Countercyclical capital rules for small open economies

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Abstract

The Great Recession proved that a mixture of microprudential and macroeconomic policies were insufficient to ensure financial stability. In the aftermath, macroprudential policies have been widely introduced to assist in this task. Such instruments are even more vital when traditional stabilisation tools, such as nominal interest and exchange rates, are not available to policy makers. We examine Ireland as a case study for the larger cohort of countries facing such issues, and develop a DSGE model to assess the effectiveness of counter-cyclical capital regulation. We find that a pro-active macroprudential rule responding to credit growth can help in smoothing economic fluctuations and promoting financial stability. In terms of policy advice, we find that bestowing even greater flexibility to regulators to move against the credit cycle has positive benefits. We also find that more aggressive action during the release phase can bolster the economy's ability to absorb a negative shock.

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1 Introduction

Macro-financial feedback loops played a key role in both triggering and propagating the recent financial crisis. Following the seminal contribution by Bernanke, Gertler and Gilchrist (1999), who were the first to provide a measure of the strength of macro-financial linkages through the so-called financial accelerator mechanism, the most recent literature has added the banking sector in DSGE models to further account for these macro-financial linkages. This literature has mainly focused on how macroprudential and monetary policy can be used to ensure financial stability[1]. However, little attention has focused on the large cohort of countries who do not have conventional macroeconomic stabilisation tools at their disposal. Small open economies in monetary unions, for example, may have such little weight in area-wide aggregates that nominal interest and exchange rates are effectively exogenous. Smaller countries who peg their exchange rate to the currency of a much larger economy are also constrained in their use of these macroeconomic instruments. Given the diminished alternative options, macroprudential policy must play an exaggerated role in maintaining financial stability in these economies[2].

We fill this gap in the literature by examining Ireland as a case study for the larger cohort of countries facing similiar issues. The awareness of the need for macroprudential policy measures is particularly acute in 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 signif-

[1]Most of the existing literature analyses macroprudential policy in closed economy DSGE models (*e.g.* Agénor *et al.*, 2013; Angeloni and Faia, 2013; Angelini *et al.*, 2014; Beau *et al.*, 2012; Beneš and Kumhof, 2011; Bailliu *et al.*, 2012; Collard *et al.*, 2012; Carrasco-Gallego and Rubio, 2014; Christensen *et al.*, 2011; Darraq-Pariès *et al.*, 2011; De Paoli and Paustian, 2013; Gelain *et al.*, 2013; Kannan *et al.*, 2012; Lambertini *et al.*, 2013a; Suh, 2012 and 2014) or in two-countries DSGE models designed for large countries which still have some room for using traditional monetary policy tools (*e.g.* Aspachs-Bracons and Rabanal, 2010 and 2011; Quint and Rabanal, 2014) or for small open economies which are not part of a monetary union and hence have an independent monetary policy (*e.g.* Brzoza-Brzezina *et al.*, 2013; Medina and Roldos, 2014; Ozkan and Unsal, 2013; Unsal, 2013).

[2]Fiscal policy provides another set of tools to stabilise macroeconomic fluctuations. However, using such instruments to effectively manage housing markets may be politically difficult (Conefrey and FitzGerald, 2010). Indeed, Lane (2010) shows that the procyclicality of Irish fiscal policy has contributed to macroeconomic volatility. In this analysis, we focus exclusively on the ability of macroprudential policy to promote financial stability.

icantly in the run-up to the financial crisis and dropped dramatically after the crash. 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 rebuild 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. 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).

[INSERT FIGURES 1-6 ABOUT HERE]

Ireland is part of the EMU, and thus interest rates are set by the European Central Bank. However, given the small weight of Ireland in the euro area (less than 1%), domestic developments are too small to affect area wide macroeconomic aggregates. This assertion is consistent with empirical evidence from Honohan and Leddin (2006), who found that nominal interest rates in Ireland were substantially lower than those implied by a standard Taylor rule, with responses insufficiently small to be stabilising[3].

[3] Honohan and Leddin (2006) note that interest rates were not appropriate for local Irish conditions

Similiar results are found in numerous other studies on this issue, and suggest that house prices in Ireland were elevated by overly accomodative monetary policy (see Moons and Hellinckx (2015) for an up-to-date discussion of this literature). Following the recent financial crisis, the Central Bank of Ireland has enacted several macroprudential instruments to help fufill its financial stability mandate[4]. One such instrument is a counter-cyclical capital buffer. Previously, the minimum regulatory capital requirement was fixed at 8%, in line with the Basel II agreement. However, the Central Bank of Ireland now has the power to require banks to set aside additional capital during periods of strong credit growth. The accumulated capital buffer would protect banks from crippling losses that can impair the supply of credit during recessions, which have excerbated past downturns.

With this instrument due to be introduced at the beginning of 2016, we develop a model to examine its ability to promote financial stability. We first demonstrate the macro-financial feedback loops present in the model by simulating a shock to agents expectations of housing demand (*i.e.* preferences). We find that positive expectations for future house prices play a role in the accumulation of credit risk. The negative effects of this over-extension of credit materialise when these expectations prove to be over-optimistic. The model can therefore replicate some of the key stylised facts, discussed above, from the recent housing boom and bust. We then compare our results to the empirical literature, and find that our model matches the empirical evidence on the macroeconomic impact of housing shocks in Ireland. Having established that the model is useful for policy analysis, we then assess the impact that counter-cyclical capital regulation can play in mitigating the build-up of these risks during "bad booms" driven by euphoria and over-optimistic expectations. We find that forcing banks to accumulate an additional capital buffer during a period of credit growth can help smooth the economy's resiliance to negative shocks.

prior to EMU either, which they attribute to agency costs arising from exchange rate pegs during the ERM period. This indirectly affirms our point that small economies pursuing a fixed exchange rate with a larger economic area also do not enjoy full use of nominal interest or exchange rates.

[4]See Central Bank of Ireland (2014) for a comprehensive discussion of their macroprudential policy aims and powers.

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. Finally, in the appendix we present some robustness checks: we assess whether the same channels are relevant when the shock originates in the financial sector, and we examine the effects of different degrees of importance of the counter-cyclical capital rules and the non-price lending channel.

2 Theoretical framework

We enhance Eire Mod, a DSGE model of the Irish real economy (Clancy and Merola, 2014), with the inclusion of a banking sector. We adapt the banking sector framework developed by Beneš, Kumhof and Laxton (2014a, 2014b) (hereafter BKL). A key feature of this framework is that banks do not act simply as intermediaries, lending out deposits placed by savers. As stated in Borio (2012, pp. 11), "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". 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[5]. In this paper, we focus on this last aspect.

The BKL framework incorporates into a standard macro model three existing fi-

[5]For a detailed discussion on this mechanism of money creation in the banking system, see Disyatat (2011) and the Bank of England (2014).

nance 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.

First, the model contains an endogenous default mechanism, which is a key feature for the analysis of regulatory policies[6]. This approach is in contrast to some of the pioneering work in DSGE models with banking sectors, such as the seminal contribution of Iacoviello (2005). There, default is not modelled endogenously as households can not obtain loans if the value of the collateral decreases below a given threshold or because banking activity is limited to collecting deposits and supplying loans[7].

Second, in most existing models, if lending risk exists, it is idiosyncratic and thus fully-diversifiable, or introduced through *ad-hoc* exogenous shocks (*e.g.* Carlstrom and Fuerst, 1997). However, in reality, a systemic risk component also exists. BKL therefore distinguish two seperate components of endogenous risk: a fully-diversifiable and a non-diversifiable component[8]. The presence of a systemic risk component allows for important non-linearities in the response of the economy to be captured. This feature can explain 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.

Third, traditional models generally focused only on the demand side of credit, whereby access to credit depends on the prices of assets used as collateral (*e.g.* Kiyotaki and Moore, 1997) or on the net worth of enterprises (*e.g.* Bernanke *et al.*, 1999).

[6] Goodhart and Tsomocos (2011) discuss the need to integrate default in DSGE models.

[7] Several other contributions, such as Iacoviello (2015), examine the impact of defaults introduced via an exogenous shock that transfers wealth from banks to households. In the BKL framework we adopt, defaults are an endogenous process that transmit shocks from the household sector to the rest of the economy (including the banking sector), and thus represent an innovation to the existing literature.

[8] See Acharya (2009) for a discussion on the distinction between systemic and idiosyncratic risk.

The BKL framework instead contains endogenous feedback loops between the financial sector and the real economy from shocks to both the demand and supply of credit. 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. Macro-financial linkages arise from the supply side of credit because banks face costs from violating minimum capital adequacy regulations. They therefore respond to negative shocks by raising their lending rate in order to rebuild their balance sheets and fulfill capital requirements[9]. This credit restriction adversely affects the real economy and impedes the recovery from a negative shock.

Fourth, a further innovation in the BKL framework is that the regulatory capital requirement is not modelled as an ever-binding inequality, as in Angeloni and Faia (2013) or van den Heuvel (2008). Instead, banks are optimisers and choose their capital buffers according to an incentive-based mechanism under uncertainty[10]. Therefore, capital buffers endogenously change over the time in response to financial cycles. The build-up of capital buffers is therefore used to strengthen the resilience of the financial system to negative shocks.

Finally, 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.*, 2014). As a result, the observed lending rates do not fully reflect the availability of credit, a commonly used definition of credit rationing (Jaffee 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 to be an infeasible solution to banks' balance sheet problems.

We adapt the BKL framework in a number of ways. First, the model is modified

[9]For a similar analysis, see, among others, Markovic (2006).
[10]A similar approach is adopted in Kollmann (2013).

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. While the analysis in the BKL framework is based on a country with autonomous monetary policy, in our framework monetary policy is exogenous and cannot be used to stabilise the economy in response to shocks. Ferrero (2012) demonstrates that nominal interest rates lower than the predictions of a standard monetary policy rule can reconcile the empirical observations of negative correlation between house prices and the current account. Fornari and Stracca (2012), amongst others, show that monetary policy is an effective tool for stabilising the economy following financial shocks. This adds to the importance of assessing the usefulness of macroprudential policy as an instrument to smooth fluctuations in the economy when monetary policy is not independent. 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. A bank's willingness to extend loans (*i.e.* mortgages) 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. We further adjust the BKL framework to differentiate between the savings and transactions motivations for bank deposits. This disaggregation means that in addition to generating interest income, deposits also provide a liquidity service to the household (In't Veld *et al.*, 2011). This additional feature allows us to replicate a precautionary motive for saving. Mody *et al.* (2012) provide empirical evidence of the importance of this effect during the recent financial crisis for a panel of advanced economies, including Ireland.

Finally, in BKL loan defaults are 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, 2011). 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. A flow-chart of the model economy is depicted in Figure 7.

[INSERT FIGURE 7 ABOUT HERE]

3.1 Households

Households gain utility from consumption C_t, housing services H_t[11], deposits demanded for saving reasons D_t^S and disutility from labour N_t. They maximise their lifetime utility according to:

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

[11]We assume that the housing stock is fixed, and so $\bar{H} = 1$. Therefore, we focus on the demand rather than the supply side of the housing market.

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[12]. 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:

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

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

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

[12]The empirical evidence indicates that there is strong co-movement between house prices and consumption, with Warren (2007) and Mian and Sufi (2014) highlighting this as one of the key drivers of US consumption growth during the early-2000s housing boom. This complementarity is particularly strong between house purchases and durable consumption in Ireland (Clancy *et al.*, 2014). DSGE models often fail to capture this important relationship however, with consumption often moving inversely to housing purchases. We therefore introduce this composite price index as a means of generating the co-movement identified in the empirical literature.

