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Countercyclical Capital Regulation in a Small Open Economy DSGE Model

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Non-Technical Summary

The Great Recession induced by the crisis in the financial sector has led to major changes in financial regulatory frameworks of advanced economies. One such change has been the introduction of rules where minimum capital requirements are based on some underlying indicator of the financial cycle. These rules have become known as the countercyclical capital buffer (CCyB) rules. The European Systemic Risk Board (ESRB) has formally recommended that macroprudential authorities pay particular attention to the deviation of the credit-to-GDP ratio from a long run trend - the credit gap - when setting CCyB rates.

Because the introduction of such rules is a structural reform that can significantly alter the response of an economy to shocks, it is natural to investigate the performance of such rules in a structural model. In this paper, we look at a number of shocks that are typically considered important for small open economies in a DSGE model calibrated to Ireland. We use this framework to analyse the performance of two types of CCyB rules, one based on the credit gap and the other on the deviation of house prices from their long-run value (the house). In addition, we also investigate the performance of constant, but substantially higher minimum capital requirements.

The main finding is that the performance of a CCyB rule depends on whether the indicator variable (the credit gap or the house price gap) moves procyclically after the shock. In particular, after a negative shock to foreign demand or to domestic producer markups, the credit gap is not procyclical and the capital rule based on the credit gap requires tightening of minimum capital requirements. This amplifies the adverse effects of shocks and exacerbates the business cycle. For shocks originating from the housing market, the credit gap is procyclical and the CCyB rule based on the credit gap is stabilising. Rules based on the credit gap can therefore create a trade-off between the stabilisation of fluctuations originating in the housing market (which are attenuated) and stabilisation of fluctuations caused by foreign demand shocks (which are amplified). This trade-off disappears if the CCyB rule is based on the house price, which in our model move procyclically following all shocks considered. Imposing higher, but constant, capital requirements also makes the economy more resilient to all shocks considered, but the stabilisation effect is marginal and the transition to higher levels of capital very costly.

Our findings indicate that the regulatory authorities in small open economies should use the flexibility provided by the ESRB Recommendation that, in addition to the credit gap, other indicators of the financial cycle, such as for instance house prices, could also be considered when setting the minimum capital requirements. The use of judgement and reliance on several indicators rather than rigid adherence to rules is likely to yield better outcomes in terms of business cycle stabilisation.

Countercyclical Capital Regulation in a Small Open Economy DSGE Model*

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Abstract

We assess the macroeconomic performance of different countercyclical capital buffer rules, where regulatory capital responds to deviation from a long-run trend in the credit-to-GDP ratio (the credit gap), in a medium scale DSGE model of the Irish economy. We find that rules based on the credit gap create a trade-off between the stabilisation of fluctuations originating in the housing market (which are attenuated) and stabilisation of fluctuations caused by foreign demand shocks (which are amplified) because the credit gap is not always procyclical. The trade-off disappears if the regulator follows a rule based on house prices instead of the credit gap.

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1 Introduction

Since the financial crisis, regulation of the financial sector has undergone several changes in advanced economies. A major change has been that financial regulators have now implemented macroprudential policy frameworks that envisage systematic variations of regulatory capital ratios of banks in response to changes in cyclical variations of aggregate variables. In the European Union, the European Systemic Risk Board (ESRB) has issued recommendations stipulating that macroprudential authorities must pay particular attention to the so-called credit gap (the deviation of the credit-to-GDP-ratio from a long run trend) when setting regulatory capital buffers (ESRB, 2014).

In this paper, we use a small open economy DSGE model in order to investigate the merits of linking such a countercyclical capital buffer (CCyB) to the credit gap, as well as the house price gap, and also compare the effects of CCyB-type rules to those of imposing a substantially higher constant capital requirement. Following Beneš and Kumhof (2014) and Jakab and Kumhof (2015), banks in our model are subject idiosyncratic shocks to their net return on assets, which may reduce their capital ratio below the regulatory minimum in the next quarter, in which case they face a penalty. An increase in the regulatory capital requirement therefore induces banks to restrict their lending, thus raising the cost of credit for the non-financial sector and providing regulators with a means to affect real activity. Furthermore, the model features spillovers from the housing market to domestic demand due to risky household borrowing from banks, similar to Clancy and Merola (2014). We embed these features in the model developed for the Irish economy by Clancy and Merola (2016). We take our model to the data by matching the impulse response functions of the DSGE model with those of an estimated structural VAR model of the Irish economy.

We find that setting CCyB rates based on a credit gap rule may dampen fluctuations originating from the housing market. As the credit gap moves strongly pro-cyclically in response to these shocks, regulatory capital and thus credit are tightened during the boom, dampening the increase in GDP. Furthermore, limiting the excesses of the boom makes a bust following a boom less painful as the economy enters the downturn with smaller debt and physical capital overhang and better capitalised banks, allowing some capital to be released. By contrast, CCyB rates based on the credit gap may amplify the response of the economy to adverse export demand and producer markup shocks, as these shocks cause the credit gap to increase, implying an increase in the minimum capital requirement. Part of the reason is that the loss in export revenue associated with these shocks tends to dampen the decline in non-financial sector borrowing relative to the decline in GDP. Hence targeting the credit gap creates a trade-off between stabilising the economy's response to housing demand shocks on the one hand and export demand or supply shocks on the other. By contrast, this trade-off disappears if the regulator uses a rule based on house prices instead of the credit gap, as house prices always move procyclically for all shocks considered here. Finally, we find that imposing substantially higher constant capital requirements makes the economy marginally more resilient in response to the shocks we consider, while the cost associated with the transition to the higher level of bank capital is substantial.

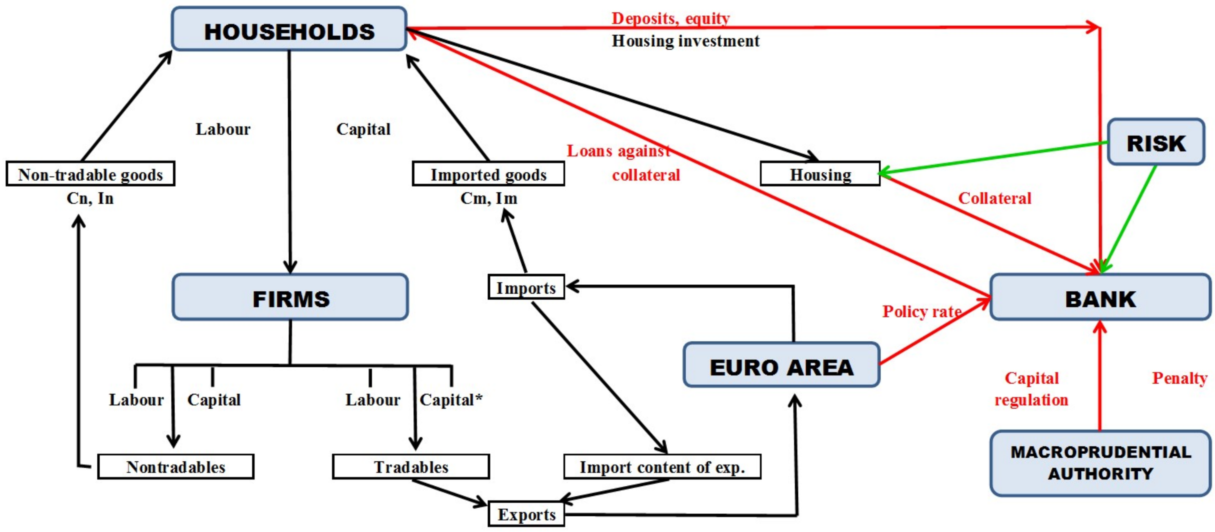
Our analysis contributes to the evolving literature by combining the following features. First, we consider regulation affecting bank capital requirements, thus complementing Carrasco-Gallego and Rubio (2015), who investigate the introduction of rules for loan-to-value ratios, or Chadha et al. (2015), who focus on the merits of a response of the central bank interest rates to stock prices. Second, we consider CCyB rules featuring the credit gap, which is considered a good predictor of financial crises and their costs (e.g. Schularick and Taylor (2012) and Jorda et al. (2012)), and therefore features in the ESRB Recommendation. Third, we also consider rules featuring deviations of house prices from their long run value, which is one of the alternative indicator variables considered in Drehmann et al. (2010). By contrast, Angelini et al. (2012) and Angeloni and Faia (2013) consider only a response of the CCyB to GDP. Moreover, the model of Angeloni and Faia (2013) is also stylised in that they assume that banks own the physical capital stock and are thus directly affected by fluctuations in its value. Christensen et al. (2011), following the empirical investigation of Drehmann et al. (2010), consider a rule for regulatory capital involving the credit gap, but not house prices, as their model does not feature a housing market. Fourth, we investigate the case of a small open economy, which as far as we are aware is considered only by Clancy and Merola (2014), who however consider a more restricted set of both shocks and policy rules. To account for the membership in the monetary union, the policymaker in our model has no control over monetary policy as the economy studied is part of a monetary union, which renders our contribution distinct from Angelini and Neri (2014), Lewis and Villa (2016) and who study the optimal interaction of monetary and macroprudential policy. Fifth, as in Clancy and Merola (2014), in our model banks serve two functions, namely channeling savings from borrowers to lenders and providing funds for transaction purposes, which makes credit more volatile compared to GDP. By contrast, the contributions cited above feature only the intermediation function of banking, like most DSGE models with financial frictions (see Jakab and Kumhof (2015) for a discussion of these two alternatives of modeling banks). Finally, unlike most of the contributions listed above, we fit the model to the data by matching the model impulse responses to those of an estimated structural VAR model.

The remainder of paper is structured as follows: Section 2 develops the model, Section 3 describes the parameterisation, Section 4 introduces the macroprudential rules whose performance we want to evaluate. Section 5 contains our main simulation results and Section 6 concludes.

2 The model

Figure 1 gives an overview of the linkages between various sectors in the model. The non-financial sector consists of firms producing consumption and investment goods for the domestic market (non-tradable goods sector) and a tradable goods sector producing export goods, as well as a household sector, and is close to Clancy and Merola (2016). The tradable goods sector uses intermediate imported goods as an input, a feature of many small open economies. Banks extend loans to, and collect deposits from, the domestic household sector, as well as the rest of the world. All foreign capital inflows are intermediated by the banking sector. Banks are subject to regulation in the form of a minimum capital requirement, which may be time varying. The economy is part of a currency union.

FIGURE 1. Structure of the model



2.1 Banks

Our formalisation of the banking sector largely follows Beneš and Kumhof (2014) and Jakab and Kumhof (2015). Banks extend loans to households, L_t, which they fund by domestic deposits, D_t, foreign deposits, B_t, and equity, $E_{b,t}$. Hence

$$L_t = D_t + B_t + E_{b,t}. \tag{1}$$

The capital adequacy ratio, el_t, is defined as the ratio of equity to loans,

$$el_t = \frac{E_{b,t}}{L_t}. \tag{2}$$

Banks raise equity from retained earnings. Bank equity therefore evolves according to

$$E_{b,t} = E_{b,t-1} R_{E,t} (1 - \theta_b), \tag{3}$$

where $R_{E,t}$ is the return on bank equity and θ_b is the share of dividends distributed to households, who own banks. This assumption ensures that banks never become fully self-financing.

The banks' net return on assets is subject to idiosyncratic shocks, which may be thought of as above average exposure to bad loans, or losses from trading activities not explicitly modeled. Their individual $t+1$ return on assets may therefore be written as $\widetilde{R_t}\omega_{b,t+1}$, where $\widetilde{R_t}$ denotes the average return on assets in the banking sector net of any costs associated with borrower bankruptcy, while $\omega_{b,t+1}$ denotes a lognormally distributed random variable with unit mean and $var(log(\omega_{b,t+1})) = \sigma_b^2$. The density and cumulative density functions are denoted as $\phi(\omega_{b,t+1})$ and $\Phi(\omega_{b,t+1})$, respectively.

The bank regulator sets a minimum capital requirement g_t. If as a consequence of a negative shock a bank's capital ratio falls below g_t, the bank has to pay a penalty equal to a fraction χ_b of its loans. This penalty represents all costs of "being caught" by regulators as badly capitalised, e.g. regulatory penalties, the damage to the brand and the dilution of shareholder value associated with being forced to recapitalise at depressed share prices. More formally, banks have to pay a penalty if

$$\omega_{b,t}\widetilde{R_t}L_{t-1} - R_{t-1}(B_{t-1} + D_{t-1}) < \omega_{b,t}g_{t-1}\widetilde{R_t}L_{t-1}, \tag{4}$$

where R_t denotes the deposit rate. We can thus define the threshold $\overline{\omega_{b,t}}$

$$\overline{\omega_{b,t}} \equiv \frac{R_{t-1}(B_{t-1} + D_{t-1})}{(1 - g_{t-1})\widetilde{R_t}L_{t-1}}. \tag{5}$$

Banks have to pay a penalty if $\omega_{b,t} < \overline{\omega_{b,t}}$. The banks optimisation problem is thus given by

$$\max_{L_t, E_{b,t}} \quad E_t\beta\tfrac{\Lambda_{t+1}}{\Lambda_t}\left[\widetilde{R_{t+1}}L_t\omega_{b,t+1} - R_t(B_t + D_t) - \chi_b L_t \Phi(\omega_{b,t+1})\right],$$

where $\beta\frac{\Lambda_{t+1}}{\Lambda_t}$ denotes the households' marginal discount factor. A bank's first-order condition with respect to loans is

$$\widetilde{R_{t+1}} - R_t = \chi_b\left(\Phi(\omega_{b,t+1}) + \phi(\omega_{b,t+1})\frac{R_t}{(1 - g_t)\widetilde{R_{t+1}}}\right). \tag{6}$$

Furthermore, the average net return on assets is determined by the lending rate $R_{L,t}$ as well as any losses associated with bankruptcy

$$\widetilde{R_t} = R_{L,t-1}\left(1-\lambda\left(J_t\right)\right), \tag{7}$$

where J_t and λ denote the share of defaulting loans, to be determined in the next subsection, and and the loss given default (LGD), respectively. Equations 6 and 7 imply that in order to increase its lending by one unit and thus becoming more leveraged, the expected net return on assets $\widetilde{R_{t+1}}$ has to compensate the bank for its cost of funds R_t and the expected increase in the risk of ending up undercapitalised in period $t+1$ that is associated with higher leverage. Hence the lending rate has to be such that after deducting all costs associated with bankruptcy, the bank expects to earn $\widetilde{R_{t+1}}$. The bank capital ratio at the end of the period will therefore typically exceed the regulatory minimum. Furthermore, the regulator can increase the costs of funds of the non-financial sector by raising g_t and thus increasing the expected penalty associated with a given leverage. Unless otherwise mentioned, we assume $g_t = gmin$, with $gmin > 0$.

