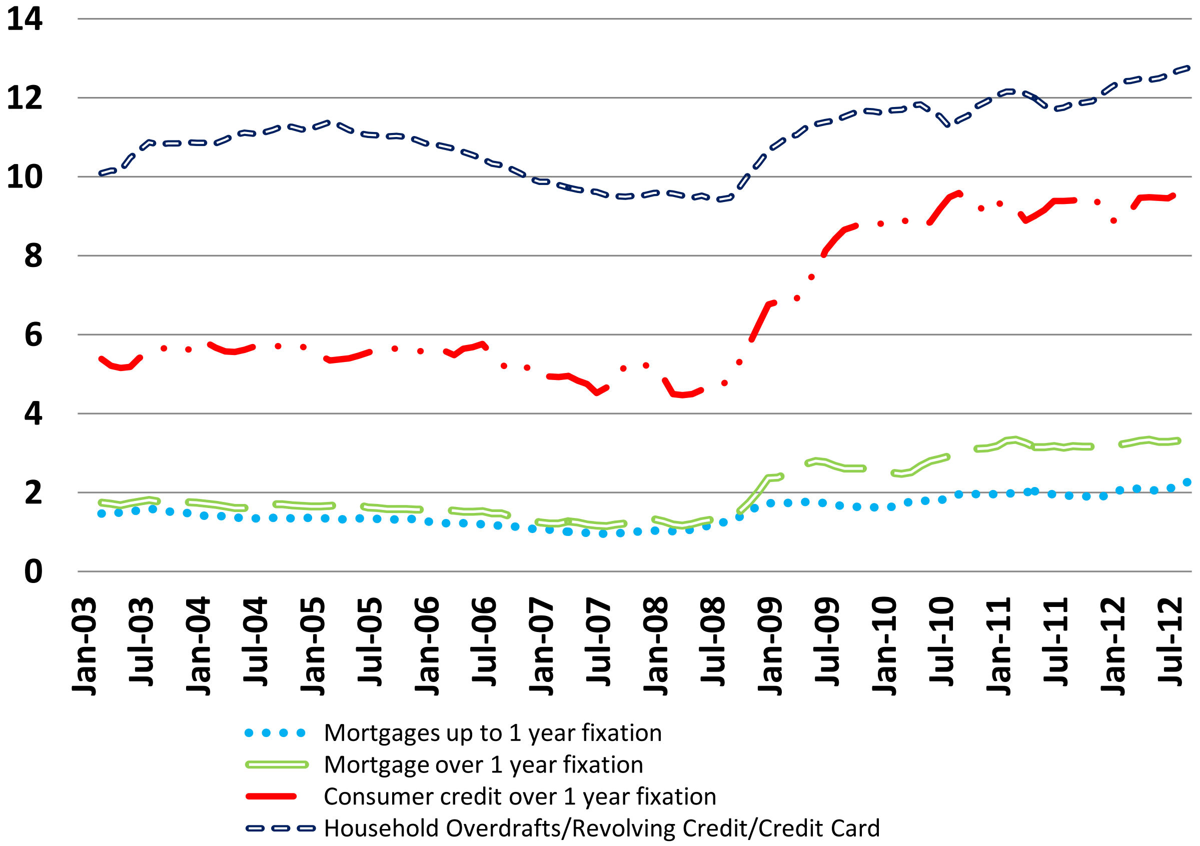
Notes: Loan volume is the percentage of mortgage accounts in arrears for 90 days or more. Loan balance is the outstanding amount owed on these loans, and not the value of arrears themselves. The data are from the Central Bank of Ireland's Residential Mortgage Arrears and Repossessions Statistics.