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[13], 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[14] 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 risk-free 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[15]. The term $\Omega_t^D = \log \frac{D_t^S}{D_{t-1}^S}$ denotes deposit adjustment costs, implying that households do not like sudden changes in their deposits[16]. 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 adjustment 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 ad-

[13]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.

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

[15]We assume that households delegate banking activity to banks and banks give households net transfers of equity, which households take as given. This choice is derived from the banks optimisation problem (see eq. 40), with the f.o.c. for equity given in eq. 42.

[16]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 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:

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

The first order conditions for C_t, H_t, D_t^S, I_t, L_t and K_t respectively are:

$$\frac{1-\chi}{C_t - \chi C_{t-1}} = \Lambda_t P_t \quad (6)$$

$$P_t^H = U_t^H \left[\frac{1}{\Lambda_t}\left(\frac{1}{H_t} + \beta \Lambda_{t+1} P_{t+1}^H\right)\right] \quad (7)$$

$$\frac{\zeta}{\Lambda_t}\left(D_t^S\right)^{-\iota}\left(P_t^D\right)^{\iota-1} = 1 - \left(\beta R_t \frac{\Lambda_{t+1}}{\Lambda_t}\right) + \xi^D \Omega_t^D \quad (8)$$

$$P_t^I = P_t^K \left[\left(1 - \frac{1}{2}\xi^I (\Omega_t^I)^2\right) - \xi^I \Omega_t^I\right] + \beta \left[P_{t+1}^K \xi^I \Omega_{t+1}^I \left(\frac{I_{t+1}}{I_t}\right)^2\right] \quad (9)$$

$$\Lambda_t = \beta \Lambda_{t+1} R_t^L \quad (10)$$

$$P_t^K = \beta \frac{\Lambda_{t+1}}{\Lambda_t}(R_{t+1}^K + (1-\delta)P_{t+1}^K) \quad (11)$$

where U_t is an autoregressive exogenous housing demand shock process:

$$\log U_t^H = \rho^{U^H} \log U_{t-1}^H + \epsilon_t^{U^H}. \quad (12)$$

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:

$$N_{i,t} = \frac{W_{i,t}}{W_t}^{-\frac{\epsilon^W}{\epsilon^W - 1}} N_t, \tag{13}$$

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

$$\frac{\mu N_t^{\eta}}{W_t \Lambda_t} = 1 + (\mu^W - 1)\xi^W \Omega_t^W - (\mu^W - 1)\xi^N \beta \Omega_{t+1}^W \tag{14}$$

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[17], 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/quantities gradually in response to a shock to demand or marginal cost (Devereux *et al.*, 2005).

[17] 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:

$$Y_t^N = A_t^N \left(K_{t-1}^N\right)^{1-\gamma^N} \left(N_t^N\right)^{\gamma^N} \tag{15}$$

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:

$$\log A_t^N = \rho^A \log A_{t-1}^N + \epsilon_t^A \tag{16}$$

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:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^N Y_t^N \left[1 - \frac{1}{2}\xi^N \left(\Omega_t^N\right)^2\right] - W_t N_t^N - R_t^K K_{t-1}^N\right] \tag{17}$$

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:

$$\gamma^N MC_t^N Y_t^N = W_t N_t^N \tag{18}$$

$$(1-\gamma^N) MC_t^N Y_t^N = R_t^K K_{t-1}^N \tag{19}$$

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:

$$Y_{i,t}^N = \left(\frac{P_{i,t}^N}{P_t^N}\right)^{-\frac{\theta^N}{\theta^N - 1}} Y_t \tag{20}$$

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:

$$(\mu_t^N - 1)\xi^N \Omega_t^N = (\mu_t^N - 1)\xi^N \beta \mathbb{E}_t \Omega_{t+1}^N + \left(\frac{\mu_t^N MC_t^N}{P_t^N} - 1\right) \tag{21}$$

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:

$$\mu_t^N = (1 - \rho^N)\mu_{t-1}^N + \rho^N \mu_{t-1}^N + \epsilon_t^N \tag{22}$$

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 then 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:

$$\left(\frac{\mu_t^M MC_t^M}{P_t^M}\right) = 1 + (\mu_t^M - 1)\xi^M \Omega_t^M - (\mu_t^M - 1)\xi^M \beta \mathbb{E}_t \Omega_{t+1}^M \tag{23}$$

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:

$$\mu_t^M = (1-\rho^M)\mu_{t-1}^M + \rho^M \mu_{t-1}^M + \epsilon_t^M \tag{24}$$

where ρ^M is the persistence of the process and ϵ_t^M is a shock to the import price markup. 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 $\overline{K}_{t-1}^X$ [18] using a Cobb-Douglas technology:

$$Z_t = A_t^X \left(\overline{K}_{t-1}^X\right)^{1-\gamma^X} \left(N_t^X\right)^{\gamma^X} \tag{25}$$

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:

$$\log A_t^X = \rho^X \log A_{t-1}^X + \epsilon_t^X \tag{26}$$

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:

$$X_t = \min\left\{\frac{Z_t}{(1-\alpha)}, \frac{X_t^M}{\alpha}\right\}. \tag{27}$$

[18] 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[19]. 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:

$$Z_t = (1-\alpha)X_t \tag{28}$$

$$X_t^M = \alpha X_t. \tag{29}$$

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:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^X X_t - W_t N_t^X - R_t^K \overline{K}_{t-1}^X \right]. \tag{30}$$

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:

$$\gamma^X MC_t^Z Z_t = W_t N_t^X. \tag{31}$$

The exporters marginal cost of production is:

$$MC_t^X = (1-\alpha)MC_t^Z + \alpha P_t^M \tag{32}$$

[19]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:

$$\frac{P_t^X}{MC_t^X} = 1 + \xi^X \Omega_t^X - \beta \mathbb{E}_t \Omega_{t+1}^X \tag{33}$$

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 macroprudential 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 macroprudential measures. A third solution is to impose direct capital adequacy regulations that penalise banks for maintaining an insufficient capital 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[20]. To access credit, each *i-th* household provides his housing wealth[21] 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 wage income) accepted as collateral is above a cut-off value:

$$\psi\left[\phi H_{i,t-1} P_{i,t}^{H}+(1-\phi) W_t N_{i,t}\right]>R_{i,t}^{L} L_{i,t} \tag{34}$$

where $L_{i,t}$ is the individual exposure on which the *i-th* household pays the non-contingent[22] lending rate $R^L_{i,t}$, 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*

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

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

[22]Non-contingent means that the lending rate is fixed at time t 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:

$$\overline{F_{i,t}} = \frac{R^L_{i,t} L_{i,t}}{\psi}. \tag{35}$$

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

$$F_{i,t+1} = \mathbb{E}_t \left(F_{t+1}\right) \exp\left(u^a_{i,t+1}\right) \exp\left(u^b_{t+1}\right) \tag{36}$$

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 (36) 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). 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:

$$J^i_{t+1} = \begin{cases} 0 & \text{loan performs, if } (F_{i,t+1}) > \overline{F_{i,t}}, \\ 1 & \text{loan defaults, if } (F_{i,t+1}) < \overline{F_{i,t}}. \end{cases} \tag{37}$$

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:

$$\mathbb{E}_t(J_{t+1}) = Pr(J_{t+1} = 1) = J^{ex-ante}_t = \varkappa + (1-\varkappa)\Phi\left[\frac{\log \overline{F_t} - \log \mathbb{E}_t(F_{t+1})}{\sigma_a + \sigma_b}\right] \tag{38}$$

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[23]. 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:

$$\mathbb{E}_t(J_{t+1}|F_{t+1}) = Pr(J_{t+1} = 1|F_{t+1}) = J_t^{ex-post} = \varkappa + (1-\varkappa)\Phi\left[\frac{\log \overline{F_{t-1}} - \log F_{t+1}}{\sigma_b}\right]. \quad (39)$$

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[24] and equity liabilities E_t (*i.e.* bank capital). Bank loans are risky because, depending on developments in the collateral (housing) market and

[23]Equation (38) 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:

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

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

[24]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. See the technical appendix for a simulation assessing this transmission channel.

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 it's 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:

$$\max \mathbb{E}_t \hat{\beta} \frac{\Lambda_{t+1}}{\Lambda_t} \left[R_t^L (1-\nu J_t^{ex-ante}) L_t - R_t D_t - \upsilon \left(\frac{L_t}{E_t} - \overline{g}_{min} \right) L_t \right] + \left[E_t - \frac{1}{2} \xi^E \left(\Omega_t^E \right)^2 E_t \right] \quad (40)$$

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.

However, banks may want to keep an additional buffer over and above this minimum regulatory capital $\overline{g}_{min}$. 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. The first order condition for L_t states that:

$$\tilde{R}_t = R_t^L(1 - \nu J_t^{ex-ante}) = R_t + \upsilon \left(\frac{L_t}{E_t} - \overline{g}_t \right) \tag{41}$$

where the term on the right-hand side is the marginal cost of lending $\tilde{R}_t = R_t + \upsilon \left(\frac{L_t}{E_t} - \overline{g}_t \right)$. 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:

$$\mathbb{E}_t \hat{\beta} \frac{\Lambda_{t+1}}{\Lambda_t} R_t^E = 1 + \xi^E \Omega_t^E \tag{42}$$

where:

$$R_t^E = R_{t-1} + (R_{t-1}^L - \tilde{R}_{t-1}) \frac{L_{t-1}}{E_{t-1}}. \tag{43}$$

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. We focus on the first option. Whenever banks deviate from the regulatory level $\overline{g}_t$, they pay a cost $\upsilon \left(\frac{L_t}{E_t} - \overline{g}_t \right)$. 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, 2013; 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:

$$\left(R_t^L\right)^{ex-post} - R_t = \tau\left(R_t^L - R_t\right) + (1-\tau)(\overline{R}^L - \overline{R}) \tag{44}$$

where τ determines to what extent credit tightening is implemented via increased lending rates and $1-\tau$ is the degree of credit rationing[25]. 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[26] 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 linked to the probability of default and hence to individual households' risk. The non-price bank lending channel is useful in delaying banks' ability to recapitalise. If the feature is disabled, banks can increase their lending spreads rapidly and use their much higher profits to rebuild their retained earnings and capital[27]. The presence of a high proportion of inelastic tracker mortgages on banks loan portfolios, coupled with political pressure following the nationalisation of the banks, meant that this strategy was very curtailed. We thus feel that it is a necessary feature to accurately capture the Irish reality.

3.4 Policy authorities

As Ireland is part of the EMU, monetary policy is assumed to be exogenous, consistent with the empirical evidence cited earlier. Therefore, instead of a Taylor rule, we

[25]In the BKL modelling framework this feature is not derived from strict first principles, and is instead modelled as an *ad-hoc* mechanism designed to mimic the dynamic reaction of the economy to credit rationing. There is, however, a large literature which considers the optimality of credit rationing (see, for example, Jaffee and Modigliani, 1969; Stiglitz and Weiss, 1981).

[26]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. Given the exogenity of euro area nominal interest rate movements to the Irish economy, banks are therefore limited in their ability to use lending rates to respond to economic developments.