The return on equity, $R_{E,t}$, is defined as:

$$R_{E,t} \equiv R_{t-1} + (\widetilde{R_{t+1}} - R_{t-1})\frac{1}{el_{t-1}} - \chi_b\frac{1}{el_{t-1}}\Phi(\omega_{b,t}). \tag{8}$$

The first term in equation 8 is the riskless rate, the second term is the spread earned on the loan portfolio (scaled by the bank leverage), and the last term is the penalty paid in case minimum capital requirements are breached.

2.2 Households

Utility and budget constraints. We assume there is a continuum of optimising households indexed by j. Household j derives utility from consumption $C_{j,t}$, real saving deposits $D_{S,j,t}/P_t$ and housing $H_{j,t}$, and disutility from labour $N_{j,t}$

$$\mathbb{E}_t\sum_{i=0}^{\infty}\beta^i\left[\frac{\left(C_{j,t+i}-\chi C_{t+i-1}\right)^{1-\sigma}}{\left(1-\chi\right)^{-\sigma}\left(1-\sigma\right)} - \phi_N\frac{N_{j,t+i}^{1+\eta}}{1-\eta} + \varepsilon_{H,t}\frac{\zeta_H H_{j,t}^{1-\nu}}{1-\nu} + \zeta_D\frac{\left(\frac{D_{S,j,t+i}}{P_{t+i}}\right)^{1-\iota}}{1-\iota}\right],$$

where β and χ denote the household discount factor and the degree of habit formation, while σ, η, ν and ι are curvature parameters and P_t denotes the price level of the consumption basket $C_{j,t}$. Households also hold deposits for transaction purposes $D_{T,j,t}$ due to a cash-in-advance constraint associated with consumption, investment and housing related transactions:

$$D_{T,j,t} = \gamma_C \left(P_t C_{j,t} + P_{I,t} I_t \right) + \gamma_H P_{H,t} H_{j,t}, \tag{9}$$

where γ_C and γ_H denote the shares of consumption and investment purchases funded by transaction deposits, respectively. $P_{I,t}$ and $P_{H,t}$ denote investment good prices and house prices. Total deposits are the sum of transaction deposits and saving deposits:

$$D_{j,t} = D_{T,j,t} + D_{S,j,t}. \tag{10}$$

In addition to deposits, households hold physical capital $K_{j,t}$, bank equity, $E_{b,j,t}$, and receive income in the form of wages W_t, rental income from the ownership of the capital stock $R_{K,t}$, and profits from the ownership of firms in the economy, $\Pi_{j,t}$. They have to pay lump sum taxes, $\Theta_{j,t}$. Their budget constraint is thus given by

$$\begin{aligned} P_t C_{j,t} + P_{I,t} I_{j,t} + P_{H,t} H_{j,t} + E_{b,j,t} - L_{j,t} + D_{j,t} \left[1 + \frac{1}{2} \xi_D \Omega_{D,t} \right] = \\ = W_t N_{j,t} \left[1 - \frac{1}{2} \xi_W \Omega_{W,t} \right] + R_{K,t} K_{j,t-1} + P_{H,t} H_{j,t-1} + R_{E,t} E_{b,j,t-1} - R_{L,t} L_{j,t-1} \\ + R_t D_{j,t-1} + \Pi_{j,t} - \Omega_{N,t} - \Omega_{M,t} - \Omega_{E,t} - \Theta_{j,t}. \end{aligned} \tag{11}$$

where I_t denotes real investment in physical capital. The introduction of the banking sector adds several elements to the household's budget constraint. L_t denotes loans from banks, on which households pay the interest rate $R_{L,t}$, while they receive the interest rate R_t on deposits D_t. Households own bank equity, $E_{b,t}$, on which they receive a return of $R_{E,t}$. As the aggregate housing stock is fixed, it holds that $P_{H,t} \int_0^1 H_{j,t} dj = P_{H,t} H$, and individual households do not take into account the effects of their choices on the aggregates. All terms denoted by Ω are quadratic adjustment costs.[1]

Total capital, K_t, is the sum of capital in the tradable sector, $K_{X,t}$, and in the non-tradable sector, $K_{N,t}$. Capital in the tradable sector is assumed to be exogenous.[2] Capital accumulation in the non-tradable sector is subject to investment adjustment costs:

$$K_{N,t} = (1 - \delta) K_{N,t-1} + I_t \left(1 - \frac{1}{2} \xi_I \Omega_{I,t} \right), \tag{12}$$

where $\Omega_{I,t} \equiv (\log(I_t / I_{t-1})^2$ and $\xi_I \geq 0$ denotes the curvature of the capital adjustment cost function.

[1] For instance, deposit-adjustment costs are defined as $\Omega_{D,t} \equiv (\log(D_{j,t}/D_{j,t-1}))^2$. Exact definitions of adjustment costs are provided in the appendix.

[2] See subsection 2.3 for details.

Household default. Housing wealth of households is subject to idiosyncratic shocks $\omega_{h,j,t}$. We assume that households default if their housing wealth declines below the value of their debt $R_{L,t-1}L_{j,t-1}$, i.e. if

$$\exp\left(\omega_{h,j,t}\right) H_{j,t-1}P_{H,t} < L_{j,t-1}R_{L,t-1}, \tag{13}$$

and $\omega_{h,j,t} \sim N\left(0, \sigma_h\right)$. The default threshold for $\omega_{j,t}$ and the default probability J_t are thus given by

$$\overline{\omega_{h,j,t}} = \log(L_{j,t-1}R_{L,t-1}/(H_{j,t-1}P_{H,t})), \tag{14}$$

$$J_t = \Phi\left(\frac{\log(L_{j,t-1}R_{L,t-1}/(H_{j,t-1}P_{H,t}))}{\sigma_h}\right), \tag{15}$$

where $\Phi\left(\bullet\right)$ is the standard normal cumulative distribution function and σ_h measures the idiosyncratic risk of households. We also assume that in case of default, households face a cost $(1-\lambda)R_{L,t-1}L_{j,t-1}$. This cost can be thought of as the social stigma or the legal costs associated with default, and implies that the household does not incur a net gain from defaulting.[3] After $\omega_{h,j,t}$ has been revealed and some households default, resources are redistributed between households such that their housing wealth is again identical before they make their consumption and saving decisions. We therefore drop the j subscript from now on.

When choosing their optimal amount of borrowing, households take into account the impact of their loan-to-value ratio, LTV, defined as ($LTV_t \equiv L_{t-1}R_{L,t-1}/(H_{t-1}P_{H,t})$), on the lending rate they are charged by banks due to the positive relationship between their LTV and the risk of default. The lending rate has to be sufficiently high for the banks' expected net return on assets to satisfy:

$$\widetilde{R_{t+1}} = R_{L,t}\left(1 - \lambda\mathbb{E}_t\left(J_{t+1}\right)\right). \tag{16}$$

First order conditions. We denote the Lagrange multiplier associated with the budget constraint (equation 11) with Λ_t, the Lagrange multiplier associated with the interest rate faced by the borrowing households (equation 16) as $\Lambda_{R_L,t}$, and the Lagrange multiplier associated with transaction deposits as $\Lambda_{T,t}$. The first order conditions with respect to C_t, L_t, $R_{L,t}$, $D_{T,t}$, $D_{S,t}$, $H_{j,t}$, I_t, and $K_{N,t}$ are

$$\Lambda_t P_t\left(1 + \gamma_C\frac{\Lambda_{T,t}}{\Lambda_t}\right) = (1-\chi)^{\sigma}\left(C_t - \chi C_{t-1}\right)^{-\sigma}, \tag{17}$$

[3] This assumption is necessary to ensure that a change in the lending rate caused by an increase in the expected probability of default (J_{t+1}) has an effect on household behavior.

$$\Lambda_t = \beta \Lambda_{t+1} R_{L,t} + \Lambda_{R_L,t} \lambda \frac{\phi(\overline{\omega_{h,t+1}})}{\sigma_h L_t}, \tag{18}$$

$$\frac{\Lambda_{R_L,t}}{\Lambda_t L_t} \left(1 - \lambda J_{t+1} - \lambda \frac{\phi(\overline{\omega_{h,t+1}})}{\sigma_h} \right) = \beta \frac{\Lambda_{t+1}}{\Lambda_t}, \tag{19}$$

$$\frac{\Lambda_{T,t}}{\Lambda_t} = 1 - \beta \frac{\Lambda_{t+1}}{\Lambda_t} R_t, \tag{20}$$

$$D_{S,t}^{-\iota} P_t^{\iota-1} \zeta_D \frac{1}{\Lambda_t} = 1 - \beta R_t \frac{\Lambda_{t+1}}{\Lambda_t} + \xi_D \Omega'_{D,t}, \tag{21}$$

$$P_{H,t} \left(1 + \gamma_H \frac{\Lambda_{T,t}}{\Lambda_t} \right) = \varepsilon_{H,t} \zeta_H \frac{H_{j,t}^{-\nu}}{\Lambda_t} + \beta \frac{\Lambda_{t+1}}{\Lambda_t} P_{H,t+1} + \frac{\Lambda_{R_L,t}}{\Lambda_t} \lambda \frac{\phi(\overline{\omega_{h,t+1}})}{\sigma_h H_t}, \tag{22}$$

$$P_{I,t} \left(1 + \gamma_C \frac{\Lambda_{T,t}}{\Lambda_t} \right) = P_{K,t} \left[1 - \frac{\xi_I}{2} \Omega_{I,t} - \xi_I \Omega'_{I,t} \right] + \beta \frac{\Lambda_{t+1}}{\Lambda_t} P_{K,t+1} \xi_I \Omega'_{I,t} \frac{I_{t+1}}{I_t}, \tag{23}$$

$$P_{K,t} = \beta \frac{\Lambda_{t+1}}{\Lambda_t} \left((1-\delta) P_{K,t+1} + R_{K,t+1} \right). \tag{24}$$

In the equations above, $\phi(\bullet)$ denotes the probability density function of household default.[4] It is through this term and through the associated terms in equation 19 that households take into account that their borrowing decisions will affect the probability of repaying the loan, and therefore the lending rate of the bank. The remaining first order conditions are fairly standard. The only exception is equation 20, which shows how the constraint on transactions drives a wedge, represented by Λ_T, into otherwise standard first order conditions for consumption, investment, and housing (standard equations are obtained by setting $\Lambda_T = 0$ for all t). Note that in equilibrium, $H_{j,t} = H$. Households also set wages under standard assumptions regarding monopolistic competition and wage adjustment costs. The details of wage setting are reported in Appendix B.

2.3 Firms

There are four types of firms (four sectors) in the model, as in Clancy and Merola (2014) and Clancy and Merola (2016). The final goods sector combines non-tradable and imported goods to produce consumption and investment goods bought by domestic households. The non-tradable sector produces its output using domestic capital and labor. Importers sell imported goods to final goods firms at a markup over the world

[4] This is the derivative of $\Phi(\bullet)$ in equation 15.

price. The export sector generates output using domestic capital and labor, as well as imported intermediate goods. The latter feature accounts for the fact that small open economies typically have substantially higher import content than domestic demand. We also assume that capital in the tradable sector is exogenous, a feature intended to reflect that a large part of exporters in the Irish economy are foreign-owned multinationals, whose investment decisions are largely independent of domestic conditions. We therefore also assume that a share of profits of the non-tradable sector are transferred abroad, which allows the model economy to match the Irish export surplus. The non-tradable, tradable and import sectors all operate under monopolistic competition, while the non-tradable sector also faces nominal rigidities in the form of price adjustment costs. We refer the reader to Appendix C for details.

2.4 International capital flows

The bank deposit rate is linked to the euro area interest rate $R_{W,t}$ by

$$R_t = e_t R_{W,t} \tag{25}$$

$$e_t = \theta_B \left(\frac{B_t}{Y_t} - \zeta \right) \tag{26}$$

where e_t denotes a country risk premium which depends positively on the deviation of the foreign-debt-to-GDP ratio from its steady state value $\zeta \equiv \overline{B}/\overline{Y}$, with a sensitivity θ_B. This assumption ensures the stationarity of foreign deposits B_t that evolve according to

$$B_t = R_{t-1} B_{t-1} - TB_t + \Gamma_t, \tag{27}$$

where TB_t and Γ_t denote the trade balance and profits transferred abroad by foreign-owned exports, respectively. The trade balance is given by

$$TB_t = P_{X,t} X_t - P_{M,t} M_t, \tag{28}$$

where $P_{X,t}$, $P_{M,t}$, X_t and M_t denote the prices of exports and imports as well as the quantity of exports and imports, respectively.

3 Calibration

We calibrate our model using data over the 1999Q1-2014Q4 period. We divide the parameters in three groups. The first group is calibrated directly, based on typical values from the literature and standard assumptions. The second group of parameters is calibrated to match the steady-state values of a number of model variables. The third group has been calibrated by matching model impulse-responses to the responses obtained from an estimated structural VAR model.

In the first group, we set the inverse of the Frisch elasticity of labour supply, η, to 2, assume log utility ($\sigma = 1$), and the curvature of the utility function with respect to housing services, ν, to 1.[5] We assume Cobb-Douglas preferences over imported and domestically produced consumption and investment goods, and we set the minimum capital requirement, $gmin$, to 8%, in line with the Basel II rules.[6] We calibrate the demand elasticities of the individual varieties in the labor, non-tradable, tradable and import CES baskets to 11, implying a steady state markup of 1.1. We assume that consumption and investment purchases are made using deposits and therefore set $\gamma_C = 1$. For transactions in housing stock we set $\gamma_H = 0.014$, based on the fact that over the 2001-2014 period, the median fraction of the housing stock transacted each year equaled 4.1% (Coates et al., 2016). The price elasticity of exports, η_X, reflects the average of available micro and macro evidence on this parameter for Ireland (see Corbo and Osbat (2013) and Bredin et al. (2003)), while we set the price elasticity of imports equal to one. The depreciation rate of capital equals $\delta = 0.04\%$. Finally, we set the elasticity of the risk premium on domestic deposits over the world interest rate, which depends on the foreign-debt-to-GDP ratio, $\theta_B = 0.0001$. Unfortunately, the only existing evidence for loss given default, λ, covers 2014 and 2015, and is based on the EBA stress test. We set λ equal to the 2014 value for mortgages.[7]

The second set of parameters, and in particular those pertaining to the various financial frictions and household preferences over asset holdings, were calibrated by first specifying targets for the steady state values of a number of model variables. This approach follows e.g. Bernanke et al. (1999), Nolan and Thoenissen (2009), Christiano et al. (2014) and Rannenberg (2016). The targets include deposit and loan interest rates faced by the non-financial sector, information on the source of bank funding, as well as the ratio of non-financial sector loans and the value of the housing stock to GDP. Without loss of generality, we first assume $P_N = P_M$.[8] Most of the other targets were calculated from multi-year averages of the relevant empirical counterparts of these variables, while some are econometric estimates.