FIGURE 5. **Loan volume and lending Spreads**



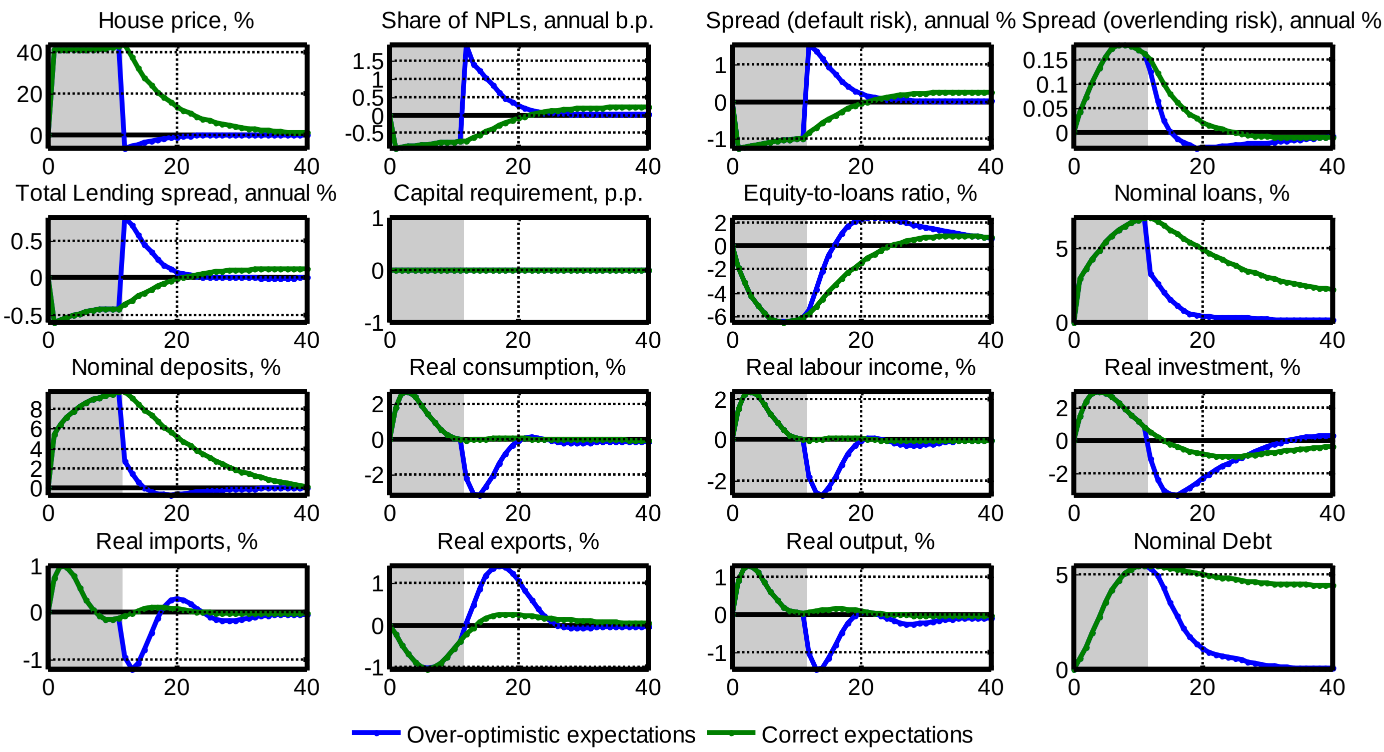
Notes: These data are mortgage spreads and product availability across loan-to-value ratios from the four Irish lenders subject to the Financial Measures Programme. Source: Central Bank of Ireland calculations. See Lydon and O' Brien (2012) for further details.