[27]We conducted simulations in which the importance of the non-price bank lending channel varied. As expected, when it is turned off banks recapitalised much faster following a larger increase in lending spreads. When banks cannot adjust at all, banks recapitalise much slower. The results are detailed in the technical appendix.

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. Government spending consists entirely of domestically produced non-tradable good, and is specified as a fraction of steady-state nominal output $\bar{Y}$:

$$G_t = g\bar{Y}. \tag{45}$$

A balanced budget is ensured in every period by a lump-sum tax (transfer) T_t that offsets any fiscal deficit (surplus):

$$P_t^N G_t = T_t. \tag{46}$$

The constraints placed on these traditional policy measures motivates the greater importance on macroprudential policy. We focus our attention on the countercylical capital requirement, which is expected to both increase the resiliance of banks to negative shocks, and attenuate any credit contraction experienced during a downturn (Drehmann and Gambacorta, 2012). In the past the minimum capital requirement was set as a constant $\overline{g}_{min}$, in line with the Basel II recommendations. However, new legislation empowers the Central Bank of Ireland to set the minimum capital requirement as a time-varying target g_t. This should allow the regulatory target to respond asymmetrically to market conditions, thereby mirroring the financial cycle. In this latter case, macroprudential policies are pro-active and the capital requirement becomes:

$$g_t = \min\left[\overline{g}_{max}, \max\left[\overline{g}_{min}, \phi_{g1} g_{t-1} + (1-\phi_{g1})\phi_{g2}\left(\log\frac{L_t}{Y_t} - \log\frac{L}{Y}\right)\right]\right] \tag{47}$$

where $\frac{L_t}{Y_t}$ is the loans-to-GDP ratio[28]. The deviation from the steady-state level, $\frac{L}{Y}$, represents a measure of credit expansion (see Angelini *et al.*, 2014). The two parameters driving the dynamic response of this rule are ϕ_{g1}, which mimics the strength of

[28]When the minimum capital requirement is set as a time-varying target, g_t replaces $\overline{g}_{min}$ in the banks' maximisation problem (Equation 40).

policy inertia, and ϕ_{g2}, which measures the weight of the response to a credit expansion. Therefore, setting ϕ_{g1} to a higher value will emphasise caution in changing the regulatory capital requirement. Meanwhile setting ϕ_{g2} to a higher value will allow for a more aggressive policy response to credit expansions and contractions. 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. Macroprudential 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 parameter υ controls the size of the penalty that the macroprudential authority imposes for breaching the regulatory capital minimum.

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:

$$R_t = R_t^\star \frac{\mathbb{E}_t S_{t+1}}{S_t} + \theta^B \left(\log \frac{B_t}{P_t} - \log \frac{B}{P} \right). \tag{48}$$

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:

$$\log U_t^F = \rho^{U^F} \log U_{t-1}^F + \epsilon_t^{U^F}. \tag{49}$$

Domestic and foreign deposits are paid at 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:

$$B_t = B_{t-1} - R_{t-1} - (P_t^X X_t - P_t^M M_t) + \left(R_{t-1}^L\right)^{ex-post} L_{t-1} \nu J_t^{ex-post} \tag{50}$$

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[29].

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[30]:

$$C_t = \omega^C C_t^M + \left(1 - \omega^C\right) C_t^N \tag{51}$$

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

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:

$$P_t C_t = P_t^N C_t^N + P_t^M C_t^M \tag{53}$$

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

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 equations represent the clearing

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

[30] 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.

conditions for the final non-tradable good, import, labour and capital markets respectively:

$$Y_t^N = C_t^N + I_t^N + G_t \tag{55}$$

$$M_t = C_t^M + I_t^M + X_t^M \tag{56}$$

$$N_t = N_t^N + N_t^X \tag{57}$$

$$K_t = K_t^N + \overline{K}_t^X \tag{58}$$

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:

$$Y_t = P_t^N C_t^N + P_t^M C_t^M + P_t^N I_t^N + P_t^M I_t^M + P_t^N G_t + P_t^X X_t - P_t^M M_t. \tag{59}$$

4 Calibration

The model is calibrated to match the underlying structure of the Irish economy, with the values of steady-state ratios and parameters provided in Tables 1-2. 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. As the calibration of the real economy is identical to that described in Clancy and Merola (2014), we focus instead on the calibration of the banking sector.

[INSERT TABLES 1-2 ABOUT HERE]

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 scenario, we assume that the macroprudential rule does not respond to a credit expansion (*i.e.* $\phi_{g1} = \phi_{g2} = 0$). However, we also consider the implications of a pro-active macroprudential rule (*i.e.* $\phi_{g1} = 0.8$ and $\phi_{g2} = 1.2$) in the simulation exercises[31].

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). Using detailed loan-level data gathered by the Central Bank of Ireland as part of the 2011 bank stress tests, Kennedy and McIndoe-Calder (2011) find that 54% of the oustanding mortgage balance is made up of loans subject to tracker interest rates. Therefore our calibration is consistent with the current loan portfolio of Irish banks, and accurately represents the constrained ability of these banks to raise lending rates by the desired amount.

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

[31]Given the importance of these parameters to our analysis, we conduct a sensitivity analysis to assess the effect of both a more cautious and more aggressive approach to changing the minimum capital requirement. These results are reported in the appendix.

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 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 Financial Accounts data from 2002 - 2012. The banks discount factor is set to be consistent with a equity-to-loans ratio of $e = 10\%$. This is the inverse of the $\frac{L_t}{E_t}$ term in the banks' maximisation problem.

5 Simulation exercises

We next present the results from various simulations, designed to highlight the macro-financial feedback loops and policy analysis capabilities of the model[32]. In most DSGE models with financial/banking sectors, recessions are the result of large financial 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.* Gertler and Karadi, 2011; Jermann and Quadrini, 2012). On the contrary, in the modelling framework adopted here, credit crunches are not necessarily triggered by financial-type shocks[33]. We simulate the transmission of a shock to housing demand (via preferences) and assess the channels through which this impulse

[32]All simulations are deterministic, and performed using the IRIS toolbox add-on to Matlab (http://iristoolbox.codeplex.com/).

[33]We also assess the transmission channels of financial shocks through our model economy, by simulating the impact of a reduction in the cost of banks' foreign liabilities (*i.e.* capital inflows). Mendicino and Punzi (2014) show that external shocks are an important driver in the current account deficits associated with sharp increases in house prices and household debt. The results are detailed in the technical appendix.

spreads through the banking sector and the real economy. The importance of housing preference shocks has been verified by studies for the US (Iacoviello and Neri, 2010), the euro area (Darracq-Paries and Notarpietro, 2008) and Spain (Aspachs-Bracons and Rabanal, 2010). Using a DSGE model with a housing sector, Gareis and Mayer (2013) find that housing preference shocks explain the vast majority of the recent Irish house price boom. De Bandt *et al.* (2010) provide empirical evidence that fundamentals do not explain Irish house price movements, and therefore demand rather than supply factors are more relevant. McCarthy and McQuinn (2013) provide empirical evidence (from a combination of regulatory and survey micro-data) that house price expectations played an important role in the Irish housing boom and bust. Kennedy and McQuinn (2012) show that expectations for house price decreases matter during a downturn in Ireland. Kenny (1998) shows that house price expectations were an important channel in Ireland even before the introduction of the euro. We therefore feel that our choice of shock is appropriate.

The literature distinguishes between two phases of house price bubbles. 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 (i.e. Piazzesi and Schneider, 2009; Burnside *et al.*, 2015). Therefore, we also explicitly consider the role that expectations[34] for future house prices play in the endogenous accumulation of credit risk. Lambertini *et al.* (2013b) provide empirical evidence for the importance of expectations over house prices for explaining the path of macroeconomic variables during house price booms. 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 dis-

[34]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 of the importance of this channel. Angeletos and La'O (2013) use a unique-equilibrium, rational-expectations macroeconomic model to demonstrate that the business cycle may be driven by shifts in expectations, without shifts in underlying preferences and technologies. Jaimovich and Rebelo (2008) show that news is also important for the business cycles of open economies.

tinguish between "good booms", based on solid economic fundamentals, and "bad booms" driven by irrational expectations or unsustainable changes in the economy (see Dell'Ariccia *et al.*, 2012 for a comprehensive discussion).

We then compare the dynamic reaction of our model to this shock to those found in the theoretical and empirical literature. This benchmarking of the model results against the empirical evidence is a particularly important component in assessing a models' suitability for policy analysis. Finally, we consider the role that counter-cyclical macroprudential 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 whether it can limit the impact of negative shocks to the financial system and the real economy. We also assess whether allowing the regulatory authority greater scope to increase capital requirements is of further benefit.

5.1 Real economy shock: housing preferences

We set a positive 5% shock to housing preferences U_t^H, expected to occur after three years (*i.e.* at $t = 13$). 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 preferences remain unchanged. The results of these simulations are reported in Figure 8.

[INSERT FIGURE 8 ABOUT HERE]

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 the 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 asset (house) 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 [35].

We next 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 the default risk 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

[35] Our results are in line with those based on survey data. For instance, Leduc and Sill (2013) find that in the United States changes in expected future economic activity is an important driver of economic fluctuations. The pure perception that good times are ahead leads to a significant rise in economic activity.

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 recapitalising.

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 Comparison with literature

Our results resemble the balance sheet and lending channels discussed in Brunnermeier (2009)[36]. In the balance sheet channel, a drop in asset prices erodes the capital of financial institutions, who respond by tightening lending standards and lending margins. In the lending channel, bank concern regarding their future access to capital markets causes them to hoard funds (even if the credit worthiness of borrowers has

[36]Our representative bank framework means that we abstract from the other two channels discussed in Brunnermeier (2009): runs on financial institutions and network effects.

not changed). Macroprudential policies which require banks to hold a minimum capital adequacy ratio can exacerbate this hoarding[37]. Our model therefore reproduces the counter-cyclical equity observed in the model of Adrian and Boyarchenko (2012). Banks build up new equity only when forced during recession periods. This matches the empirical evidence provided by Kelly *et al.* (2011) of the statistical significance of the relationship between credit and output growth in Ireland. These patterns contrast with the assumptions in Brunnermeier and Sannikov (2014) and He and Krishnamurthy (2012, 2013), which feature pro-cyclical equity.

The negative association between higher economic activity and external competitiveness is a common feature of empirical studies of the Irish economy (see, for example, Bergin *et al.*, 2013; Bermingham and Conefrey, 2014). In fact, Podstawski (2014) provides empirical evidence that this price competitiveness channel is the most important driver of Irish current account deficits[38]. The model dynamics, both in terms of direction and magnitude, are in accordance with the empirical literature. Hubrich *et al.* (2013), using data up to and including part of the current crisis (their last data observation is the final quarter of 2010), find that a negative house price shock of approximately 30% persistently lowers Irish GDP by over 1%. Duffy *et al.* (2005) find that a positive house price shock of approximately 10% boosts output (measured by GNP) by 0.5% and the average real wage by 0.4%. Finally, Bergin *et al.* (2013) find that a 10% fall in house prices leads to a reduction in output, consumption and investment by 0.5%, 1.3% and 4.3% respectively, and an increase in the current account of 0.6%. The relative magnitudes of our impulse reponses correspond to the empirical literature, and therefore we consider our model well tailored for the Irish economy and useful for counterfactual policy experiments.

[37]In the next sub-section, we assess if counter-cyclical capital requirements can reduce banks' incentives to hoard funds when it is most damaging to the economy.