All values in Table 1 are computed based on annual levels and model values are reported to be consistent, i.e. on annual levels.[9] Parameter values implied by calibration

[5]As the housing stock is assumed to be fixed at 1, the value of ν has no effect on our results.

[6]We also set the steady-state values of productivities in the tradable and non-tradable sectors.

[7]The estimated loss-given default (LGD) on Irish mortgages equals 42.7% and 34.8% for 2014 and 2015, respectively. The estimated LGD on all Irish exposures would be even higher, namely 73.7% and 52.1%.

[8]Setting a target for P_N allows a recursive analytical calibration of the steady state of the model, while setting $P_N = P_M$ conveniently implies that ω_C and ω_M are the shares of imports in final consumption and investment goods, respectively. See Appendix H for details.

[9]As the model is on quarterly frequency, ratios involving a division of stock with a (quarterly) flow (e.g., housing stock-to-GDP ratio) in the model have to be multiplied by 4.

targets in Table 1 are listed in Table 2 and marked by asterisks accompanying the names of parameters. Parameters not used to match targets are without asterisks. Appendix G provides more detail on how the ratios in Table 1 were obtained.

The third group of model parameters (see Table 3) affects only the dynamics, but not the steady state of the model, and include the curvature of wage, price and investment adjustment costs, the degree of price indexations in the non-tradable sector, and the persistence and standard deviations of the exogenous driving processes. We estimated these parameters by matching the impulse-responses (IRFs) of the model with the impulse-responses of an identified VAR model, using a variation of the approach of Altig et al. (2005) and Bilbiie et al. (2013). The variables included in the VAR are real GDP, the GDP deflator, real house prices (deflated with the GDP deflator), real exports and the EONIA, and the sample period is 1999Q1-2014Q4. We identify four shocks by placing the minimum set of sign restrictions necessary to achieve theoretically meaningful responses.[10] The sign restrictions are listed in Table 4, where each row refers to a shock and each column to a variable.[11]

We collect all model parameters to be estimated in the vector ζ_{par}, whose values we choose in order to minimise the criterion function

$$(\hat{\Psi} - \Psi(\zeta_{par}))' V^{-1} (\hat{\Psi} - \Psi(\zeta_{par})),$$

where ζ_{par}, denotes the parameters of the model, $\hat{\Psi}$ the vector of IRFs from the VAR, $\Psi(\zeta_{par})$ the IRFs from the model., and V denotes the diagonal weighting matrix based on the sample variances of each IRF. This matrix attaches a higher weight to the more precisely estimated IRFs during the calculation of the criterion.[12]

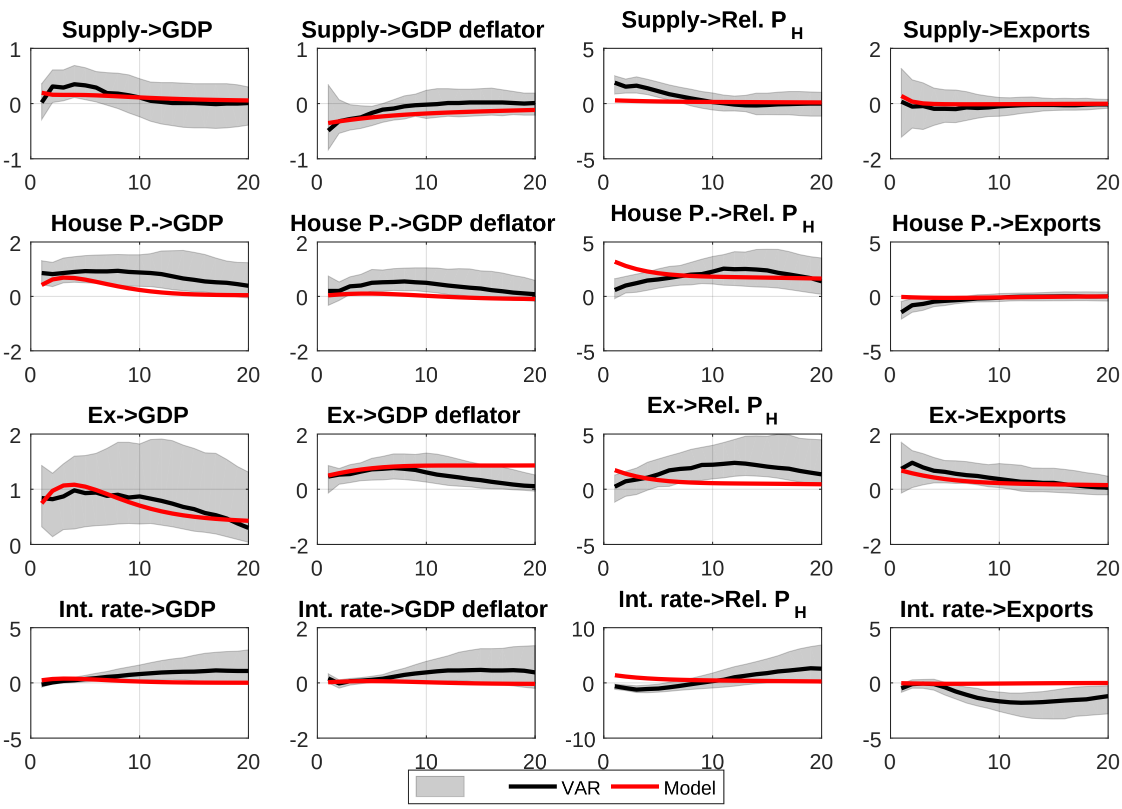
Figure 2 displays the response of the model and the VAR to the four identified shocks. The model matches the response of GDP, exports and the GDP deflator very well. The model also matches the order of magnitude of the house price response to various shocks, though not its hump shape. The reason for this is that the house price in the model is an asset price and thus purely forward looking, i.e. it depends only on the future discounted marginal utility of housing services. The failure of rational expectation models to generate hump shaped responses of house prices is well documented (e.g. Iacoviello and Neri (2010)).

[10] The only redundant restriction for identification purposes is the positive restriction on the response of the house price to the supply shock, which was placed for theoretical reasons.

[11] We leave one shock unidentified. Importantly, the responses of the variables to the unidentified shock do not correspond to the sign restrictions of any of the identified shocks. Moreover, they fluctuate around zero and are not statistically significant.

[12] Since we identify four shocks, we have 4x4xTx1 vector of IRFs stacked on top of each other, where T denoted the number of time periods from the IRF we attempt to match. Also, the first T nonzero elements of V are equal to the average variance of the first IRF in $\hat{\Psi}$, the second T elements are equal the average variance of the second IRF in $\hat{\Psi}$, etc. We set T=12.

Figure 2. VAR and model IRFs



Notes: Impulse response functions of the model and the impulse responses in the VAR to the identified shocks. Shaded areas denote 65% confidence intervals.

4 Capital Regulation

In the simulations below, we consider five alternative minimum capital rules:

$$g_t = gmin \tag{29}$$

$$g_t = gmin + 8\ p.p., \tag{30}$$

$$g_t = 8\% + \begin{cases} 0 & if\ gap_t \leq 2\% \\ 0.3125 \cdot gap_t - 0.625 & if\ 2\% < gap_t \leq 10\% \\ 2.5\% & if\ gap_t > 10\%, \end{cases} \tag{31}$$

$$g_t = 8\% + 0.43 \cdot gap_t, \tag{32}$$

$$g_t = 8\% + 0.85 \cdot price\ gap_t, \tag{33}$$

where

$$gap_t = \left(\frac{L_t}{Y_t + Y_{t-1} + Y_{t-2} + Y_{t-3}} - \frac{\overline{L}}{4 \cdot \overline{Y}} \right), \tag{34}$$

and

$$price\ gap_t = \frac{P_{H,t} - \overline{P_H}}{\overline{P_H}}. \tag{35}$$

Equations (29) and (30) represent the case where the minimum capital requirement is kept constant over the business cycle, namely at the level mandated by the Basel regulations (equation 29) and the level that exceeds the Basel regulation by 8 percentage points (equation 30). The value of 8 percentage points was chosen in order to illustrate the degree of stabilisation achieved by a rather substantial increase in the minimum capital requirement. Equations (31) to (33) represent cases where the macroprudential authority alters g_t depending on either the credit gap (equation 34) or the house price gap (equation 35). Equation (31) is the rule based on the ESRB Recommendation (we refer to this as the ESRB rule), and says that g_t should respond to the credit gap in an asymmetric and piece-wise linear fashion.[13] In particular, g_t responds only to positive values of the credit gap exceeding 2 p.p., and the maximum increase of g_t is capped at 2.5 p.p.. Due to the rather complex nature of this rule, we also consider the case of a simple linear response to the credit gap (equation 32). Finally, as responding to the credit gap turns out to be destabilising in response to several shocks, we also consider a rule based on house prices, an indicator variable suggested by Drehmann et al. (2010).

Note that with the higher minimum capital requirement (equation 30), the structure of banks' balance sheets will be different. Accordingly, there will be a different steady state, with lower bank leverage, and different values for the other variables as well. Lower bank leverage implies that, on the one hand, a given absolute change in the portfolio return has less of an effect on the level of equity (percentage-wise), thus tending to make the economy more stable. On the other hand, the transition to the higher capital requirement will be associated with costs, which we examine in subsection 5.6.

[13] The ESRB defines the credit gap as the deviation of $\frac{L_t}{Y_t+Y_{t-1}+Y_{t-2}+Y_{t-3}}$ from a trend computed using a Hodrick-Prescott (HP) filter with a smoothing constant of 400,000. The resulting trend will be extremely smooth, implying that the steady state value represents a reasonable counterpart in the model.

5 Main results

This section discusses the response of the economy to two variants of a housing demand shock, an exogenous decline in export demand, a supply shock and an exogenous decrease in the cost of foreign borrowing, all for the five alternative rules described by equations (29) to (33). The magnitude of the shocks we assume in the simulations below exceeds the magnitude of the estimated standard deviations listed in Section 3.[14] Finally, because one of the regulatory policies we consider is a constant but higher regulatory capital ratio, we simulate transition from the current minimum capital requirement of 8% to the minimum capital requirement of 16% in subsection 5.6.

5.1 Positive housing demand shock

A positive housing demand shock is modeled as a temporary increase in household preferences for housing, which increases the house price on impact (Figure 3).[15] We first discuss the case of a constant bank capital requirement of 8% (dashed line). With the supply of housing fixed, the increase in housing demand causes an increase in house prices, which is transmitted to domestic demand through lowering the households' loan-to-value ratios and thus the default rate. Lower expected losses from non-performing loans are passed on to households in the form of a lower loan rate, which stimulates consumption and investment. Lower interest rates and higher consumption induce house prices to increase even more, which can be interpreted as a financial accelerator mechanism. Furthermore, wages and prices increase. As a result, exports increase and imports decrease, implying that foreign borrowing in the form of foreign deposits rises, and is intermediated to the non-financial sector in the form of loans.

Total loans to households increase in response to the housing demand shocks for three reasons. First, the sudden increase in house prices and domestic demand increases households' demand for transaction deposits. Second, the decline in the loan rate increases the demand of households for saving deposits. Third, the increase in households' expenditure relative to their revenue requires an increase in borrowing. Bank equity increases due to the decline in the share of non-performing loans. The expansion in bank equity helps accommodate the increase in loans, implying that the bank capital ratio declines only marginally.

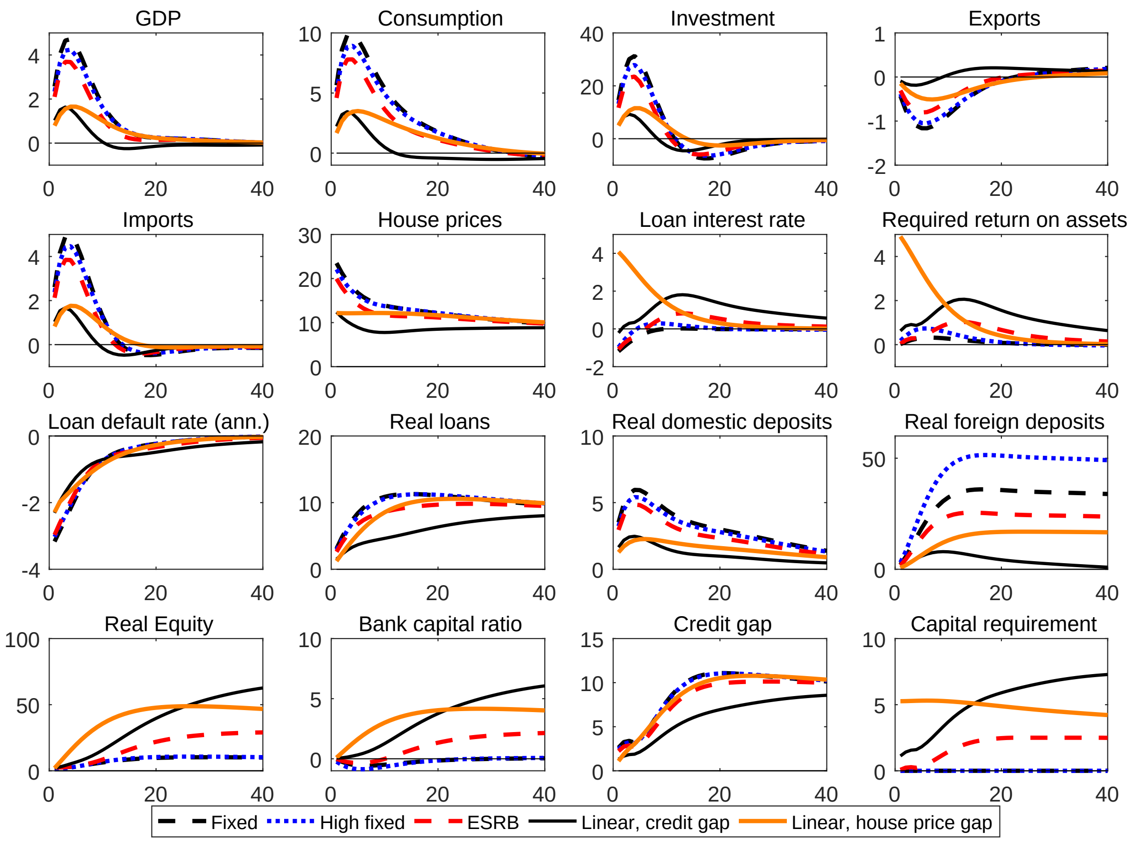
We now turn to the four alternative rules. When the rule recommended by the ESRB and the linear credit gap rule are in place instead of a fixed capital requirement, g_t increases on impact under both rules (bottom-right panel in Figure 3) since the increased

[14]We do so because for each of the exogenous driving process in our model, a shock of one standard deviation is too weak to cause an increase in the credit gap exceeding the two percent threshold, implying that g_t would always remain constant under the rule recommended by the ESRB.

