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Countercyclical capital regulation in a small open economy DSGE model

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Abstract

We examine, conditional on structural shocks, the macroeconomic performance of different countercyclical capital buffer (CCyB) rules in small open economy estimated medium scale DSGE. We find that rules based on the credit gap create a trade-off between the stabilization of fluctuations originating in the housing market and fluctuations caused by foreign demand shocks. The trade-off disappears if the regulator targets house prices instead. As a result, the optimal simple CCyB rule depends only on the house price but not the credit gap. Moreover, the optimal simple rule leads to significant welfare gains compared to the no CCyB case.

JEL classification: F41, G21, G28, E32, E44.

Keywords: bank capital, countercyclical capital regulation, housing bubbles, boom-and-bust.

Non-technical summary

This paper investigates the merits of linking countercyclical capital buffers (CCyB) to the credit gap and the house price gap. To do so, we build a DSGE model of a small open economy in a monetary union. In addition to the standard New Keynesian features, the model includes a realistic financial sector. Banks in our model are subject to 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, increasing the cost of credit for the non-financial sector. It is through this channel that the regulator can affect real activity. The model also allows for spillovers from the housing market to domestic demand due to risky household borrowing from banks. To ensure that the model is credible, we calibrate it by matching the impulse response functions of the model with those of an estimated structural VAR of the Irish economy.

We use this setting to investigate the performance of several countercyclical capital buffer rules based on the credit gap and the real house prices as indicator variables, conditional on a set of structural shocks that are typically considered important for small open economies. We take as benchmark the case where the minimum capital requirement is fixed at 8%. Against this benchmark we compare the performance of CCyB rules where the regulatory capital ratio is positively linked to the credit gap, including the rule recommended by the ESRB, as well as a simpler and more reactive linear policy rule, optimised to give the best performance in terms of welfare. We call this rule a restricted optimal simple rule. In addition we consider an extended CCyB rule that can be based on both the credit gap and the real house price gap, which is also optimised to give the best welfare outcome. We call this rule the optimal simple rule.

Our main finding is that CCyB rules based on the credit gap are able to dampen the fluctuations of the economy to housing demand shocks as well boom and bust cycles driven by expectations. The reason is that in such cases the credit gap is procyclical, implying that the regulatory capital is tightened when GDP increases. This limits the development of foreign debt overhang, and creates a bank capital cushion which can be released once the economy and borrowing contract. For shocks of realistic magnitudes, the ESRB rule does not act in a stabilising manner, because the credit gap threshold of 2 p.p. is never exceeded. In addition, the rule does not allow for a response to negative credit gap values, which limits the scope for stabilisation when the credit gap becomes negative.

Importantly, CCyB rules based on the credit gap not only fail to attenuate the response of the economy to shocks that cause an acyclical credit gap response, but even amplify their negative effects when a shock triggers a 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: If the macroprudential authority responds aggressively to the credit gap, it worsens the export-induced downturn by effectively making borrowing more expensive. Overall, 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. In 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 considered. It is therefore not surprising that when we allow for the simple CCyB rule to depend both on the credit gap and the house price gap, the optimised rule turns out to be based on a strong response to real house price gap, but not to the credit gap.

The implication of our findings is that policymakers should take seriously the part of the ESRB Recommendation that allows them to consider a wider set of indicators, in particular house prices, when setting CCyB rates. They also suggest that the prominence given to the credit-gap-based rules and its thresholds should be taken with caution.

1 Introduction

Since the financial crisis, regulation of the financial sector has undergone many changes in advanced economies. Several financial regulators have 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 recommended that macroprudential authorities 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). However, in its Recommendation, the ESRB suggests that macroprudential authorities may take into account other indicators as well, among them price gaps in the housing market.

In this paper, we investigate the merits of linking countercyclical capital buffers (CCyB) to the credit gap and the house price gap. Following Beneš and Kumhof (2015) and Jakab and Kumhof (2015), banks in our model are subject to 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. We embed these features in the model developed for the Irish economy by Clancy and Merola (2017). 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.

Our main finding is that the optimal simple policy rule for the CCyB is based on a strong response to real house prices but not to the credit gap.[1] The reason is that house prices always move procyclically, implying that regulatory capital is tightened when GDP increases, which limits the increase in domestic demand, while providing relief during a

[1] The welfare gain associated with the optimal simple rule amounts to 0.23% of quarterly consumption in the absence of the CCyB, the bulk of which is related to lower inefficient nominal wage volatility in the presence of the CCyB.

cyclical downturn. By contrast, the credit gap moves procyclically in response to housing demand shocks, but countercyclically in response to export demand shocks, implying that linking the CCyB to the credit gap would amplify fluctuations in domestic demand in response to this type of shock. Hence, linking the CCyB to the credit gap creates a trade-off between stabilizing fluctuations originating in the housing market and fluctuations caused by foreign demand shocks. We also examine the rule for the CCyB suggested by the ESRB, which requires an increase in the CCyB once the credit gap exceeds a threshold. We find that it is very unlikely to make a difference as it is activated only for extremely large shocks.