[38]Honohan and Leddin (2006) also document the loss of competitiveness during the economic boom, and show that without positive migratory flows this problem would have had a much more counteracting effect on economic growth.

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 macroprudential policies could limit pro-cyclicality by encouraging the accumulation of buffers and restraining the build-up of credit during an expansionary 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.

Unfortunately, distinguishing between "good booms" and "bad booms" is extremely challenging. Policymakers are often faced with a difficult trade-off between containing tail risk in the financial system and facilitating the financial sector's contribution to economic growth[39]. Macroprudential tools therefore need to be flexible, and permit both action and caution. 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 47. The results are detailed in Figure 9.

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 breach (and ensuing penalty). 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". With a pro-active macroprudential rule, we now discuss the effects of increasing the minimum capital requirement. This scenario is represented by the green line

[39]See Popov and Smets (2011), and the references therein, for a discussion.

in Figure 9. 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 a 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 a 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. We therefore confirm the findings of Martin and Philippon (2014) that macroprudential policy is helpful in Ireland. Interestingly, our results now replicate the phenomena of pro-cyclical equity observed in Brunnermeier and Sannikov (2014) and He and Krishnamurthy (2012, 2013). This pro-cyclicality occurs as banks build up capital buffers during booms, rather than being forced by stress tests (for example) to issue new equity during recessions. This suggests that counter-cyclical capital rules have the desired properties of encouraging banks to build buffers during booms, while being flexible enough to allow banks to support economic activity during a downturn.

Although it is possible in principle to extend minimum capital requirements beyond this amount, the need for approval at European level[40] may discourage its po-

[40]Following the creation of the Single Supervisory Mechanism, macroprudential policy is now a shared competency between the Central Bank of Ireland and the ECB.

tential 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 minimum capital requirement is reached very quickly, after which the regulatory authority has no ability to act further in this regard. We next 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 by the red line 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% instead of being capped at 10.5% as in the other (green line) scenario).

[INSERT FIGURE 9 ABOUT HERE]

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.

A notable feature of our results is the gradual reduction in capital requirements following the onset of the economic downturn. This is due to the mechanical nature of the counter-cyclical rule. Drehmann *et al.* (2011) show that although the credit gap is the best indicator of the need to accumulate additional capital, it is not as effective at signalling the need to release this buffer. This may dampen the effectiveness of the policy rule. We therefore examine the effect of immediately reducing the minimum capital requirement when a crisis emerges. We do so by implementing a negative shock to $\overline{g}_{max}$ in order to reduce it to the regulatory minimum $\overline{g}_{min}$ in tandem to the shock to expectations that causes the economic downturn. We compare this to the case where capital regulation moves in accordance with the rule. The results are presented in Figure 10.

[INSERT FIGURE 10 ABOUT HERE]

We find that this more aggressive policy stance prevents the economy from entering a recessionary period. The buffers accumulated by banks during the boom period facilitate the continued extension of loans to the real economy. As banks are well capitalised, they also do not need to charge higher lending spreads, and so these loans are affordable for consumers. This allows domestic demand to remain high and prevent a contraction in output. This comes at the cost of a higher debt level, with exports increasing to pay down the economy's net foreign liabilities. Of course, in reality policy makers may not be able to move so aggressively, and therefore this simulation represents a best case scenario. However, even if the buffer was not drawn down for a quarter or two, the decisive action to bring it down fully provides real benefits to the economy.

6 Conclusions

The Great Recession proved that a mixture of microprudential and macroeconomic policies were insufficient to ensure financial stability. In the aftermath, many international institutions such as the BIS, the IMF and the ECB have espoused the potential of macroprudential policies to help in this regard. Macroprudential policies are seen as a complement to more traditional stabilisation instruments, such as nominal interest and exchange rates. However, there are a large cohort of small open economies for which such policy tools are not available. This may be due to their membership of a monetary union, or because of pegging their exchange rate to a larger economy. In either case, the small size of the economy means that domestic developments are not reflected in the movements of key relative prices. This has the effect of placing an even greater burden on macroprudential policy to ensure financial stability.

We examine Ireland as a case study for the larger cohort of countries facing such issues. As a (small) member of the EMU, monetary policy is focused on area wide aggregates and therefore has not been able to stabilise cyclical fluctuations in the domestic economy. Following a spectacular housing boom and bust, the Central Bank of Ireland has been granted a range of macroprudential tools to reduce the probability of such a crisis unfolding again. However, since these policies are conceptually quite new, there is little empirical evidence for how they should work in practice. We therefore develop a DSGE model with a banking sector for Ireland. We use this model to highlight the transmission channels through which macro-financial linkages operate via the housing market. We find that we can replicate the key stylised facts from the Irish housing boom and bust, and demonstrate how expectations of future favourable events, such as a long-lasting increase in house prices, may accelerate credit growth and potentially result in a more vulnerable economy susceptible to downward revisions to the original expectations. Finally, we find that a pro-active macroprudential rule responding to credit growth helps in smoothing economic fluctuations and promoting financial stability. In terms of policy advice, we find that bestowing even greater flexibility to regulators to move against the credit cycle has positive benefits. We also find that more aggressive action during the release phase can greater boost the economy's ability to absorb a negative shock.

Although already suitable for policy analysis, there are still room for further extensions and improvements. When analysing the effects of macroprudential tools in mitigating credit and output volatility, we focus exclusively on capital target instruments (*i.e.* counter-cyclical macroprudential 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. Lastly, further research should address the implications of banks' losses on public finances, and the interaction between fiscal and macroprudential policy.

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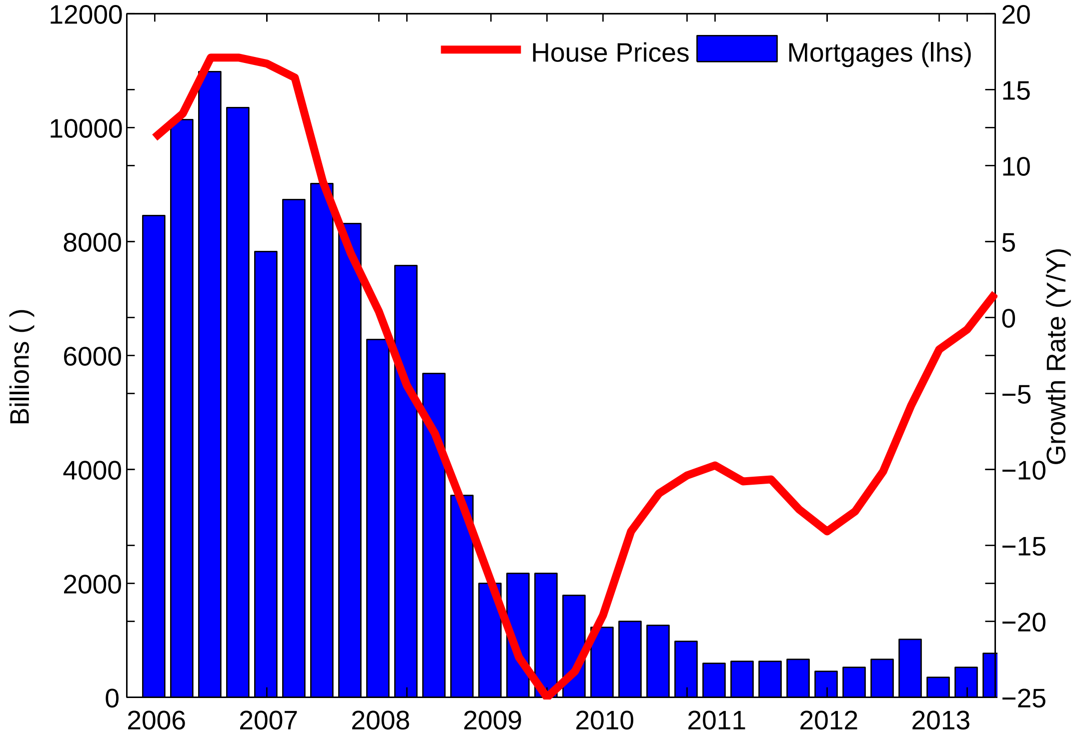
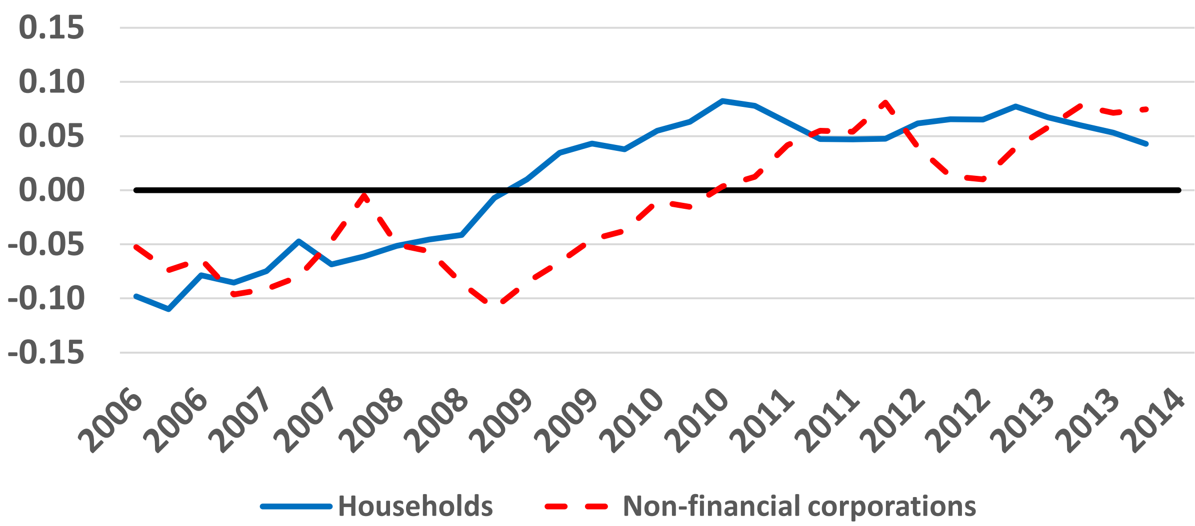
FIGURE 1. **House prices and mortgage credit**



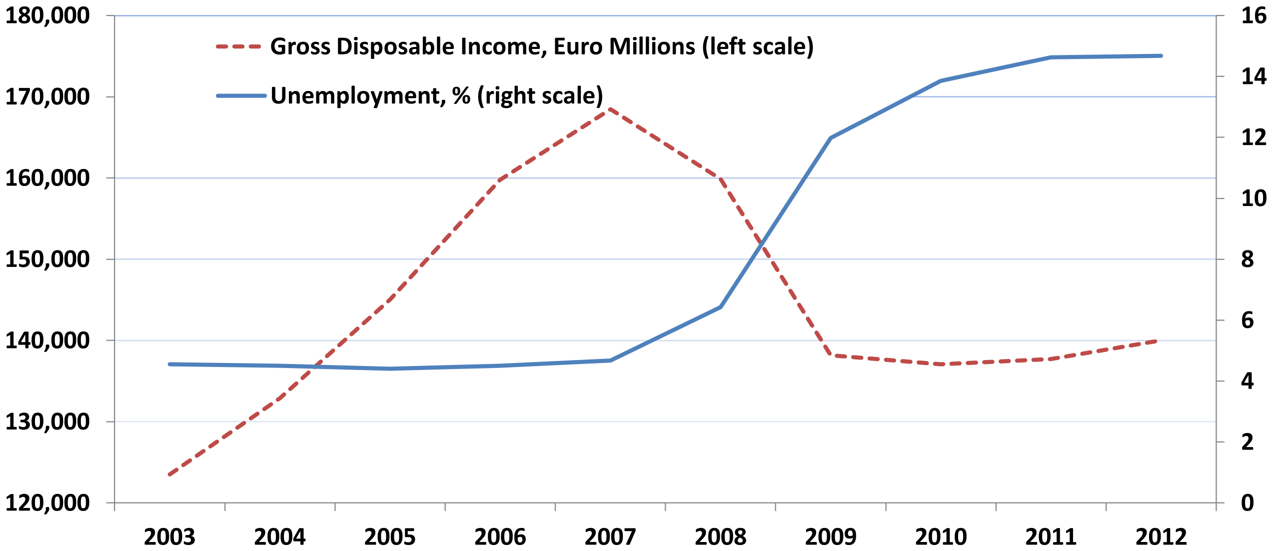
Notes: The house price series is the Central Statistics Office Property Price Index. See O'Hanlon (2011) for details on the construction of the index. Mortgage credit is represented by new mortgage drawdowns, as reported by the Irish Banking Federation.