[15]Formally, this is a persistent shock to ε_H, which evolves as $ln(\varepsilon_{H,t}) = \rho_H ln(\varepsilon_{H,t-1}) + e_{H,t}$, where $e_{H,t}$ is the shock.

lending immediately opens the credit gap exceeding the 2 p.p. threshold in the ESRB Recommendation (equation 31). With a higher g_t, banks' capital buffer is smaller and the risk of ending up undercapitalised in period $t+1$ and having to pay a fine has increased. This effect is reflected in a higher required expected return on assets, i.e. $\widetilde{R_{t+1}}$ increases. Banks pass this increase in their expected cost of lending on to households, implying a higher trajectory for the loan interest rate. As a result, the responses of consumption, investment and house prices are all reduced compared to the case of a constant g_t. Under the ESRB rule, the peak of GDP is lowered by about 20%. Under our assumed linear credit gap rule, g_t increases substantially more than under the ESRB rule, as we calibrated it to achieve a two thirds reduction in the peak GDP response to the housing demand shock.

FIGURE 3. Housing demand shock



Notes: Impulse responses to a positive housing demand shock. All variables are in percentage deviations from the steady state, except interest rates, default rate, and marginal regulatory penalty, which are in annualised percentage-point deviations, and bank capital ratio, credit gap, and capital requirement, which are in percentage-point deviations.

By assumption, the peak of GDP under the linear house price rule is the same as under the linear credit gap rule. As the increase in the credit gap is more gradual than the increase in house prices, so is the increase in g_t. However, for both rules, g_t ultimately increases by more than twice as much than under the ESRB rule. Finally, fixing the minimum capital requirement at a higher level (dotted line in Figure 3) very slightly attenuates the response of the economy to the housing demand shock. Lower bank leverage reduces the impact of a lower default rate and thus a higher net return on assets on bank equity.

5.2 Boom and bust in the housing market

We model the boom-and-bust scenario on the housing market (a housing bubble) by assuming that the agents expect an increase in the demand for housing to occur in three years (i.e., in quarter 13). When this date arrives and the shock is expected to materialise, the demand increase does not happen.[16]

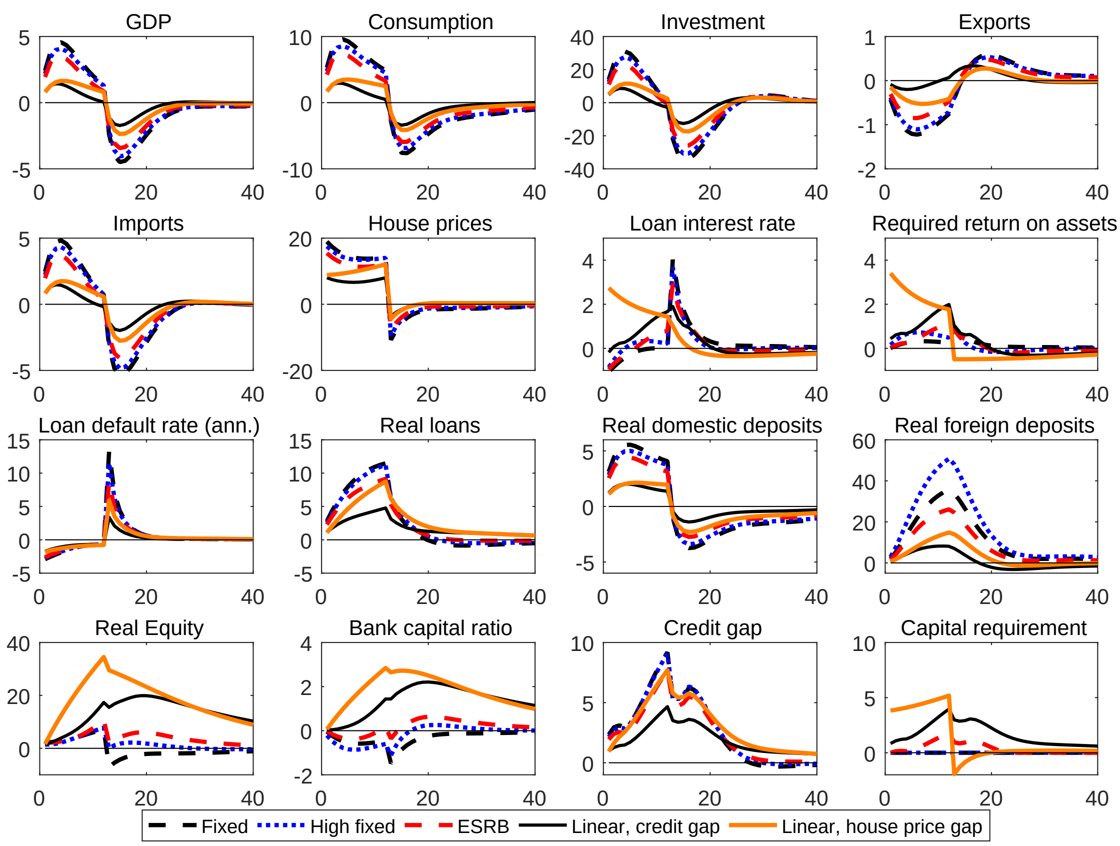
Expectations of a future increase in housing demand cause an immediate increase in house prices (see Figure 4), which transmit across the economy in a qualitatively similar manner as the housing demand shock. The main difference is that when quarter 13 arrives, the demand for housing *does not increase*. The disappointment causes a recession because the economy now has a too high physical capital stock and too much (foreign) debt. The disappointment causes a sharp drop in house prices and a substantial increase in the default rate. With fixed capital requirements this implies an increase in the loan interest rate (an increase in the default rate dominates the drop in the required expected return on assets due to deleveraging) and results in a sharp recession. High fixed minimum capital requirements do provide some stabilisation, but not enough.

All rule-based approaches to setting the CCyB stabilise the economy both during the boom and the bust. During the boom, the increase in the credit gap causes an increase in the regulatory capital ratio both under the ESRB rule and the linear rule based on the credit gap. Higher minimum capital requirements increase the risk of breaching the regulatory minimum capital and result in higher required return on assets and therefore the lending rate than when minimum capital is fixed (either at a low or at a high level). Higher lending rates dampen the the increase in domestic demand, and bank equity increases. The main difference between various CCyB rules is with respect to what happens during the bust. Because of the drop in GDP partly offsets the sharp decline in borrowing, the credit gap does not close and the ESRB rule and the linear rule based on the credit gap still require banks to hold capital above the regulatory minimum (see the bottom-right panel of Figure 4). While there is some relief for the bank capital ratio from the swift decline in loans, the capital buffer of banks (the distance between their capital

[16] This should be viewed as a stylised representation of a housing bubble - a shock that has no "fundamental" basis, or a purely expectation-driven shock. Technically, we implement this scenario by simulating the model with the shock to housing demand expectations and then take the levels reached in quarter 13 as initial values for another simulation of the model, this time with no shocks.

ratio and g_t) remains therefore depressed and thus the required expected return on loans remains above its steady state value for one to two years. Essentially, the ESRB rule and the linear rule based on the credit gap do not react sufficiently to release capital when the housing bubble bursts, and thus cannot counter the sharp increase in lending rates caused by the rising default rate. During the bust, the stabilisation of the economy under the credit gap rules therefore comes mainly from limiting the excesses of the boom in the form of capital overaccumulation and the run-up in domestic and foreign borrowing.

FIGURE 4. Stylised boom and bust in the housing market



Notes: Responses to an anticipated increase in housing demand in the future, which does not materialise. All variables are in percentage deviations from the steady state, except interest rates, default rate, and marginal regulatory penalty, which are in annualised percentage-point deviations, and bank capital ratio, credit gap, and capital requirement, which are in percentage-point deviations.

By contrast, the linear rule based on house prices reacts strongly during the both boom and bust phases. First, it reacts strongly to the increase in house prices during the boom phase, pushing up lending rates and dampening the domestic expansion. Higher lending rates during the boom phase make bank lending more profitable and both bank equity and bank capital ratio improve substantially (see bottom-left panels of Figure 4). When the bubble bursts, the accumulated capital buffer is released, which undoes a large part of the lending rate increase. Moreover, the default rate does not increase as much during the bust because house prices fall by less (because they have also risen by less during the boom). Note that even though the rule based on house prices allows banks to decrease their capital below the regulatory minimum, this actually does not happen for the average bank. The reason is that banks have accumulated substantial capital buffer during the boom.[17]

Finally, it should be emphasised that the effectiveness of the ESRB rule in stabilising the cycle depends on the timing of the events (first boom, then bust), because the rule does not allow bank capital to decrease below the minimum. Linear rules do not share this property and perform better when the sequence of shocks is reversed.

5.3 Reduction in the foreign deposit interest rate

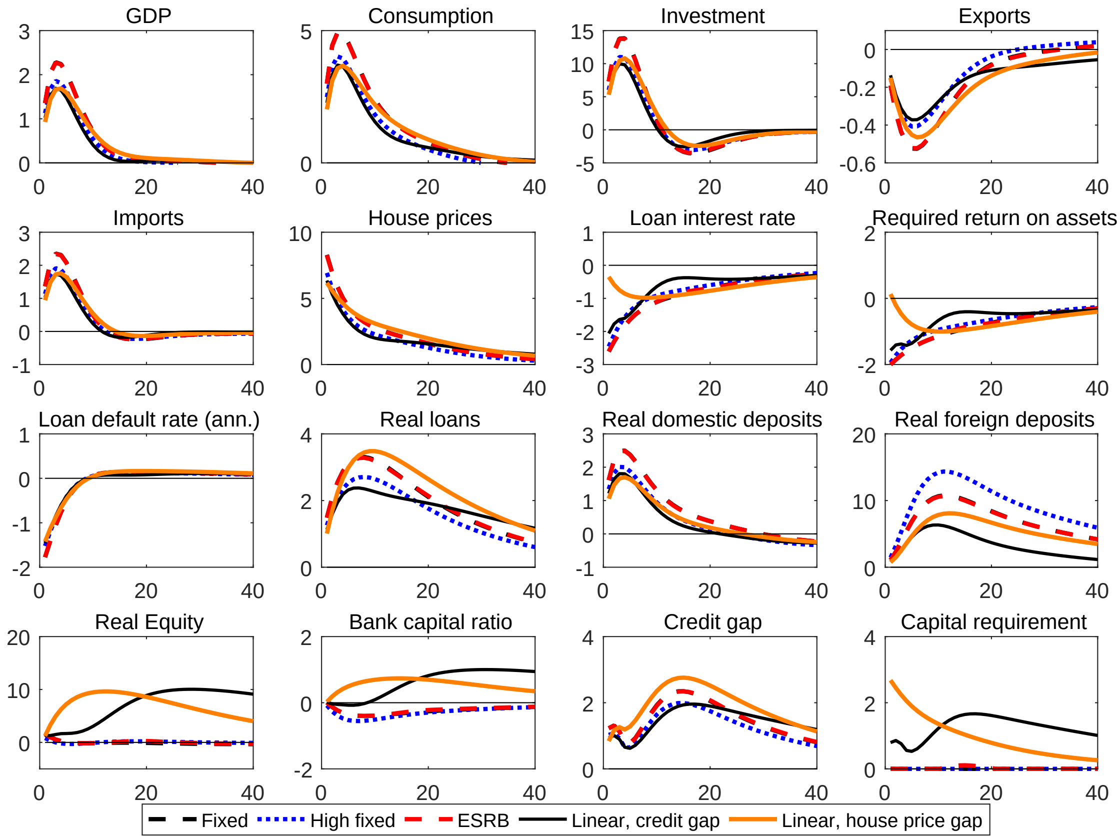
In this scenario, domestic bonds become more attractive to foreign investors, for instance due to lower risk perceptions.[18] We simulate this scenario as a decline in the foreign deposit rate. Banks pass the reduction in their borrowing costs to households through a lower lending rate (see Figure 5), which increases consumption, investment, and house prices. The associated decline in the default rate further lowers the lending rate. Higher domestic demand results in higher wages, prices and imports as well as lower exports, which increases the amount of foreign borrowing. Higher house prices and domestic activity increase the demand for transaction deposits.

The credit gap does not open much because of the simultaneous increase in GDP and loans. Because the 2 p.p. threshold is not breached, the ESRB rule does not react at all. By contrast, the two linear rules both lower the peak of GDP by about a fifth. Under a higher fixed level of g_t, a similar stabilisation gain is achieved.

[17]Note that by making the linear rule based on house prices more aggressive, one could achieve even greater degree of stabilisation without banks breaching the minimum capital requirement.

[18]Formally, this is a shock to the interest rate foreigners require for holding Irish assets, $R_{W,t}$. The shock is modelled as $R_{W,t} = (1 - \rho_{R_W})\overline{R_W} + \rho_{R_W} R_{W_{t-1}} + e_{R_{W,t}}$, where $e_{R_{W,t}}$ is the shock.