Our analysis contributes to the existing literature on the cyclical variation of financial market regulation by simultaneously incorporating the following six features. First, we consider regulation affecting bank capital requirements rather than other regulatory instruments. We analyse CCyB rules based on 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 prominently in the ESRB Recommendation. Second, as far as we are aware, our contribution is the first to investigate CCyB rules including house prices, one of the alternative indicator variables considered in Drehmann et al. (2010). Third, unlike Clerc et al. (2015), we focus on a small open economy within a monetary union, implying that monetary policy is absent as a stabilizing factor. Fourth, banks serve two functions in our model, namely channelling savings from (foreign) lenders to (domestic) borrowers, and meeting the liquidity preference of domestic households by supplying deposits to them. We find that this feature is important for replicating the procyclicality of non-financial sector credit. Fifth, we validate our model by matching the model impulse responses to those of an estimated structural VAR model. The ability of our model to broadly mimic the empirical response of house prices, credit and standard macro variables renders it a good candidate to compare the welfare consequences of linking the CCyB to the credit gap and to house prices. Finally, we search for the optimal weights on the credit gap and the house prices in the CCyB rule that maximise welfare in our model.

This is different from some recent contributions that investigate the merit of cyclically varying loan to value ratios (e.g. Rubio and Carrasco-Gallego (2016)) or other policy instruments (Chadha et al. (2015)) in response to financial variables. Some papers that allow for cyclical variation of the CCyB consider policy rules based on GDP (Angelini et al. (2014) and Angeloni and Faia (2013)), while regulators tend to respond to financial variables. 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, and their model does not feature a housing market. The only contribution incorporating the small open economy dimension is Clancy and Merola (2017), who however consider a more restricted set of shocks. By contrast, Angelini et al. (2014), Lewis et al. (2016) and Beneš and Kumhof (2015) study the optimal interaction between macroprudential and monetary policy. Furthermore, among the aforementioned contributions, only Beneš and Kumhof (2015) and Clancy and Merola (2014) study regulatory policy in a model where credit does not merely serve the purpose of intermediating savings between borrowers and lenders. Finally, from the contributions cited above, only Angelini et al. (2014) employ an estimated model, while Beneš and Kumhof (2015) consider only first and second moments of the data.

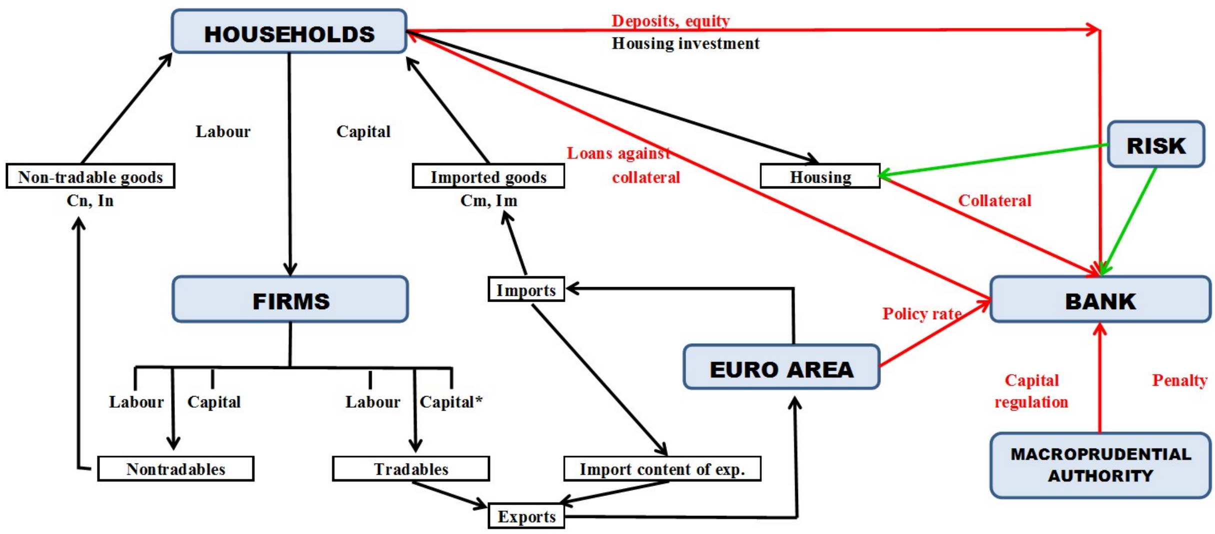
The paper is structured as follows: Section 2 develops the model, Section 3 describes the parameterisation, Section 4 introduces the macroprudential rules whose performance we evaluate. Section 5 contains the main results and Section 6 concludes.