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



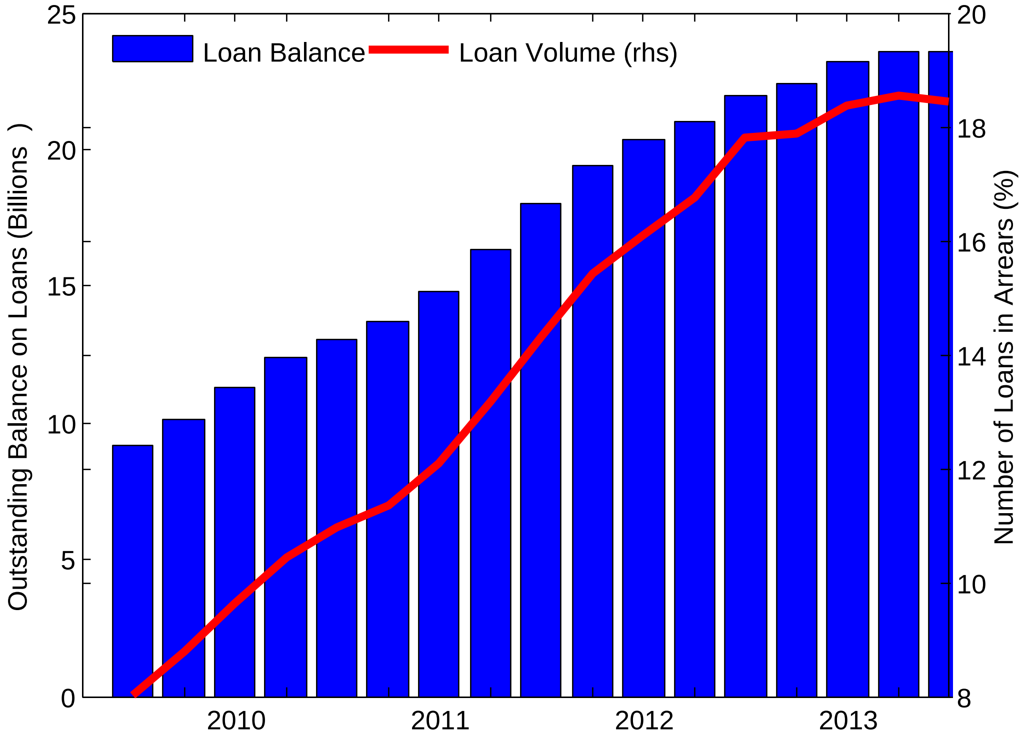
Notes: Sectoral deleveraging is represented by net lending/borrowing reported in the Central Bank of Ireland's Quarterly Financial Accounts. A positive (negative) number in any given period indicates that the sector in question is reducing (increasing) their liabilities. The figures are stated as a percentage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

FIGURE 3. **Unemployment and disposable income**



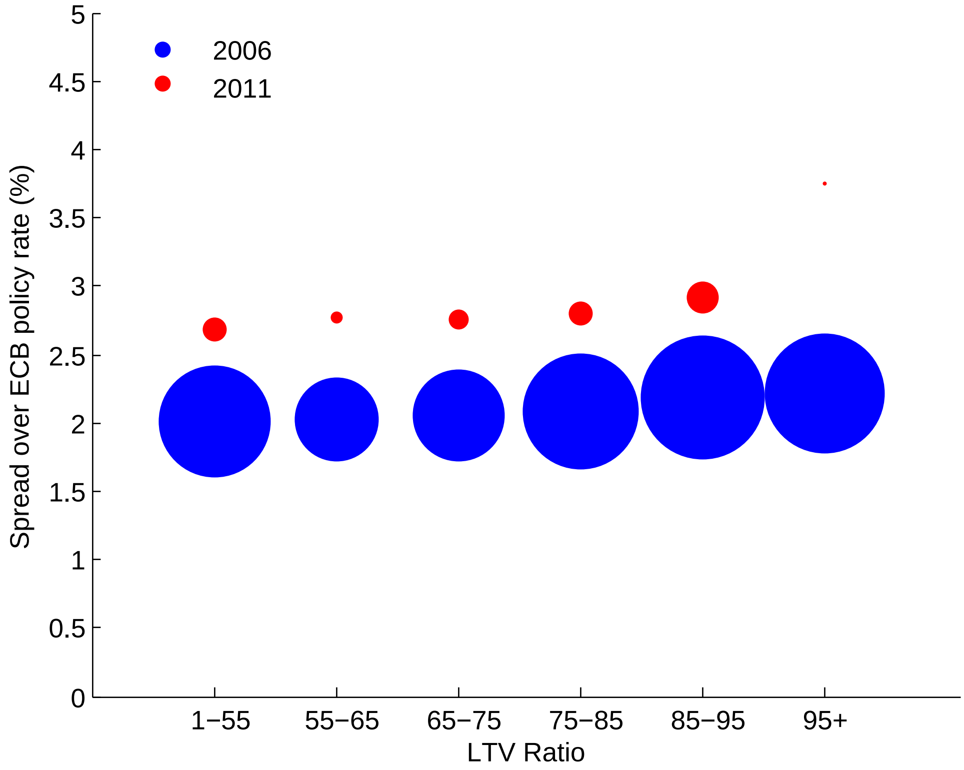
Notes: The unemployment rate is seasonally-adjusted and for both sexes. National gross disposable income is in millions of euros. Source: Central Statistical Office.

FIGURE 4. **Mortgage arrears**



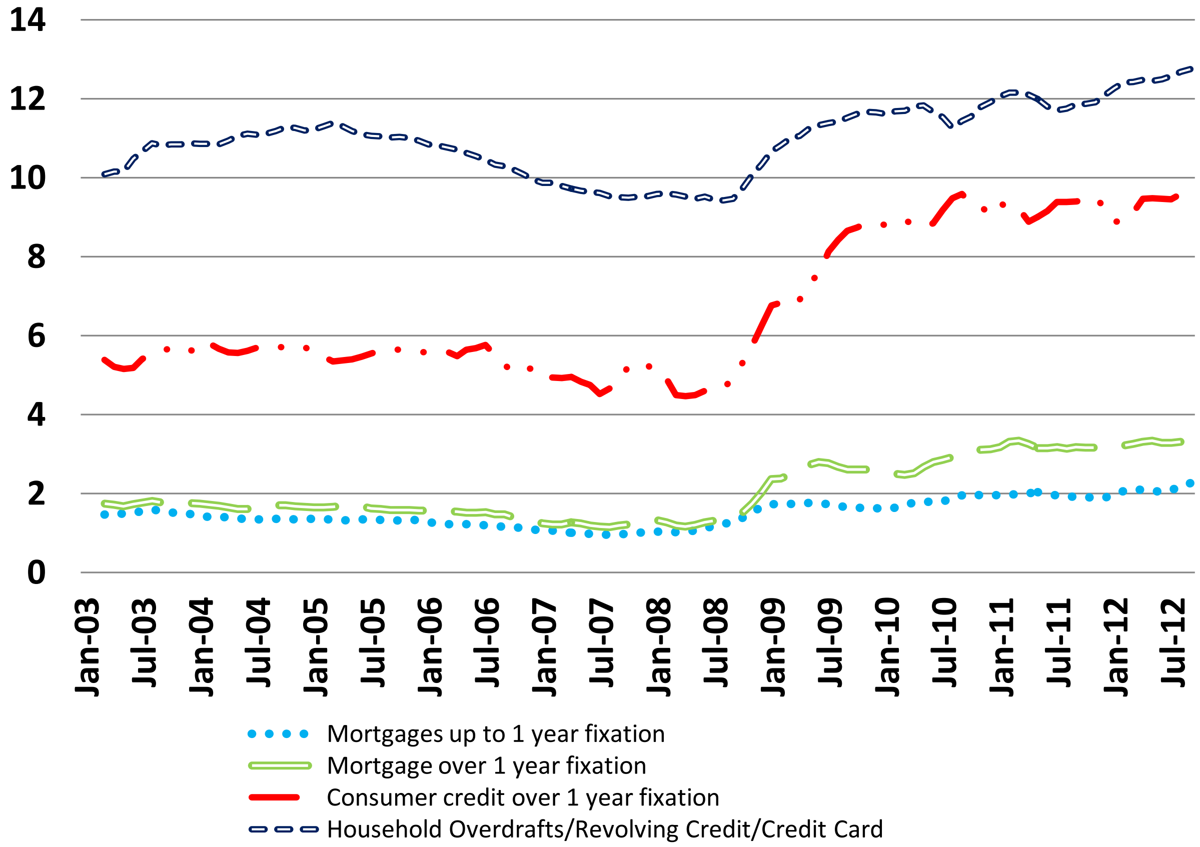
Notes: Loan volume is the percentage of mortgage accounts in arrears for 90 days or more. Loan balance is the outstanding amount owed on these loans, and not the value of arrears themselves. The data are from the Central Bank of Ireland's Residential Mortgage Arrears and Repossessions Statistics.

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 internal calculations.

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.