Figure 5. Reduction in the foreign deposit interest rate



Notes: Impulse responses to a decrease in the risk premium. All variables are in percentage deviations from the steady state, except interest rates, default rate, and marginal regulatory penalty, which are in annualised percentage-point deviations, and bank capital ratio, credit gap, and capital requirement, which are in percentage-point deviations.

5.4 Temporary decline in export demand

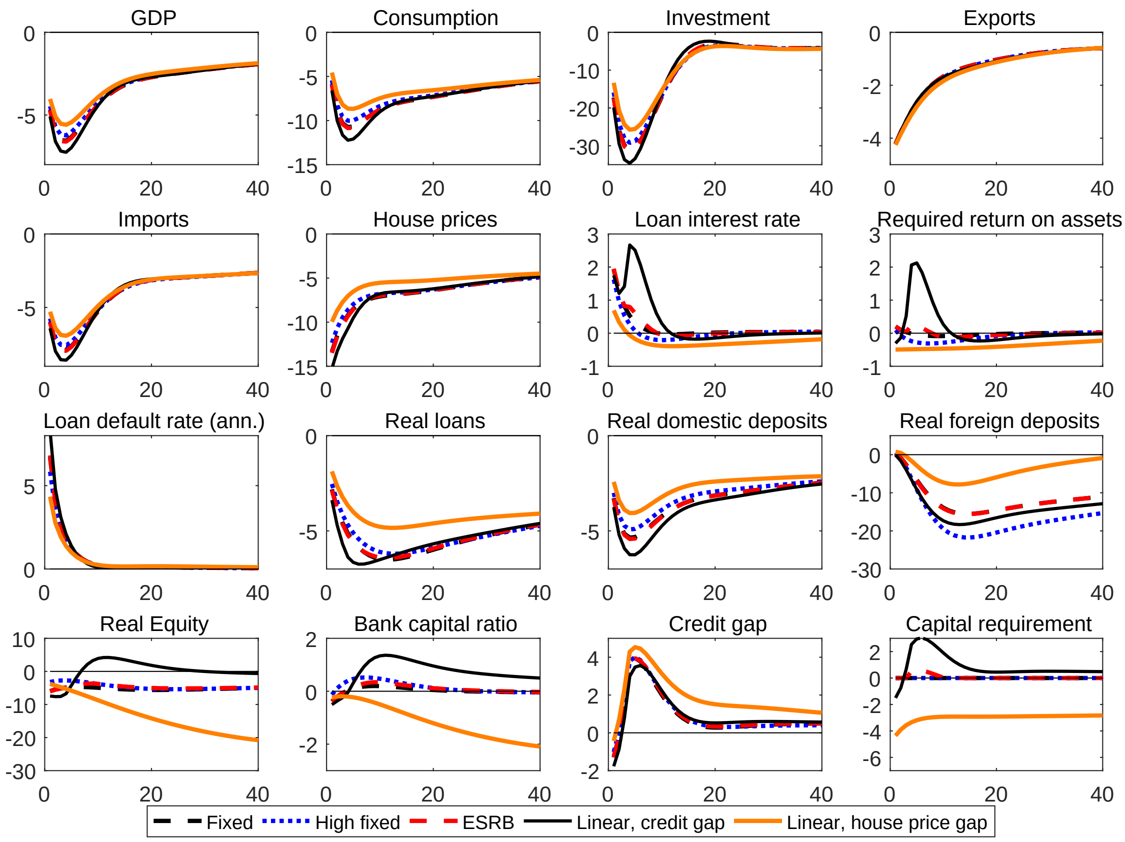
In this scenario, foreign demand for domestic export goods temporarily declines.[19] The decline in foreign demand depresses exports and therefore employment (Figure 6). The associated decline in wage pressure causes a decline in inflation and thus an increase in the real lending rate, which in turn depresses consumption, investment and house prices. The decline in house prices substantially increases the default rate and thus the lending rate, regardless of the type of capital rule used. This interest rate increase further depresses house prices, consumption, investment, and GDP.

The decline in domestic spending and a reduced incentive to hold saving deposits leads to the decline in loans. However, because GDP declines by more than loans do,

[19]The shock is modelled as a temporary decrease in export demand. If XD_t is the shifter of the export quantity demanded and $\overline{T}$ is the steady-state level of the terms-of-trade, the shock process is $ln(XD_t) = (1 - \rho_X)ln(\overline{T}) + \rho_X ln(XD_{t-1}) + e_{XD,t}$, where $e_{XD,t}$ is the shock.

the credit gap opens. Part of the reason is that the loss in export revenue associated with these shocks tends to dampen the decline in non-financial sector borrowing relative to the decline in GDP. Under the linear credit gap rule, this causes a sufficiently large increase in the minimum capital requirement to worsen the downturn caused by the shock (bottom-right panel of Figure 6). The same happens under the ESRB rule, just that the increase in g_t is less pronounced.

FIGURE 6. Temporary decline in export demand



Notes: Impulse responses to a temporary decline in foreign demand. All variables are in percentage deviations from the steady state, except interest rates, default rate, and marginal regulatory penalty, which are in annualised percentage-point deviations, and bank capital ratio, credit gap, and capital requirement, which are in percentage-point deviations.

By contrast, under the rule based on the house price gap, the regulator quickly lowers the minimum capital requirements, because house prices decline. This reduces the likelihood that banks will have to pay the penalty for breaching the minimum capital requirement and banks can decrease the required return on their assets to account for this. The lending rate does not increase as much as under the alternative rules and it declines after a few quarters because the reduction in house prices is persistent. A less pronounced interest rate increase and their subsequent decline alleviate the decrease in consumption, investment and GDP. For example, the drop in GDP under the house price rule is about 1 p.p. lower at the trough than under the ESRB rule or the linear rule based on the credit gap.

Note that the model may actually understate the increase in the credit gap and thus the tightening prescribed by rules featuring the credit gap. The model does not feature import content adjustment costs to be found, say, in the ECB's New Area Wide Model (Christoffel et al., 2008), implying that short and long-run price elasticities of are identical. A lower short run price elasticity would lower the decline in imports and strengthen the GDP decline. Furthermore, it would cause a higher path for foreign borrowing, which in our simulation actually decreases, and thus a higher path for domestic lending. Lower GDP and higher lending would imply a higher path for the credit gap and therefore even stronger tightening of capital requirements under the rules based on the credit gap.

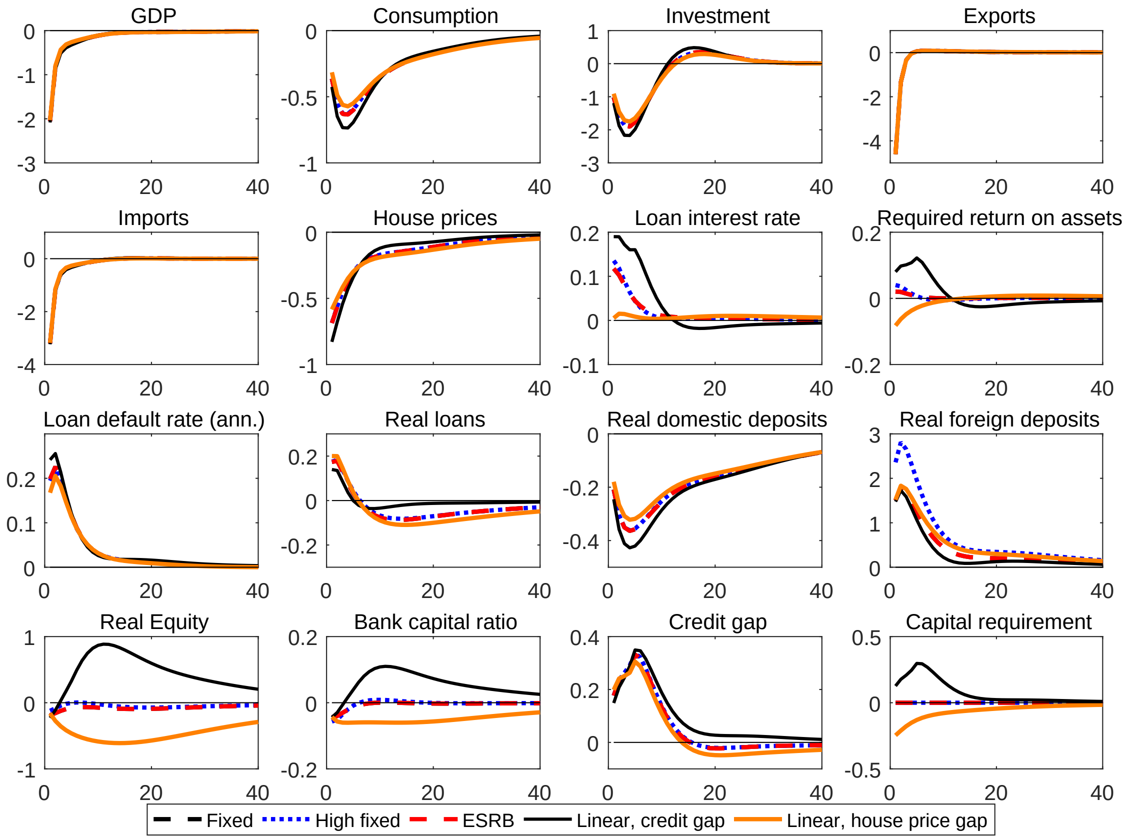
These results suggests that the credit gap may be a problematic indicator variable under a very common shock for small open economies. It prescribes tightening minimum capital requirements exactly at the time when foreign borrowing could be used to help smooth the adverse effects of a decline in foreign demand. The reason for such an adverse outcome is that the credit gap is countercyclical in this case. Furthermore, while the tightening of the capital requirement in recession is less pronounced under the ESRB rule than under linear the credit gap rule, the stabilisation gains achieved under the ESRB rule in the presence of house price shocks are also much more modest, especially so in the boom-bust scenario. Policy rules featuring the credit gap thus appear to create a trade-off between stabilising the economy's response to housing demand and export demand shocks. By contrast, this trade-off is absent when the capital requirement responds to house prices.

5.5 Supply shock

We model the supply shock as a temporary increase in the price markups in non-tradable goods and export sectors [20] The increase in price markups makes domestic goods less competitive, which lowers exports and increases the import content of domestic consumption and investment goods (see Figure 7). The resulting current account deficit increases foreign borrowing (see also equations 60 and 59), which in turn requires an increase in the deposit rate. The latter is passed on by the banks to the loan rate. Hence consumption, investment and house prices decline. The decline in house prices causes an increase in the share of non-performing loans and further increase in the loan rate, worsening the downturn.

[20] Formally, this is a simultaneous shock to μ_X and μ_N, where e.g. $\mu_X \equiv e^X/(e^X - 1)$. The shock process is $ln(\mu_{X,t}) = (1 - \rho_\mu)ln(\overline{\mu_X}) + \rho_\mu \mu_{X,t-1} + e_{\mu_X,t}$, where $e_{\mu_X,t}$ is the shock.

FIGURE 7. Increase in non-tradable and export goods markup



Notes: Impulse responses to an increase in markup for non-tradable goods and for export goods. All variables are in percentage deviations from the steady state, except interest rates, default rate, and marginal regulatory penalty, which are in annualised percentage-point deviations, and bank capital ratio, credit gap, and capital requirement, which are in percentage-point deviations.

Just as in the case of a decline in export demand, the credit gap is countercyclical, as GDP declines and loans increase initially due to the increase in foreign borrowing caused by the temporary current account deficit. The increase in the credit gap is too small to trigger an increase in g_t under the ESRB rule, while the linear credit gap rule triggers a small increase and thus somewhat amplifies the decline in consumption and investment. By contrast, as house prices decline in response to the shock, the house price rule prescribes a small decline in the minimum capital requirement and thus somewhat attenuates the decline in consumption and investment.

5.6 Transition to higher capital requirement

The above results suggest that a higher minimum capital requirement makes a small contribution to stabilising the economy. However, the transition to double the level of minimum capital requirements will be associated with costs. In the following exercise, we simulate an increase in the minimum regulatory capital ratio from 8% to 16% (we emphasise that this scenario is for illustrative purposes only).[21]

An increase in the minimum capital requirement means that banks suddenly face a higher marginal regulatory penalty, as the distance between the level of equity they are supposed to hold and the amount they actually do hold has widened. As a consequence, the banks find themselves paying the cost of breaching the minimum capital requirements and cut their supply of loans, which increases lending rates (Figure 8).[22] The increase in the lending rate depresses domestic consumption and investment, causing a decline of GDP of 5.8% at the trough. The decline in domestic demand leads to an improvement of the current account, as imports decline and exports increase due to lower wage pressure. Furthermore, house prices decline as the current and future utility from owning a house is discounted more heavily. The resulting house price decline increases the share of nonperforming loans.

The decline in house prices and economic activity lower households' demand for transaction-related funds, which has an immediate negative effect on borrowing. Furthermore, the improvement in the current account is reflected both in lower borrowing of households from banks and in lower borrowing of banks from abroad. At the same time, the increase in the lending rate increases the revenues of banks and thus gradually raises their equity. The bank capital ratio slowly approaches the new higher regulatory ratio and the marginal cost of lending declines, allowing domestic demand and house prices to recover.