FIGURE 6. **Lending spreads over policy rate**



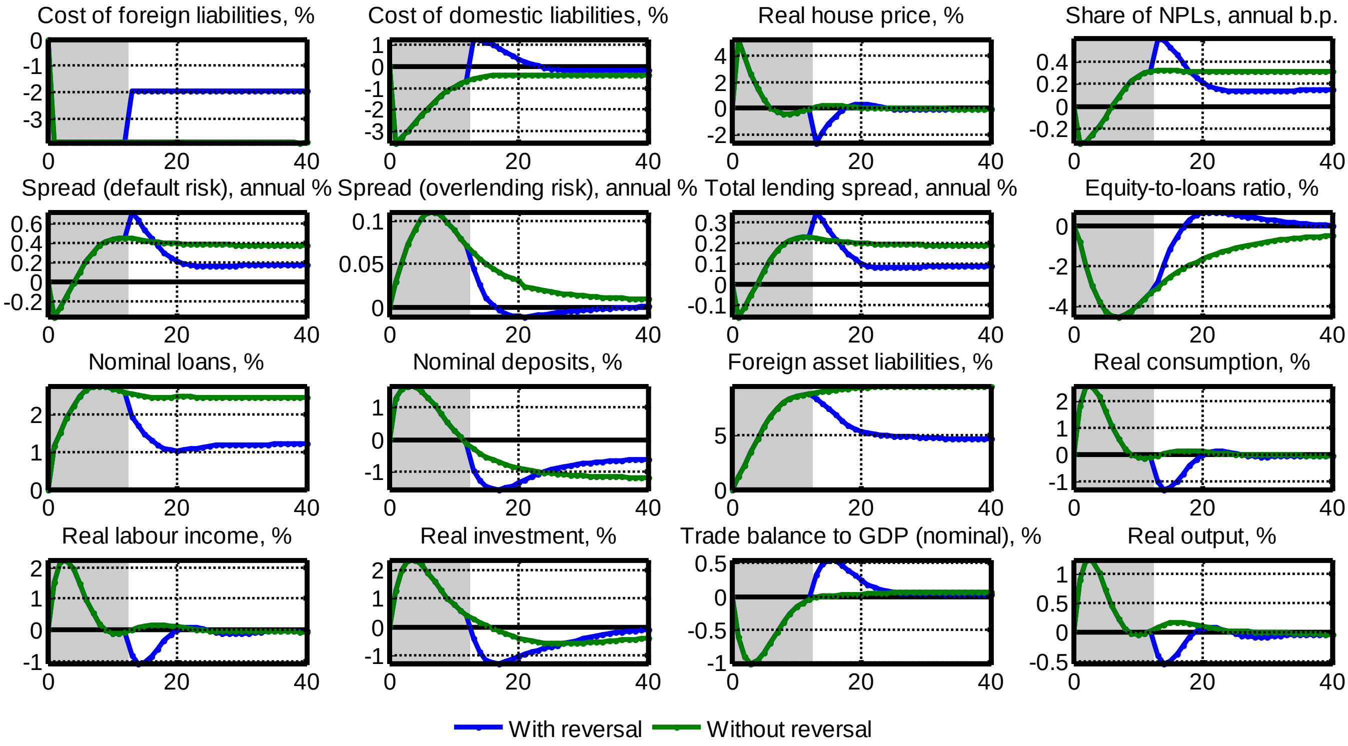
Notes: The data are lending spreads over households loans versus vs ECB MRO. Source: Central Bank of Ireland Money and Banking Statistics, all institutions, 3-month moving average. See Lydon and O' Brien (2012) for further details.

FIGURE 7. **House demand shock**



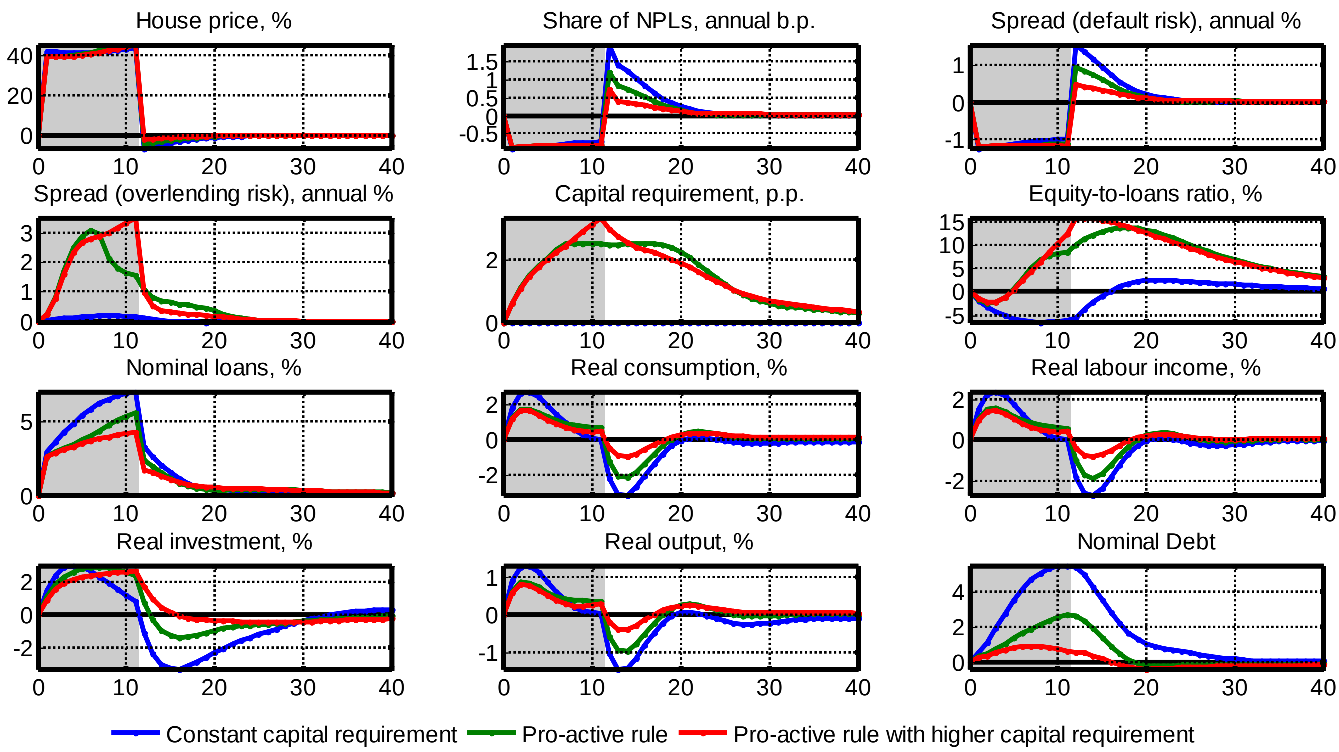
Note: Figure 7 reports the IRFs to an house demand shock expected at time $t = 12$. Under the first scenario (green line), the expectations are correct and the shock materialises. Under the second scenario (blue line), expectations turn to be over-optimistic and the shock never materialises.