FIGURE 7. **Model economy flow chart**

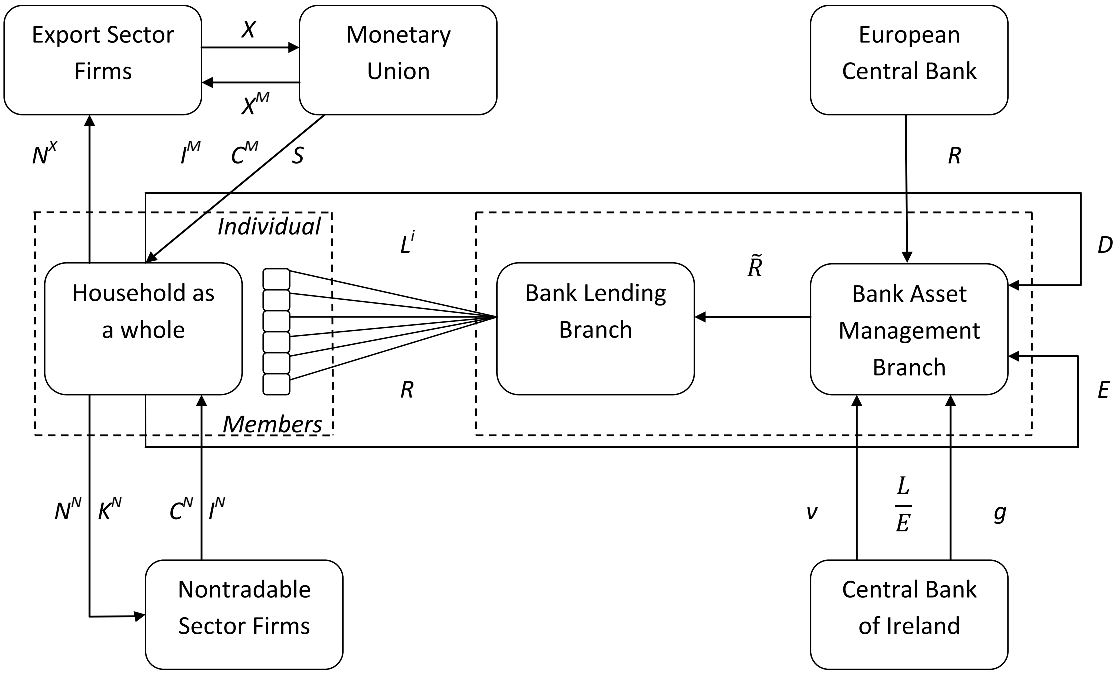
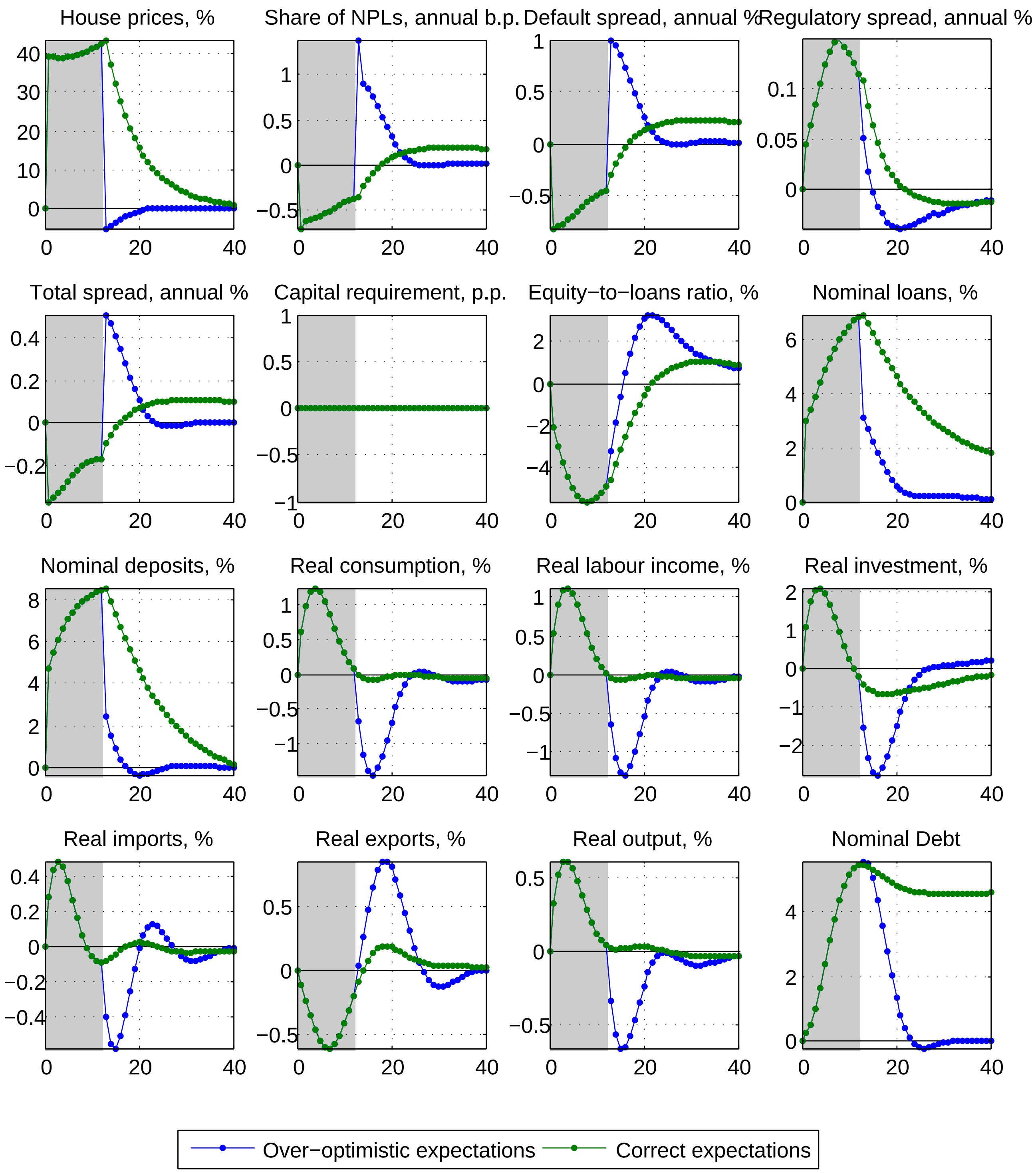
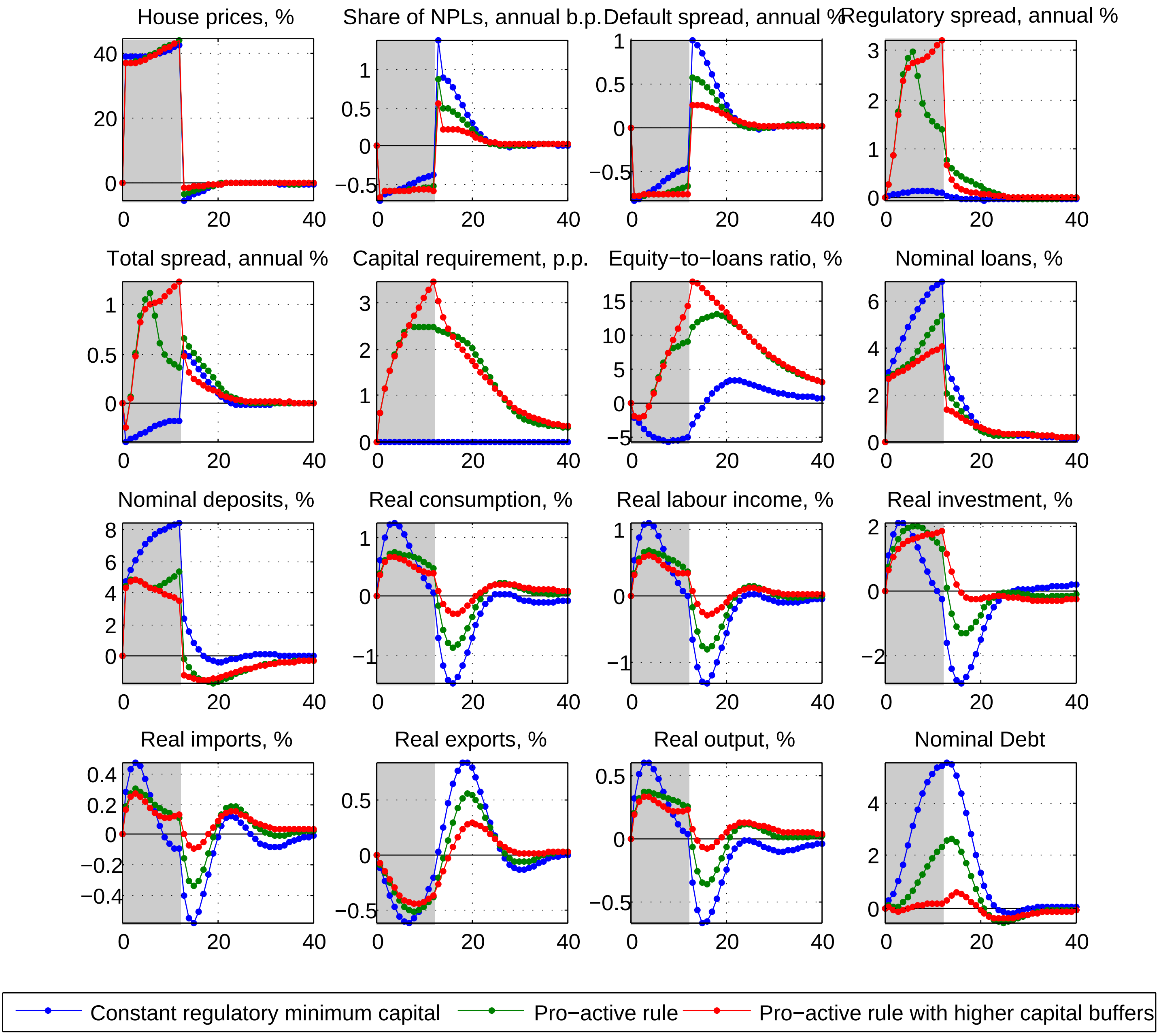


FIGURE 8. **House preference shock**



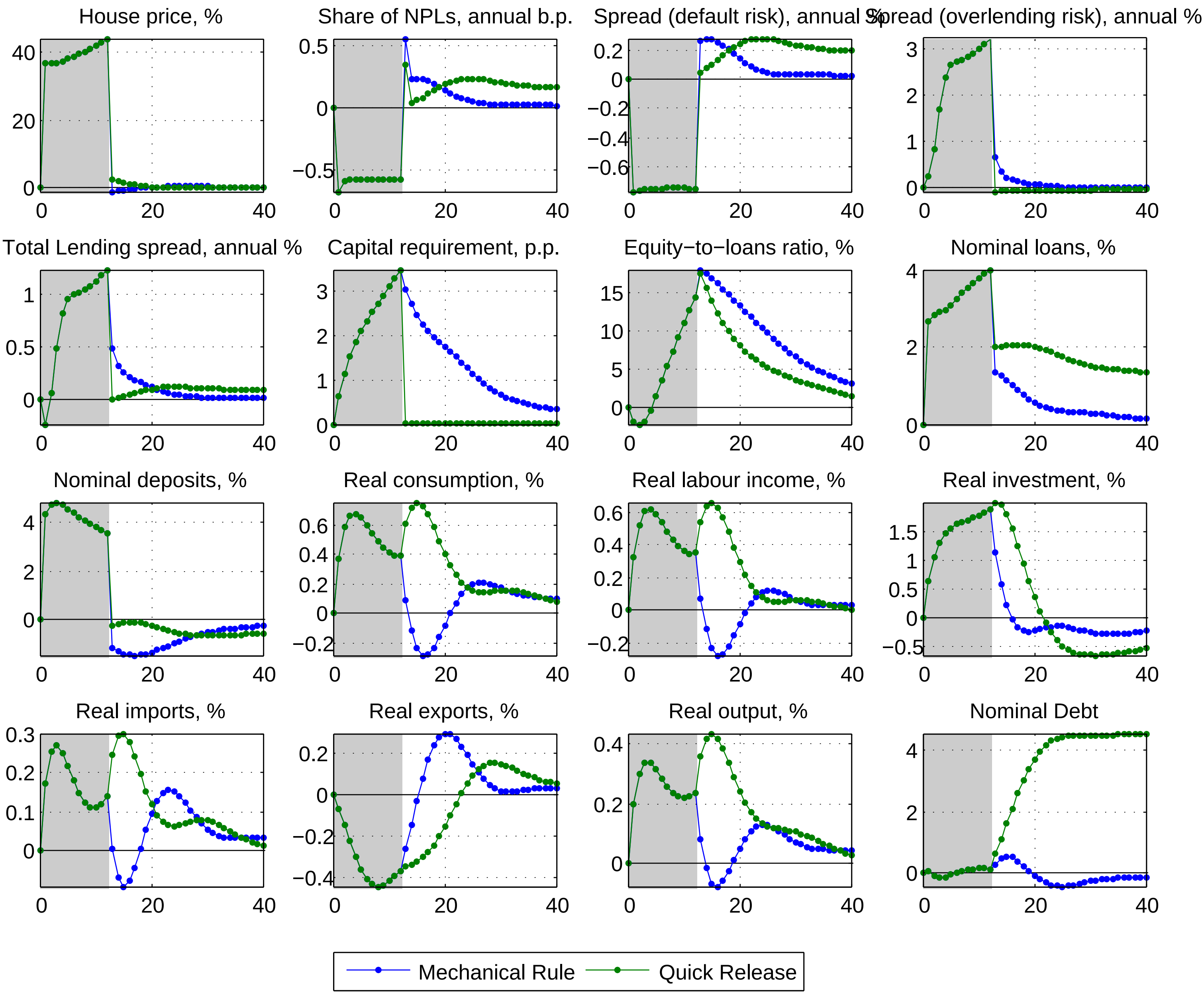
Note: Figure 8 reports the IRFs to an house demand shock expected at time $t = 13$. Under the first scenario (green line), the expectations are correct and the shock materialises. Under the second scenario (blue line), expectations turn out to be over-optimistic and the shock never materialises.