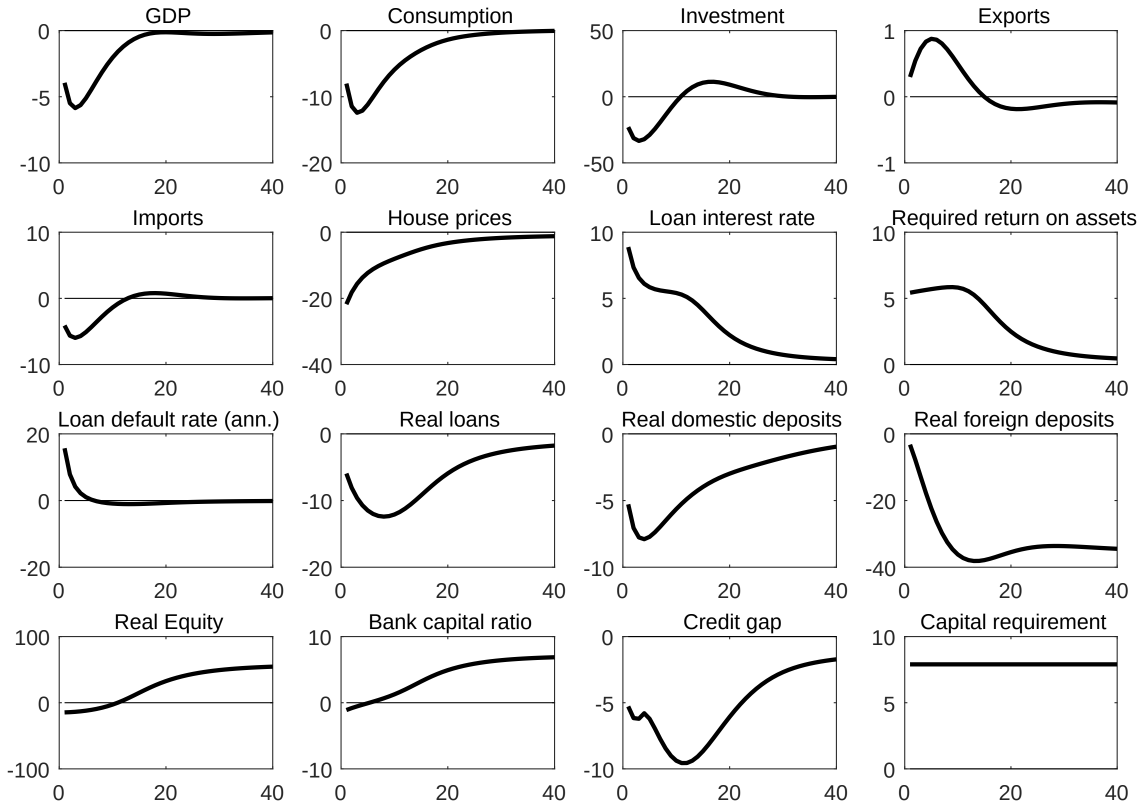
In the new steady state, the liability side of the bank balance sheet has changed. Banks rely more on equity and less on foreign deposits, while domestic deposits return to their pre-shock value. This implies that foreign debt of the economy as a whole is lower than before the increase in the capital requirement. Furthermore, the steady state of all other variables, including GDP and its components, lending and the lending rate are essentially unchanged.[23]

[21] The reason why we consider a substantial increase in bank capital is because such an increase is required to change bank leverage sufficiently in order to have a meaningful impact on dampening the fluctuations (which is what we consider in scenarios in the sections above).

[22] Note that in our model, banks can increase their capital only through retained earnings.

[23] An important caveat to the analysis that the model does not capture any effect of higher bank equity and lower bank leverage on the cost of equity and thus lending. A lower steady state level of bank leverage might reduce the cost of equity by lowering the risks associated with owning bank equity. But it might also increase the cost of equity if domestic households had preferences over the share of equity in their portfolio, requiring an increase in order to be willing to hold more equity. Furthermore, the analysis abstracts from the possible benign effects lower foreign debt might have on the costs of borrowing from abroad.

FIGURE 8. Increasing the minimum capital requirement



Notes: Transition to new, higher minimum capital requirements (from 8% to 16%). All variables are in percentage deviations from the initial steady state, except interest rates, default rate, and marginal regulatory penalty, which are in annualised percentage-point deviations, and bank capital ratio, credit gap, and capital requirement, which are in percentage-point deviations.

Our simulated GDP response to an increase in capital requirements is broadly in line with the literature. We compared the response of the model to an increase in capital requirements for a shock of similar magnitude as considered in the literature, i.e., 1 p.p. increase. The response of output in our model was of similar magnitude as that considered in Slovik and Cournède (2011), and well within the range of model responses considered in BCBS (2010).[24]

6 Conclusion

In this paper, we investigate the performance of several countercyclical capital buffer rules based on two different indicator variables, using a medium scale DSGE model of the Irish economy. First, we consider rules where the regulatory capital ratio is positively linked to the credit gap, including a rule recommended by the ESRB, as well as a simpler

[24]The comparison is with respect to a two-year gradual increase of capital requirement in BCBS (2010).

and more reactive linear policy rule. Second, we also consider specifications where the regulatory capital ratio is positively linked to house prices. Finally, we investigate a more conventional alternative (or complement) to the CCyB approach, namely substantially increasing acyclical regulatory capital requirements.

We obtain the following results. On the one hand, CCyB rules requiring that regulatory capital increases with the credit gap are able to dampen the response of the economy to housing demand shocks as well as news shock type boom and bust cycles. The reason is that, in all these cases, the credit gap moves strongly procyclically, implying that regulatory capital is tightened when GDP increases. This limits physical capital overaccumulation and the development of a foreign borrowing overhang, and creates a bank capital cushion which is released once the economy and borrowing contract. However, the stabilisation benefit is modest under the rule proposed by the ESRB. Part of the reason is that the ESRB rule caps the maximum increase in the minimum capital requirement during the boom, and that it is asymmetric, as it does not allow for a response to negative credit gap values.

Most importantly, CCyB rules based on the credit gap may fail to attenuate the response of the economy to other shocks, or even amplify their negative effects, if the shocks trigger an acyclical or countercyclical credit gap response. A relevant example, especially for small open economies, is a temporary decline in export demand, which lowers GDP more than domestic lending. Hence if the macroprudential authority responds aggressively to the credit gap, it worsens the export-induced downturn by effectively making borrowing more expensive. A similar effect occurs for the negative supply shock. Hence by targeting the credit gap, the macroprudential authority creates a trade-off between stabilising the response of the economy to housing demand shocks and destabilising the economy after export demand shocks. By contrast, such a trade-off does not arise if the regulator targets the house price gap, since house prices move procyclically in response to all shocks we consider. These results provide further justification for policymakers to consider a wider set of indicators, and particularly house prices, when setting CCyB rates. They also suggest that the prominence given to credit-gap-based thresholds for setting CCyB rates should be re-examined in the context of the ESRB recommendations on the conduct of macroprudential policy.

Finally, imposing a substantially higher constant capital requirement makes the economy only slightly more resilient in response to fluctuations. However, the costs associated with the transition to this higher regulatory capital ratio are substantial.

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A Tables

Table 1. Steady state values of important variables and their counterparts in the data

Name	Model	Data	Sources
Consumption share, $\frac{PC}{Y}$	51.8	45.5	CSO NIE
Private inv. share, $\frac{P_I I}{Y}$	14.4	19.9	CSO NIE
Gov. exp. share*, $\frac{P_N G}{Y}$	20.6	20.6	CSO NIE
Export share, $\frac{P_X X}{Y}$	92.3	92.6	CSO NIE
Import share, $\frac{P_M M}{Y}$	79.2	78.3	CSO NIE
Export surplus* , $\frac{P_X X - P_M M}{Y}$	13.2	14.3	CSO NIE
Imp. share cons.* , $\frac{P_M C_M}{PC}$	45.0	45.0	CSO IO tables
Imp. share inv.* , $\frac{P_M I_M}{Y}$	50.0	50.0	CSO IO tables
Imp. share exports* , $\frac{P_M X_M}{P_X X}$	56.0	57.2	CSO IO tables
Labour share* , $\frac{WN}{Y}$	40.0	39.6	CSO IO tables
Non-fin. sec. loan rate* , R_L	4.0	4.0	CBI, OC
Deposit interest rate* , R	1.8	1.8	CBI, OC
Deposit interest semi-elast.*	1.5	1.5	Gerlach and Stuart (2013)
Deposit adjustment speed*	0.2	0.2	Gerlach and Stuart (2013)
Prob. of undercap.* , F_b	2.5	2.5	Jakab and Kumhof (2015)
Loan-to-GDP rat.* , $\frac{L}{Y}$	104.4	104	Internal CBI data
Foreign dep. share* , $\frac{B}{L}$	22.2	22.2	CBI, OC
Bank equity ratio* , $\frac{E}{L}$	12.1	12.1	CBI, OC
Housing stock ratio* , $\frac{P_H H}{Y}$	244.9	244.9	CBI, CSO NIE
Loan default rate* , F_h	0.8	0.8	CBI, OC, Kelly and O'Malley (2015)

Notes: All values are in %. CSO=Central Statistical Office; NIE=National Income and Expenditure, IO=Input-Output. OC = own calculations. Own calculations are detailed in Appendix G. An asterisk denotes a target value in the calibration.

TABLE 2. Calibrated Parameters

Symbol	Name	Value
Households		
β	Discount factor*	0.9855
ϕ_N	Utility weight of labour*	1.9282
ζ_D	Utility weight of deposits*	0.3526
ζ_H	Utility weight of housing*	0.1017
η	Labour supply elast.	2
ν	Elast. of housing demand	1
ι	Curvature of saving deposit utility*	5
ξ_D	Deposit adjustment cost*	2
γ_C	Share of consumption trans. dep.	0.2
γ_H	Share of housing trans. dep.	0.05
δ	Depreciation rate	0.04
σ_h	Idiosyncratic risk*	0.4721
μ_C	Final cons. demand elasticity	1.01
μ_I	Final inv. demand elasticity	1.01
e_N	Non-tradable goods varieties elasticity	11
e_M	Import varieties elasticity	11
e_X	Export varieties elasticity	11
$e_{X,W}$	Export basket demand elasticity	2
Banking sector		
λ	Loss given default	0.4217
σ_b	Idiosyncratic risk*	0.4721
ζ	Share of foreign debt in GDP*	1.0564
$gmin$	SS. minimum capital requirement	0.08
θ_b	Fraction retained equity*	0.9882
$\frac{B}{Y}$	SS. foreign-deposit-to-GDP*	23.2%
θ_B	Risk premium sensitivity	1e-8
R_W	World interest rate*	3%
Firms		
α	Share of imports in exports*	0.49
ω_C	Share of consumption imports*	0.2
ω_I	Share of investment imports*	0.3
γ^N	Share of labour (non-tradable)*	0.44
γ^X	Share of labour (tradable)*	0.44
e_W	Labour varieties elasticity	11
θ_Π	Tradable profits transferred abroad*	82.0%

Parameters denoted with an asterisk are implicitly calibrated in order to support targets listed in Table 1, as well as $P_N = 1$.

Table 3. Estimated parameters

Symbol	**Name**	**Value**
ξ_W	Wage adj. cost	1500
ξ_I	Investment adj. cost	2.55
ξ_N	Non-tradable price adj. cost	1500
χ	Habit formation	0.7
ω^{P_N}	Non-tradable price indexation	0.1
σ_μ	Sd. supply shock	0.05
σ_H	Sd. housing demand shock	0.14
σ_X	Sd. export demand	0.01
σ_R	Sd. monetary policy shock	0.005
ρ_μ	AR(1) supply shock	0.3
ρ_H	AR(1) housing demand shock	0.995
ρ_X	AR(1) export demand	0.993
ρ_{R_W}	AR(1) risk premium shock	0.957

Table 4. Matrix of sign restrictions

Shock in VAR (model)	GDP	GDP defl.	Real P_H	Exports	EONIA
Supply (markup)	+	-	+		0
Housing demand (prefer.)	+	+	+	-	0
Export demand (XD)	+	+		+	0
Monetary policy (R)	+	+			+

Note: In the estimation, the sign restriction is always applied to the fifth element of the IRF of the respective variable to the respective shock. An exception is the response of the EONIA, where restriction applies directly to the equation for the EONIA in the VAR.

B Wage setting

Wage and price adjustment costs are specified in terms of deviations from past growth rate of prices and wages.[25] However, we allow for a degree of indexation, which implies that only part of the deviation from previous-period price or wage inflation is subject to adjustment costs. E.g., for wages we have

$$\Pi_{t-1}^{W} = \left(\pi_{t-1}^{W}\right)^{\omega_W} (\pi)^{1-\omega_W}$$

where $0 \leq \omega_W \leq 1$ denotes the degree of indexation to past wage inflation.

Households set wages assuming monopolistic competition, where households are facing a downward sloping demand curve $N(\bullet)$ of the form

$$N\left(W_{i,t}\right) = \left(\frac{W_{i,t}}{W_t}\right)^{-e^W} N_t.$$

and wage adjustment costs

$$\Omega_{W,t} \equiv \frac{\xi_W}{2}\left(\log\left(\frac{W_{i,t}}{W_{i,t-1}}\frac{1}{\Pi_{t-1}^{W}}\right)\right)^2$$

The objective is given by

$$-\frac{1}{1+\eta}N_t^{1+\eta}\left(W_{i,t}\right) + \Lambda_t W_{i,t} N\left(W_{i,t}\right)\left[1-\Omega_{W,t}\right] + \beta\Lambda_{t+1}W_{i,t+1}N\left(W_{i,t+1}\right)\left[1-\Omega_{W,t+1}\right] \quad (36)$$

Substituting $N\left(W_{i,t}\right)$ and writing-out the adjustment costs gives

$$\begin{aligned}
&-\frac{1}{1+\eta}\left(\left(\frac{W_{i,t}}{W_t}\right)N_t\right)^{1+\eta} + \Lambda_t \frac{W_{i,t}}{W_t^{e^W}}^{1-e^W} N_t\left[1-\frac{\xi_W}{2}\left(\log\left(\frac{W_{i,t}}{W_{i,t-1}}\frac{1}{\Pi_{t-1}^{W}}\right)\right)^2\right] \\
&+\beta\Lambda_{t+1}W_{i,t+1}N\left(W_{i,t+1}\right)\left[1-\frac{\xi_W}{2}\left(\log\left(\frac{W_{i,t+1}}{W_{i,t}}\frac{1}{\Pi_{t+1}^{W}}\right)\right)^2\right]
\end{aligned}$$

Because $\frac{\partial N(W_{i,t}/W_t)}{\partial W_{i,t}} = -\frac{e^W}{e^W-1}\left(\frac{W_{i,t}}{W_t}\right)^{-\frac{e^W}{e^W-1}-1} N_t \frac{1}{W_t} = -\frac{e^W}{e^W-1}N_t\frac{1}{W_t}$, as all optimising households set the same wage in equilibrium. Hence the FOC w.r.t. $W_{i,t}$ is given by

$$\begin{aligned}
\phi_N N_t^{\eta}\frac{e^W}{e^W-1}\frac{1}{W_t\Lambda_t} = 1 - \frac{\xi_W}{2}\left(\log\left(\frac{\pi_t^W}{\Pi_t^W}\right)\right)^2 + \xi_W\left(\log\left(\frac{\pi_t^W}{\Pi_t^W}\right)\right)\frac{1}{e^W-1} \\
-\frac{1}{e^W-1}\beta\frac{\Lambda_{t+1}}{\Lambda_t}\pi_{t+1}^{W}\frac{N_{t+1}}{N_t}\xi_W\log\left(\frac{\pi_{t+1}^{W}}{\Pi_{t+1}^{W}}\right) \quad (37)
\end{aligned}$$

[25]Note that steady-state inflation is calibrated to zero.