FIGURE 8. **Capital inflows**



Note: Figure 8 reports the IRFs to a shock to the cost of foreign liabilities, which stimulates capital inflows. Under the first scenario (green line), there is no capital reversal. Under the second scenario (blue line), capital reversal occurs at time $t = 12$.

FIGURE 9. **House demand shock, pro-active macro-prudential policies and higher allowable minimum capital requirement**



Note: Figure 9 reports the IRFs to a housing demand shock expected at time $t = 12$, which however never materialises. Under the first scenario "Constant capital requirement" (blue line), regulatory capital is fixed at 8%. Under the second scenario "Pro-active capital regulation" (green line), the macro-prudential policy is allowed to respond counter-cyclically to the credit cycle ($\phi_{g1} = 1.2$ and $\phi_{g2} = 0.8$) with an upper limit $\overline{g}_{max} = 10.5\%$. Under the third scenario (red line), macro-prudential policies are pro-active ($\phi_{g1} = 1.2$ and $\phi_{g2} = 0.8$) and the minimum capital requirement can be raised to $\overline{g}_{max} = 12\%$.

TABLE 1. Calibrated parameters (quarterly frequency)

Households		
Discount Factor	β	0.98
Frisch elasticity of labour supply	η	0.50
Elasticity of deposits	ι	5
Preference on housing	θ	0.5
Preference on deposits	ζ	0.007
Consumption habit persistence	χ	0.65
Depreciation rate	δ	0.025
Wage markup	μ^W	0.10
Weight on housing in P^D	ω^D	0.20
Weight on consumption and investment goods in deposits for transactions	γ^C	0.20
Weight on housing in deposits for transactions	γ^H	0.05
Degree of debt convergence to the steady state	θ^B	0.10
Firms		
Export sector share of labour	γ^X	0.40
Non-tradable sector share of labour	γ^N	0.70
Import content of exports	α	0.50
Bias towards imported consumption goods	ω^C	0.29
Bias towards imported investment goods	ω^I	0.48
Non-tradable good price markup	μ^N	0.10
Imported good price markup	μ^M	0.10
Banks		
Discount factor	$\hat{\beta}$	0.9186
"Fixed" rate of default	$\varkappa$	0.005
Loss given default	ν	0.50
Minimum capital adequacy ratio	$\overline{g}_{min}$	0.08
Maximum capital adequacy ratio	$\overline{g}_{max}$	0.105
Idiosyncratic uncertainty	σ_a	0.05
Aggregate uncertainty	σ_b	0.10
Degree of credit rationing	$1-\tau$	0.50
Loan-to-value ratio	LTV	0.74
Weight on housing wealth in the default	ϕ	0.20
Adjustment costs		
Deposits	ξ^D	0.5
Equity	ξ^E	0
Exports	ξ^X	3
Imports	ξ^M	20
Investment	ξ^I	10
Non-tradables	ξ^N	50
Wages	ξ^W	50

TABLE 2. Steady-state ratios, in nominal terms and as share of GDP
(if not differently specified)

Domestic Demand	
Private Consumption	74.97%
Private Investment	11.17%
Public Expenditure	12.96%
Trade Balance	0.9%
Trade	
Imports of consumption goods	25.83%
Imports of investment goods	5.88%
Imports of intermediate goods	32.62%
Exports (total)	65.24%
Imports (total)	64.33%
Production	
Tradables	64.28%
Non-tradables	32.62%
Wage income	53.94%
Labour input in the non-tradable sector (as share of total labour)	75.79%
Labour input in the tradable sector (as share of total labour)	24.21%
Financial (annual)	
Housing stock	200%
Deposits	87%
Loans	147%
Net foreign assets	46%