FIGURE 9. **Counter-cyclical capital regulation**



Note: Figure 9 reports the IRFs to a housing demand shock expected at time $t = 13$, 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 ($\phi_{g1} = 0.8$ and $\phi_{g2} = 1.2$) with an upper limit $\overline{g}_{max} = 10.5\%$. Under the third scenario (red line), macro-prudential policies are pro-active ($\phi_{g1} = 0.8$ and $\phi_{g2} = 1.2$) and the minimum capital requirement can be raised to $\overline{g}_{max} = 14\%$.

FIGURE 10. **Rules versus discretion**



Note: Figure 10 reports the IRFs to an house demand shock expected at time $t = 13$, which however never materialises. Under the first scenario (green line), the counter-cyclical capital buffer is reduced mechanically inline with equation 47. Under the second scenario (blue line), the policy authorities use their discretion to pursue a more aggressive reduction in the capital buffer.

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%

Counter-cyclical capital rules for small open economies. Technical Appendix

May 15, 2015

1 Financial shock: capital flows

Having examined the reaction of the model economy to a real economy shock, it is appropriate to ask whether the same channels are important when the shock originates in the financial sector. We consider a shock that decreases the cost of banks' foreign liabilities, a key channel in cross-border capital inflows (Bruno and Shin, 2013). Boissay *et al.* (2013) show that credit booms driven by a sequence of positive supply shocks are the primary cause of systemic banking crises. Similarly, Shin (2012) claims that the "global banking glut" has played an important role in easing financial conditions in the United States during the boom and then has been responsible for the propagation of the crisis during the bust. Mendicino and Punzi (2014) show that external shocks are an important driver in the current account deficits associated with sharp increases in house prices and household debt. Guajardo (2008) shows that foreign interest rate shocks can help DSGE models of small advanced economies replicate the empirical evidence of procyclicality of consumption and investment and the counter-cyclicality of net exports.

Although the contribution of financial variables to real fluctuations can be quite heterogeneous (Chirinko et al. 2008), Hubrich et al. (2013) provide empirical evidence that financial shocks play an important role in explaining the movement of key macroeconomic variables such as output, consumption and investment. Fornari and Stracca (2012) find similar results for a panel of countries which includes Ireland. The results in Kelly *et al.* (2011) and Arestis and Gonzalez (2013) further support the importance of credit availability as an explanation for house price growth in Ireland. However, there is a disagreement amongst these studies as to whether the results are context-specific, with greater effects in time of financial stress for example. A further motivation for the inclusion of these shocks is the empirical evidence provided by Ciccarelli et al. (2012), that both asset price and loan market factors played an important role in the recent Irish downturn.

However, as discussed in Lane (2014), the role that international flows played in driving the rapid growth in the external debt of the banking system during the boom remains unclear. On the one hand, bank-intermediated debt inflows certainly contributed to the amplification of the property boom. Yet, 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.

We assess this transmission channel of the model by introducing 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[1]. This shock mimics the increase in foreign funding flows that facilitated the Irish credit boom[2]. We assess two

[1]Similarly, Justiniano *et al.* (2013) model capital inflows as a reduction in the spread between the interest rate paid by (mortgage) borrowers and the funding rates of the shadow banking system, which are tied in turn to the interest rate earned by savers. A reduction in spreads is also an outcome of the more sophisticated and realistic model of intermediation proposed by Shin (2012) to formalize the effects of the "Global Banking Glut".

[2]See, for example, Coates and Everett (2013) and Lane (2015) for details.

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 (i.e. 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 11. 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.

[INSERT FIGURE 11 ABOUT HERE]

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 fulfill 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.

Our model replicates the channels in Fagan and Gaspar (2007) through which a significant fall in the costs of international financing can trigger an expenditure boom, associated current account deficits and an increase in household indebtedness. Our simulations are also in line with the mechanism suggested in Shin (2012) and Justiniano *et al.* (2013) who argue that capital inflows played a key role in triggering and propagating the financial crisis in the United States. Spreads are negatively related to the total amount of funds intermediated by the financial system. Lower interest rates stimulate the demand for non-durable consumption, investment and housing by the lenders. The resulting upward pressure on house prices then relaxes the collateral constraint of the borrowers, who can thus also consume more. Then, when the boom turned to bust and capital inflows reversed, the mechanism worked in reverse, contributing to the propagation of the U.S. financial crises around the world.

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. This result is in accordance with a study by Hristov et al. (2012), who provide empirical evidence of the adverse effect that loan supply shocks have on output and loan volume growth in Ireland. Bergin et al. (2013) find that a 1% increase in domestic interest rates reduces output by 0.5%, consumption by 0.4% and investment by 1.5%. Curiously, exports decrease as a result of this shock. This may be because the Bergin et al. (2013) analysis assumes that multinationals are affected by the rise in domestic interest rates, whereas we follow Clancy and Merola (2014) and assume that the capital decisions of the export sector are made abroad by their parent corporations. 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).

2 Sensitivity Analysis

The subject of our analysis is the performance of a counter-cyclical minimum capital requirement relative to the old benchmark where this level was fixed. We showed that by forcing banks to accumulate a capital buffer during periods of output and credit growth, their resiliance to negative shocks was enhanced. This allowed the model economy to recover much faster from a downturn. We model the counter-cyclical capital target through a Taylor-type rule that has two key parameters: ϕ_{g1} which mimics the strength of policy inertia, and ϕ_{g2}, which measures the weight of the response to a credit expansion. We examine the effect of alternative values for these parameters and the impact that they have on the models results. We also examine the impact of the non-price bank lending channel in the model. This channel is particularly important in Ireland due to the large proportion of tracker mortgages in the banks' loan portfolios. In all of the sensitivity analysis we work with the housing preference shock presented in the main text.

2.1 Counter-cyclical capital rule

In our baseline we assume that the regulators place a higher weight on credit expansion when decided on the minimum capital requirement. However, we also allow for a strong role for policy inertia. We now compare this baseline to scenarios in which the policy maker is more cautious ($\phi_{g1} = 1$, $\phi_{g2} = 0.5$) and more aggressive ($\phi_{g1} = 0.5$, $\phi_{g2} = 2$). The results of this experiment are detailed in Figure 12.

[INSERT FIGURE 12 ABOUT HERE]

Our results show that a more aggressive approach to capital regulation is most beneficial to macroeconomic and financial stability. The cautious strategy is by far the worst, with uncurtailed banks facilitating a credit boom that drives domestic demand and output up. The more aggressive strategy delays the positive spillovers in to the real economy, but when they arrive they are more sustainable. During the release phase, banks are well capitalised and do not have to substantially raise lending rates, as is the case in the cautious scenario. These results therefore match the evidence from the main text (see Section 5.3) showing that a more decisive policy response to a negative shock prevents the economy from entering a prolonged downturn.

2.2 Non-price bank lending channel

In the baseline scenario, banks can pass-on a large part of the adjustment in the lending spread they need to recapitalise in the face of a negative shock. However, in reality, this may not be the case. This is particularly true for Ireland where banks have a large proportion of tracker mortgages on their loan book. These loans have a set spread over the ECB refinancing rate and therefore cannot be adjusted by banks if the desire to do so should arise. All of the desired adjustment therefore has to come on the quantity, rather than the price, of loans. We analyse the effect that such imperfect lending rate pass-through can have on the propagation channels and persistence of booms and busts. The results are detailed in Figure 13.

[INSERT FIGURE 13 ABOUT HERE]

Despite rising house prices and wage income reducing the probability of default on loans, banks are unable to fully pass on the desired lending rate cuts. This has the effect of limiting the increase in demand for credit. It also impacts on banks profitability, as a lower amount of less risky loans are now extended relative to the baseline simulation. As these excess returns are used to develop capital buffers, protecting the bank from breaches of the minimum capital requirement, the spread covering this risk must also be increased. This further reduces demand for loans.

Accordingly, debt levels do not expand as quickly and the real economy does not experience as large a boom. During the downturn, banks' lending prudence in the boom period helps them to avoid large losses in their loan portfolio. The legacy of bad loans from the boom are not as big a problem, and thus the economy can return to normal levels following the downturn at a much faster rate. Also, the need to deleverage debt accumulated during the boom is not as strong, and thus real economic activity is not as adversely affected by the house price crash.