C Firms

There are five types of firms: Non-tradable goods firms, tradable goods firms, exporters, importers and final goods firms that aggregate intermediate goods into final goods.

C.1 Non-tradable goods firms

There is a continuum of non-tradable goods firms, indexed by i. Each non-tradable goods firm produces output using a Cobb-Douglas production function and face quadratic price adjustment costs. Its objective is given by

$$\sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} \left[P_{N,i,t+j} Y_{N,i,t} \left[1 - \Omega_{P_N,t}\right] - W_{t+j} N_{t+j} - R_{K,t+j} K_{t+j-1}\right],$$

where

$$\Omega_{P_N,t} \equiv \frac{\xi_N}{2} \left(\log\left(\frac{P_{N,i,t+j}}{P_{N,i,t+j-1}} \frac{1}{\Pi_{N,t}}\right)\right)^2$$

are price-adjustment costs. Similarly as for wages, adjustment costs permit partial indexation that is costless. Variable Π_t^N denotes the indexation scheme for price changes in the non-tradable sector.

Each intermediate goods firm is a monopolistic supplier of its own variety and thus faces a downward-sloping demand curve, which it takes as a constraint in its optimisation problem:

$$Y_{N,i,t+j} = \left(\frac{P_{N,i,t+j}}{P_{N,t+j}}\right)^{-e^N} Y_{N,t+j}. \tag{38}$$

The other constraint it faces is its production function, which is assumed to be a standard Cobb-Douglas production function:

$$Y_{N,t+j} = A_{N,t+j} K_{N,t+j-1}^{1-\gamma_N} N_{N,t+j}^{\gamma_N} \tag{39}$$

Each firm chooses prices, capital, and labour, and both constraints bind. The first-order conditions w.r.t. $P_{N,i,t}$ is given by (note that in equilibrium, all non-tradable goods firms choose the same price and therefore $P_{N,i,t}/P_{N,i,t-1} = P_{N,t}/P_{N,t-1} \equiv \pi_t^N$

$$\frac{\xi_N}{e^N - 1} \log\left(\frac{\pi_t^N}{\Pi_t^N}\right) = \beta \frac{\Lambda_{t+1}}{\Lambda_t} \pi_{t+1}^N \frac{Y_{N,t+1}}{Y_{N,t}} \left[\frac{\xi_N}{e^N - 1} \log\left(\frac{\pi_{t+1}^N}{\Pi_{t+1}^N}\right)\right] + \\ + \frac{MC_{N,t}}{P_{N,t}} \frac{e^N}{e^N - 1} - \left[1 - \Omega_{P_N,t}\right] \tag{40}$$

The optimality conditions w.r.t. capital and labour are given by:

$$\left(1 - \gamma_N\right) MC_{N,t} Y_{N,t} = R_{K,t} K_{t-1} \tag{41}$$

and

$$\gamma_N MC_{N,t} Y_{N,t} = W_t N_{N,t}. \tag{42}$$

C.2 Importers

Importers buy an import good at the (exogenous) world price $P^*_{M,t}$, which, converted into domestic units through the exchange rate S_t is their marginal cost:

$$MC_{M,t} = S_t P^*_{M,t} \tag{43}$$

Importers then use this good and transform it into varieties to be used in a CES basket. They thus face the following demand curve

$$M_{i,t+j} = \left(\frac{P_{M,i,t+j}}{P_{M,t+j}} \right)^{-e^M} M_{t+j}$$

and price adjustment costs $\Omega_{M,t} \equiv \frac{\xi_M}{2} \left(\log \left(\frac{P_{M,i,t+j}}{P_{M,i,t+j-1}} \frac{1}{\Pi_{N,t}} \right) \right)^2$. The objective is thus given by

$$\sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} \left[P_{M,i,t+j} M_{i,t} \left[1 - \Omega_{M,t} \right] - M_{i,t+j} MC_{M,t+j} \right],$$

implying that the FOC is analogous to the non-tradable sector:

$$\begin{aligned} \frac{\xi_M}{e^M - 1} \log \left(\frac{\pi^M_t}{\Pi^M_t} \right) - \frac{MC_{M,t}}{P_{M,t}} \frac{e^M}{e^M - 1} + \left[1 - \Omega_{M,t} \right] = \\ = \beta \frac{\Lambda_{t+1}}{\Lambda_t} \pi^M_{t+1} \frac{M_{t+1}}{M_t} \left[\frac{\xi_M}{e^M - 1} \log \left(\frac{\pi^M_{t+1}}{\Pi^M_{t+1}} \right) \right]. \end{aligned} \tag{44}$$

C.3 Tradable goods producers

The competitive sector combines locally produced goods Z_t and imports $X_{M,t}$ to produce an export good using a Leontieff technology:

$$X_t = \min \left\{ \frac{Z_t}{(1-\alpha)}, \frac{X_{M,t}}{\alpha} \right\}$$

where

$$Z_t = A_{X,t} \overline{K}^{1-\gamma_X}_{X,t-1} N^{\gamma_X}_{X,t}, \tag{45}$$

and $\overline{K}_{X,t-1}$, the capital used in the production of tradable goods, is exogenous.

Tradable goods producers sell their products to the final goods sector at price $P_{XI,t+j}$. Their objective is thus given by:

$$\sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} \left[\begin{array}{c} P_{XI,t+j} X_{t+j} \left[1 - \frac{1}{2} \xi_X \left(\log \left(\frac{X_{t+j}}{X_{t+j-1}} \right) \right)^2 \right] - W_{t+j} N_{X,t+j} - R_{K,t+j} \overline{K}_{X,t-1+j} \\ -\alpha P^M_{t+j} X_{t+j} - MC_{Z,t} \left((1-\alpha) X_t - A_{X,t} \overline{K}^{1-\gamma_X}_{X,t-1+j} N^{\gamma_X}_{X,t+j} \right) \end{array} \right]$$

The FOC w.r.t. X_t is given by

$$\frac{MC_{X,t}}{P_{XI,t}} - \left[1 - \frac{1}{2}\xi_X \log\left(\frac{X_t}{X_{t-1}}\right)^2\right] + \xi_X \log\left(\frac{X_t}{X_{t-1}}\right) =$$

$$= \beta\frac{\Lambda_{t+1}}{\Lambda_t}\pi_{XI,t+1}\frac{X_{t+1}}{X_t}\xi_X \log\left(\frac{X_{t+1}}{X_t}\right), \quad (46)$$

$$MC_{X,t} = \alpha P_{M,t} + MC_{Z,t}\left(1-\alpha\right), \quad (47)$$

and $\pi_{XI,t+1} \equiv \frac{P_{XI,t+1}}{P_{XI,t}}$.

The FOC w.r.t. labor is given by

$$\gamma_X MC_{Z,t} = W_t N_{X,t} \quad (48)$$

Note that because of Leontief technology, the shares of domestic production in exports and the import-content of exports are:

$$Z_t = (1-\alpha)X_t \quad (49)$$

and

$$X_{M,t} = \alpha X_t \quad (50)$$

C.4 Final goods firms

Final goods firms combine intermediate and imported goods to create final goods used for consumption and investment. They use constant-elasticity-of-substitution (CES) technology, which is allowed to differ in consumption and investment sector.

$$C_t = \left((1-\omega_C)^{\frac{1}{\mu_C}}\left(C_{N,t}\right)^{\frac{\mu_C-1}{\mu_C}} + (\omega_C)^{\frac{1}{\mu_C}}\left(C_{M,t}\right)^{\frac{\mu_C-1}{\mu_C}}\right)^{\frac{\mu_C}{\mu_C-1}}$$

Consistent with the CES production, demand functions for imported consumption goods, $C_{M,t}$, and for non-tradable consumption goods $C_{N,t}$, are

$$C_{M,t} = \omega_C\left(\frac{P_{M,t}}{P_t}\right)^{-\mu_C} C_t \quad (51)$$

$$C_{N,t} = (1-\omega_C)\left(\frac{P_{N,t}}{P_t}\right)^{-\mu_C} C_t, \quad (52)$$

where ω_C is the bias towards imported consumption goods, μ_C governs the elasticity of substitution between imported and non-tradable consumption goods, $P_{M,t}$ is the import price, $P_{N,t}$ is the price of non-tradable goods, and P_t is the general price index. The latter is defined as

$$P_t = \left(\omega_C P_{M,t}^{1-\mu_C} + (1-\omega_C)P_{N,t}^{1-\mu_C}\right)^{\frac{1}{1-\mu_C}}. \quad (53)$$

The equations for investment goods are analogous.

C.5 Exporters of final goods

Intermediate goods are transformed into final exports goods by monopolistically competitive exporters subject to price rigidities:

$$\sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} \left[P_{X,i,t+j} X_{i,t+j} \left[1 - \frac{\xi_X}{2} \left(\log \left(\frac{P_{X,i,t+j}}{P_{X,i,t+j-1}} \frac{1}{\Pi_t^X} \right) \right)^2 \right] - P_{XI,t+j} X_{i,t+j} \right]$$

with Π_t^X denoting possibly time varying reference (i.e. indexation scheme) for price changes in the non-tradable sector. Demand is given by

$$X_{i,t+j} = \left(\frac{P_{X,i,t+j}}{P_{X,t+j}} \right)^{-e^X} X_{t+j}$$

and the price setting is determined as

$$\frac{\xi_X}{e^X - 1} \log \left(\frac{\pi_t^X}{\Pi_t^X} \right) =$$

$$= \beta \frac{\Lambda_{t+1}}{\Lambda_t} \pi_{t+1}^X \frac{X_{t+1}}{X_t} \frac{\xi_X}{e^X - 1} \log \left(\frac{\pi_{t+1}^X}{\Pi_{t+1}^X} \right) + \frac{P_{XI,t}}{P_{X,t}} \frac{e^N}{e^N - 1} - \left[1 - \frac{\xi_X}{2} \left(\log \left(\frac{\pi_t^X}{\Pi_t^X} \right) \right)^2 \right] \quad (54)$$

Finally, we assume that the demand curve for the export basket X_t is:

$$X_t = X_{D,t} \left(\frac{P_{x,t}/S_t}{P_{W,t} T_t} \right)^{-e^{X,W}}, \quad (55)$$

where $X_{D,t}$ denotes the exogenous component of world demand, S_t denotes the exchange rate and $P_{W,t}$ and T_t are both exogenous. Note that we assume $S_t = 1$, implying that the numerator of the above equation is equal to the export price firms charge, $P_{X,t}$. This implies that, given $D_{D,t}$, exports will fall when exporters charge higher prices.

We allow that export demand depends negatively on interest rates. This is because we use a monetary union setup, where interest rates are determined exogenously for Ireland, but we do take into account that the demand for Irish exports to the rest of the Euro area will tend to decline when Euro area interest rates increase and reduce demand abroad.

$$log(X_{D,t}) = (1 - \rho_{XD}) log(\overline{X}) + \rho_{XD} log(X_{D,t-1}) - XD_{RW}(R_{W,t} - \overline{R}), \quad (56)$$

where ρ_{XD} measures persistence of foreign export demand, XD_{RW} determines the sensitivity of this demand to interest rates, $R_{W,t}$ is exogenous, and bars over variables denote their steady-state values.

D Net foreign asset position

The domestic interest rate is linked to the Euro Area one via

$$R_t = e_t R_{W,t} \frac{S_{t+1}}{S_t} \tag{57}$$

$$e_t = \theta_B \left(\frac{B_t}{Y_t} - \zeta \right), \tag{58}$$

where θ_B denotes the parameter that determines the sensitivity of the interest rate payable on domestic debt, depending on the deviation of the current indebtedness of the country from its steady-state value, $\zeta \equiv \overline{B}/\overline{Y}$.

Foreign debt B_t evolves according to

$$B_t = R_{t-1} B_{t-1} - TB_t + \theta_\Pi \left((P_{X,t} - \alpha P_{M,t}) X_t - W_t N_{X,t} \right), \tag{59}$$

where θ_Π denotes the share of profits transferred abroad by foreign-owned firms.

$$TB_t = P_{X,t} X_t - P_{M,t} M_t, \tag{60}$$

E Policy authorities

The exchange rate is fixed, and government spending is funded by lump sum taxes on optimising households

$$S_t = 1 \tag{61}$$

$$P_{N,t} G_t = \Theta_t \tag{62}$$

F Market clearing conditions

$$P_t C_t = P_{N,t} C_{N,t} + P_{M,t} C_{M,t} \tag{63}$$

$$P_t I_t = P_{N,t} I_{N,t} + P_{M,t} I_{M,t} \tag{64}$$

$$Y_{N,t} = C_{N,t} + I_{N,t} + G_t \tag{65}$$

$$M_t = C_{M,t} + I_{M,t} + X_{M,t} \tag{66}$$

$$N_t = N_{N,t} + N_{X,t} \tag{67}$$

$$K_t = K_{N,t} + \overline{K}_{X,t} \tag{68}$$

$$Y_t = P_t C_t + P_{I,t} I_t + P_{N,t} G_t + P_{X,t} X_t - P_{M,t} M_t \tag{69}$$

G Computation of empirical values

In this section we discuss the calibration of values reported in Table 1.

Imports for consumption, investment and export purposes. The targets for the import content of private consumption, private investment and exports used to calibrate ω_C, ω_I and α are computed based on the CSO input output tables.

Share of private consumption, private investment, government expenditure, exports, imports, the export surplus and the compensation of employees in GDP.

- Private investment I=gross fixed capital formation - government gross physical capital formation.
- Government expenditure G = Government consumption (=final consumption expenditure of government+net expenditure by central and local government on current goods and services) + GGPCF.
- Compensation of employees $W * N$= wages and salaries + Employers contribution to social insurance.
- The average shares are computed over the 2001-2014 period.

Housing stock value and non-financial-sector loan to GDP ratios.

- L=Total notional non-financial private sector loans to Irish counterparts, see McElligott and O'Brien (2011).
- $P_H * H$: Internal CBI series.