3 References

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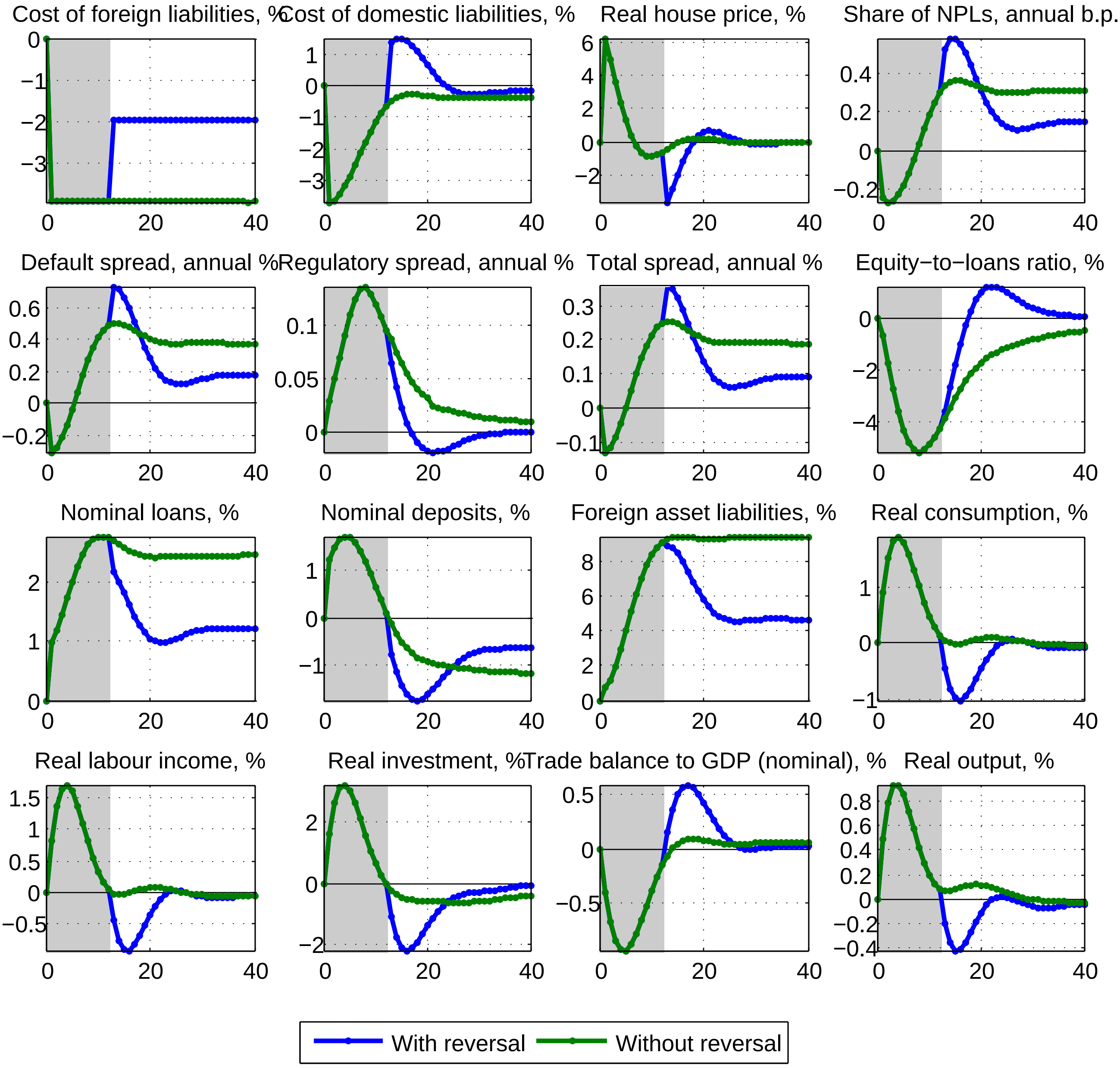
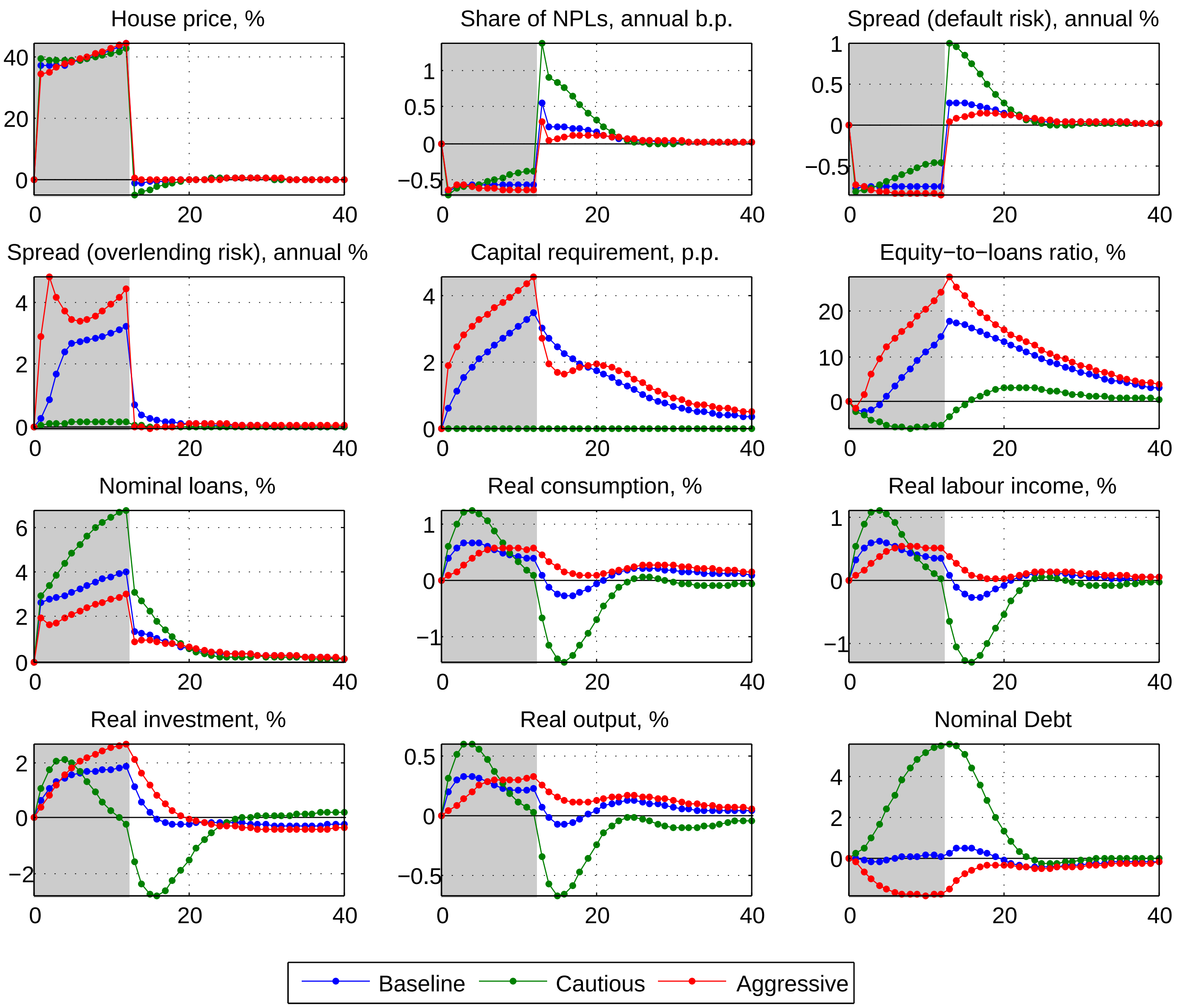
FIGURE 1. **Capital flows shock**



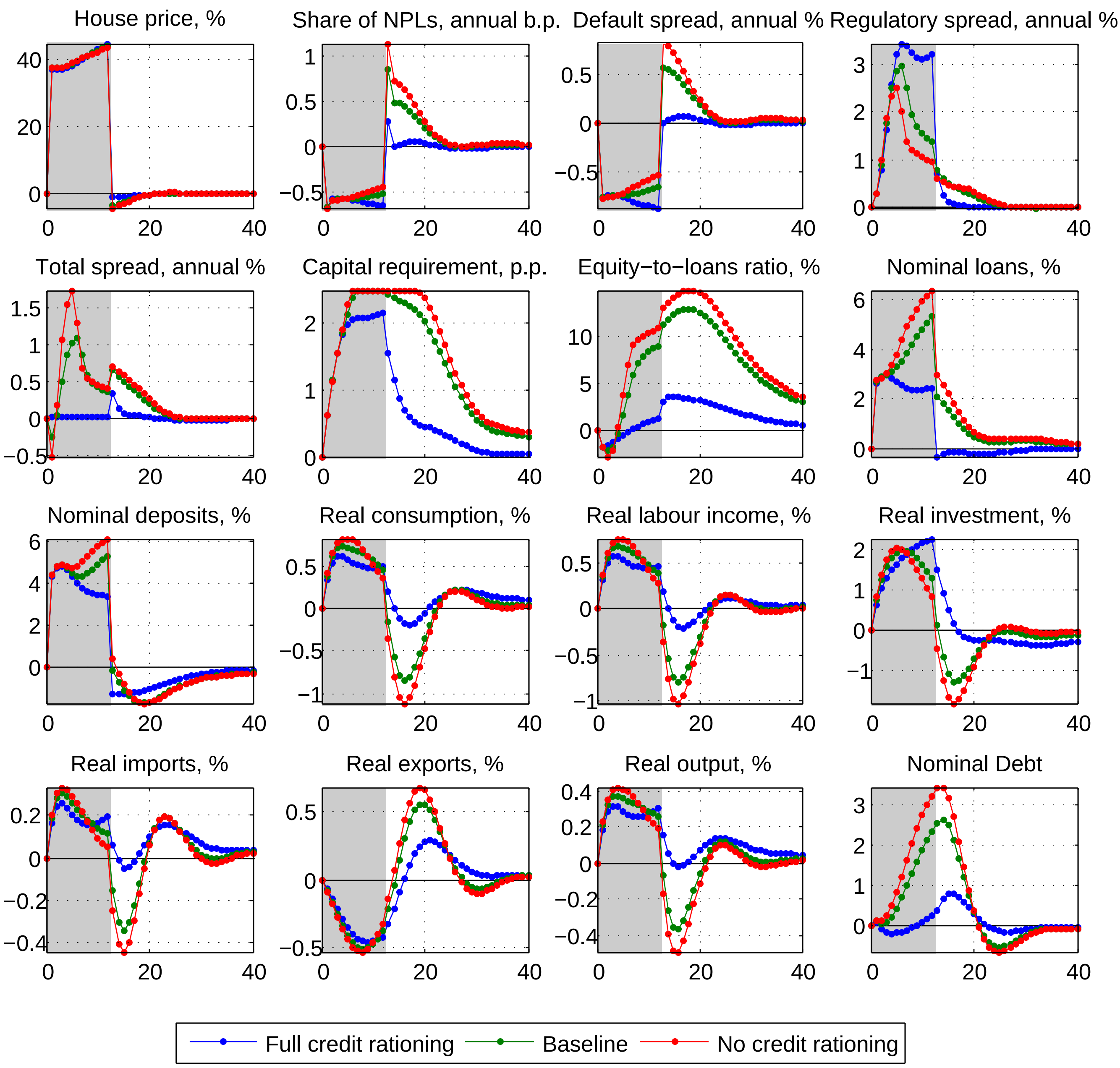
Note: Figure 1 reports the IRFs to a shock to the cost of foreign liabilities, which stimulates capital inflows. Under the first scenario (green line), there is no capital reversal. Under the second scenario (blue line), capital reversal occurs at time $t = 13$.

FIGURE 2. **Counter-cyclical capital rules parameters**



Note: Figure 2 reports the IRFs to an house demand shock expected at time $t = 13$, which however never materialises. Under the first scenario (green line), the policy authorities pursue a cautious approach to adjusting capital requirements ($\phi_{g1} = 1$ and $\phi_{g2} = 0.5$). Under the second scenario (blue line), the policy authorities have a balanced approach as in our baseline ($\phi_{g1} = 0.8$ and $\phi_{g2} = 1.2$). In the third scenario (red line) the policy authorities follow an aggressive approach ($\phi_{g1} = 0.5$ and $\phi_{g2} = 2$).

FIGURE 3. **Non-price bank lending channel**



Note: Figure 3 reports the IRFs to a housing demand shock expected at time $t = 13$, which however never materialises. All the scenarios assume that capital regulation is counter-cyclical. However, under the first scenario (red line), credit tightening is implemented only by increasing lending rates ($\tau = 1$). Under the second scenario (blue line), the adjustment is mainly through credit rationing ($\tau = 0$). The third scenario (green line) assumes that the adjustment is implemented by a mix of credit rationing and interest rate tightening ($\tau = 0.5$).