Calculation of bank funding shares B/L and E/L. All data is taken from Table A.4.1 – Assets and A.4.1 – Liabilities. The data is monthly

- D = Deposits from Irish residents (private sector) + Debt securities issued (Irish residents) + Remaining liabilities (resident)
- B = Debt securities issued (Euro Area) + Debt securities issued (rest of the World) + Deposits from non-residents (Euro Area) + Deposits from non-residents (rest of the World) + Remaining liabilities (non-resident) - (Loans to non-residents (Euro Area) + Loans to non-residents (rest of the World) + Holdings of securities issued by non-residents (Euro Area) + Holdings of securities issued by non-residents (rest of the World) + Central bank balances (resident) + Remaining assets (non-resident)).
- E=Capital and reserves (resident)+ Capital and reserves (non-resident)

The share of D, B and E in total funding is thus given by $\frac{D}{D+B+E}$, $\frac{B}{D+B+E}$ and $\frac{E}{D+B+E}$.

Non financial sector loan and deposit rates R_L and R. These are based on the CBIs retail interest rate statistics, Table B.2.1 "Retail Interest Rates and Volumes - Loans and Deposits, New Business". For both loan and deposit rates, we compute volume-weighted interest rates over all the reported maturities.

Household default rate J_t. The only attempt to estimate transition-into-default rates for Irish mortgages is Kelly and O'Malley (2015), who cover the 2010-2014 period. They estimate an average annual transition-into-default probability of 3.1% and 6.1% for owner occupier and buy-to-let (BTL) mortgages respectively. We compute the the median share of BTL mortgages in total mortgages outstanding during this period from "According to the Residential Mortgage Arrears and Repossessions Statistics", which equals 22%. We can then estimate the average probability of default as 0.78*3.1%+0.22*6.1%=3.76%, implying a quarterly default probability of 0.96%.

Saving deposit demand long interest elasticity and speed of adjustment Gerlach and Stuart (2013) estimate an error correction model for M2 money demand on annual data over the 1934-2012 period, and find a long run interest rate semielasticity of 2 and 1 depending on whether they use the short or long term interest rate, respectively (see their Table 2). We thus set our target value for the long run annual semielasticity of the demand for saving deposits $\epsilon_{D_S,R}$ to1.5. Their estimated speed of adjustment equals 0.2 (see their Table 5), which we denote as $Speed_A$. Linearising equation 21 yields

$$(\hat{D}_{S,t} - \hat{D}_{S,t-1}) = \frac{\iota(1-\beta R)}{\xi_D}(\frac{1-\iota}{\iota}\hat{P}_t + \frac{-\hat{\lambda}_t + \beta R(\hat{R}_t + \hat{\lambda}_{t+1})}{\iota(1-\beta R)} - \hat{D}_{S,t}), \tag{70}$$

implying that the long-run quarterly interest semielasticity and speed of adjustment are given by $\frac{\beta R}{\iota(1-\beta R)}$ and $\frac{\iota(1-\beta R)}{\xi_D}$. We can thus determine ι and ξ_D as

$$\iota = \frac{\beta R}{4\epsilon_{D_S,R}(1-\beta R)}$$
$$\xi_D = \frac{4\iota(1-\beta R)}{Speed_A}$$

H Steady state

H.1 Financial variables: Rates of return and ratio targets

Note first that

$$R_L = \frac{1}{\beta} \text{ from (18)}$$

Hence

$$\begin{aligned}
\widetilde{R} &= R + Spread \\
R_{L1} &= R_L\,(1-\lambda J) \;\text{ from (7)} \\
\overline{\omega_b} &= \frac{R\left(\frac{1}{E/L}-1\right)}{\left(\frac{(1-g)\tilde{R}}{E/L}\right)} \\
f(\overline{\omega_b}) &= \phi\left(log(\overline{\omega_b}) + \frac{1}{2}\sigma_b^2)\right) \\
R_E &= R + \frac{R_{L1}-R}{E/L} - \chi_b\frac{\Phi(\overline{\omega_b})}{E/L} \text{ from (8)} \\
J &= \frac{\left(1-\frac{\widetilde{R}}{R_L}\right)}{\lambda} \text{ from (15)} \\
\frac{D}{Y} &= \frac{L}{Y}\left(1-\frac{E}{L}\right) - \zeta \text{ from (1)}
\end{aligned}$$

Spread is set to achieve the target return on equity of banks (set at 11%). Recall that ϕ denotes the standard normal density function, which is equivalent to the derivative of Φ in our notation. Note that the steady state value R_E enters equation (3) also as a parameter in order to ensure that bank equity is stationary in the long run.

H.2 Real variables

First, MC_M, P_M are calculated as

$$\begin{aligned} MC_M &= \frac{P_M}{\frac{\mu_M}{\mu_M - 1}} \\ P_M^* &= \frac{MC_M}{S} \end{aligned}$$

We then set $P_N = P_N$, which allows to compute (using equations 53, 23, 24 and 40

$$\begin{aligned} P_I &= P_N (1 - \omega_I) + P_M \omega_I \\ P &= P_N (1 - \omega_C) + P_M \omega_C \\ P_K &= P_I (1 + \gamma_C (1 - \beta R)) \\ R_K &= P_K (1 - (1 - \delta)\beta)/\beta \\ MC_N &= P_N (\mu_N - 1)/\mu_N \end{aligned}$$

This allows to rearrange (41) to get

$$k_N = \frac{K_N}{N_N} = \left(\left(\frac{(1 - \gamma_N) MC_N A_N)}{R_K} \right)^{\frac{1}{\gamma_N}}$$

which allows to calculate

$$\begin{aligned} y_N &= A_N (k_N)^{1-\gamma_N} \text{ from (38)} \\ W &= \gamma_N MC_N A_N (k_N)^{1-\gamma_N} \text{ from (42)} \end{aligned}$$

It is now necessary to turn to the export sector first, for which we can compute all variables given that we have determined the wage W in the economy and using the fact that the export sector capital stock K_X is exogenous.

$$\begin{aligned} T &= 1 \text{ from calibration} \\ P_{X\_} &= P_M^* T \\ P_X &= S P_{X\_} \\ MC_X &= \frac{P_X}{\mu_X} \text{ from (54) and (46)} \end{aligned}$$

Then

$$MC_Z = \frac{(MC_X - \alpha P^W S)}{(1 - \alpha)} \text{ from (47)}$$

This allows to compute

$$
\begin{aligned}
k_X &= \frac{K_X}{N_X} = (W/(A_X \gamma_X MC_Z))^{\frac{1}{1-\gamma_X}} \quad \text{from (48)} \\
N_X &= \frac{K_X}{k_X} \\
Z &= A_X (K_X)^{1-\gamma_X} (N_X)^{\gamma_X} \quad \text{from (45)} \\
X &= \frac{Z}{1-\alpha} \text{ from (49)} \\
X_M &= \alpha X \text{ from (50)} \\
PTR &= \Theta_{\Pi}((P_X - \alpha P_M)X - WN_X),
\end{aligned}
$$

where PTR denotes profit repatriation from multinationals. Having determined the export sector variables, it is now possible to derive an expression for N_N based on the steady state level of foreign debt and the implied trade balance, which restrict the size of the domestic economy. We start by assuming a steady state fraction of foreign debt in nominal GDP ζ. Hence we have

$$B = \zeta Y$$

(from 57) Note that nominal GDP can be written as the sum of value added in both sectors:

$$Y = P_N Y_N + (P_X X - P_M X_M) = P_N Y_N + (P_X - \alpha P_M) X$$

Hence

$$B = \zeta (P_N Y_N + (P_X - \alpha P_M) X)$$

Furthermore, we define

$$L = Y * L2GDP$$

$$TB = [(R-1)\zeta + J\lambda R_C * L2GDP](P_N Y_N + PTR) \text{ from (59)}$$

Furthermore, combining (60), the definition of imports and (50), it is possible to write

$$C_M + I_M = \frac{X(P_X - P_M^* S\alpha) - TB}{P_M^* S} \tag{71}$$

which can be written as

$$C_M + I_M = \frac{\begin{array}{c} X(P_X - P_M^* S\alpha - [(R-1)\zeta + J\lambda R_L * L2GDP](P_X - \alpha P_M)) - PTR \\ -[(R-1)\zeta + J\lambda R_C * L2GDP] P_N Y_N N_N \end{array}}{P_M^* S} \tag{72}$$

Note that on the r.h.s., the only unknown is N_N. We can also express the l.h.s. in terms of N_N alone using (51), (52) and the equivalent for investment goods, (66), (12) , $k_N = \frac{K_N}{N_N}$ and $y_N = \frac{Y_N}{N_N}$ as

$$C_M + I_M = N_N \left[\left(Y_N - \delta \left(1-\omega_I\right) k_N\right) \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} + \omega_I \left(\frac{P_M}{P_I}\right)^{-\mu_I} \delta k_N \right] - \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} G \tag{73}$$

We now express steady state government expenditure as $G = \frac{Y*govsh}{P_N}$

$$G = \frac{\left(P_N Y_N + \left(P_X - \alpha P_M\right) X\right) * govsh}{P_N} \tag{74}$$

Hence we can write

$$C_M + I_M = N_N \left[\left(y_N - \delta \left(1-\omega_I\right) k^n\right) \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} + \omega_I \left(\frac{P_M}{P_I}\right)^{-\mu_I} \delta k^n \right] - \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} \left[\frac{\left(P_N Y_N + \left(P_X - \alpha P_M\right) X\right) * govsh}{P_N}\right]$$

Combining (72) and (74) and defining

$$Denominator \equiv \frac{\left[(R-1)\zeta + J\lambda R_C * L2GDP\right] P_N Y_N}{P_M^* S} + \\ + \left(y_N - \delta \left(\left(1-\omega_I\right)\left(\frac{P_N}{P_I}\right)^{-\mu_I}\right) k_N\right) \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} + \omega_I \left(\frac{P_M}{P_I}\right)^{-\mu_I} \delta k_N$$

allows to solve for N_N as

$$N_N = \frac{\frac{X\left(P_X - P^W S\alpha - [(R-1)\zeta + J\lambda R_C * L2GDP](P_X - \alpha P_M)\right) - PTR}{P_M^* S} + \frac{\omega_C}{1-\omega_C}\left(\frac{P_M}{P_N}\right)^{-\mu_C}\left[\frac{(P_X - \alpha P_M) X * govsh}{P^n}\right]}{Denominator} \tag{75}$$

Now the remaining real variables can be calculated easily:

$$
\begin{aligned}
N &= N_N + N_X \text{ using (68)} \\
K_N &= k_N N_N \\
Y_N &= y_N N_N \\
Y &= P_N Y_N + (P_X - \alpha P_M) X \\
G &= govsh * Y/P_N \\
K &= K_X + K_N \text{ using (69)} \\
I &= \delta K_N \text{ using (12)} \\
I_N &= (1-\omega_I)\left(\frac{P_N}{P_I}\right)^{-\mu_I} I \text{ (using the equivalent of (52) for investment)} \\
I_M &= \omega_I \left(\frac{P_M}{P_I}\right)^{-\mu_I} I \text{ (using the equivalent of (51) for investment)} \\
C_N &= Y_N - I_N - G \text{ using (66)} \\
C &= \frac{C_N}{(1-\omega_C)\left(\frac{P_N}{P}\right)^{-\mu_C}} \text{ using (52)} \\
C_M &= C\omega_C \left(\frac{P_M}{P}\right)^{-\mu_C} \text{ using (51)} \\
M &= X_M + C_M + I_M \text{ using (67)} \\
B &= \zeta Y \\
TB &= \left[(R-1)B + J\lambda R_C * L\right] \text{ using (59)} \\
\Theta &= G \text{ using (62)} \\
L &= \left(\frac{L}{Y}\right) Y \\
\Lambda &= \frac{1}{PC^{\sigma}(1+(1-\beta R))} \text{ using (17)} \\
\Lambda_T &= \Lambda(1-\beta R).
\end{aligned}
$$

Using 37, we can back out ϕ_N as

$$\phi_N = \frac{1}{\mu_W N^{\eta}/(W/\Lambda)}.$$

H.3 Remaining financial variables

We can now compute the remaining financial variables and the missing Lagrange multiplier. To see this, recall that we calibrate the ratios $P_H H/Y$, D/Y and L/Y. We denote these calibrated ratios with bars in the equations below:

$$
\begin{aligned}
P_H &= \left(\frac{\overline{P_H H}}{\overline{Y}}\right)\frac{Y}{H} \\
D_T &= \gamma_C \left(P * C + P_I I\right) + \gamma_H P_H H \text{ (from 9)} \\
D_S &= \left(\frac{\overline{D}}{\overline{Y}}\right) Y - D_T \\
D &= D_T + D_S \text{ (from 10)} \\
F &= P_H H \\
\overline{F} &= L R_L/\psi \text{ (using 13)}
\end{aligned}
$$

To support the calibrated ratios, we have to compute the consistent values of ζ_H, ζ_D and σ_h. We first compute ζ_D and σ_h as follows:

$$
\begin{aligned}
\zeta_D &= \frac{(1-\beta R)}{D^{-\iota}\left(P\right)^{\iota-1}}\Lambda \text{ (using 21)} \\
\sigma_h &= \frac{\left(\log\left(\overline{F}-F\right)\right)}{\Phi^{-1}\left(\frac{J-\pi}{1-\pi}\right)} \text{ (using 15)}
\end{aligned}
$$

with Φ^{-1} denoting the inverse of the standard normal distribution function. To back out the value od ζ_H, we require the value of the household's Lagrange multiplier on the bank's lending rate, Λ_{R_L}. To avoid congestion we define an auxilliary variable, Aux, as follows:

$$
Aux = (1-\lambda J) - (1-\pi)\phi\left(\frac{log\left(\frac{R_L \overline{L}/\overline{Y}}{\psi(\overline{P_H H}/\overline{Y})}\right)}{\sigma_h}\right)\frac{\lambda}{\sigma_h}
$$

The Lagrange multiplier on the bank's lending rate is then

$$
\Lambda_{R_L} = \frac{\Lambda L \beta}{Aux},
$$

which allows us to back out ζ_H as

$$
\zeta_H = \frac{\Lambda P_H(1-\beta+\gamma_C(1-\beta R)) - \Lambda_{R_L}\lambda(1-\pi)\frac{\phi\left(log\left(\frac{R_L \overline{L}/\overline{Y}}{\psi(\overline{P_H H}/\overline{Y})}\right)/\sigma_h\right)}{\sigma_H H}}{H^{-\nu}},
$$

where $\phi(\bullet)$ denotes the normal density function.