2 The model

Figure 1 gives an overview of the linkages between various sectors in the model. The non-financial firm 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.

Households consist of two types of members, workers and bankers. Workers supply labour to the non-financial firm sector. Bankers use their scarce net worth to provide equity financing to the banking sector. The have finite working lives and transfer their net worth to the household once they retire. 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 minimum capital regulation, which may be time varying. The economy is part of a currency union.

FIGURE 1. Structure of the model



2.1 Banks

Following Gertler and Karadi (2011) and Mendicino et al. (2018), we assume that some members of the household are bankers with finite working lives. With a fixed probability $1 - \theta_b$, they retire and transfer their accumulated net worth to the household. They are replaced by an equal number of household members. The household endows the newly created bankers with "start-up" funds, which we assume to equal a fraction ω of total bank equity at the beginning of period t. Under these assumptions, aggregate bank equity at the end of period t $E_{b,t}$ is given by

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

where $R_{E,t}$ denotes the period t return on bank equity. These assumptions capture the empirical finding that banks are reluctant or unable to raise equity or cut dividends when faced with higher regulatory capital requirements or higher demand for credit (see Mesonnier and Monks (2015), Gropp et al. (2016) and Jimenez and Ongena (2017), and imply that banks never become fully self-financing.

Banks assets consist of loans to households, L_t, which they fund by domestic deposits, D_t, foreign deposits, B_t, and equity, $E_{b,t}$:

$$L_t = D_t + B_t + E_{b,t}. \tag{2}$$

Following Beneš and Kumhof (2015) and Jakab and Kumhof (2015), we assume that the banks' net return on assets is subject to idiosyncratic shocks, which cause individual banks' return on assets to deviate from the banking industry average $\widetilde{R_t}$. Those idiosyncratic shocks may represent above average exposures to bad loans, or losses from trading activities not explicitly modelled. More formally, an individual banks' $t+1$ return on assets is defined as $\widetilde{R_t}\omega_{b,t+1}$, where $\omega_{b,t+1}$ 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, and includes 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

$$\omega_{b,t}\widetilde{R_t}L_{t-1} - R_{t-1}(B_{t-1} + D_{t-1}) < \omega_{b,t}g_{t-1}\widetilde{R_t}L_{t-1}, \tag{3}$$

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

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

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

$$\max_{L_t} \mathbb{E}_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} \left[\widetilde{R_{t+1}} L_t \omega_{b,t+1} - R_t(B_t + D_t) - \chi_b L_t \Phi(\overline{\omega_{b,t+1}}) \right],$$

where $\beta \frac{\Lambda_{t+1}}{\Lambda_t}$ denotes the households' marginal discount factor. A bank's first-order condition with respect to loans determines the interest rate they charge on new loans:

$$\widetilde{R_{t+1}} - R_t = \chi_b \left(\Phi(\overline{\omega_{b,t+1}}) + \phi(\overline{\omega_{b,t+1}}) \frac{R_t}{(1-g_t)\widetilde{R_{t+1}}} \right). \tag{5}$$

Furthermore, the average net return on assets must compensate the bank for any expected losses associated with bankruptcy, so that the actual lending rate $R_{L,t}$ is

$$\widetilde{R_{t+1}} = R_{L,t} \left(1 - \lambda \mathbb{E}_t \left(J_{t+1}\right)\right), \tag{6}$$

where J_{t+1} and λ denote the expected share of defaulting household loans, explained in the next subsection, and and the loss given default (LGD), respectively.[2] Equations 5 and 6 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 $t+1$ due to higher leverage. 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. 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:

[2] Note that the share of loans in default depends on house prices, which implies that lower house prices lead to higher losses from defaults. This is similar to assuming that loans default due to causes unrelated to house prices, but where the recovery rate itself is lower when house prices are lower.

$$R_{E,t} \equiv R_{t-1} + (\widetilde{R_{t+1}} - R_{t-1})\frac{1}{el_{t-1}} - \chi_b \frac{1}{el_{t-1}}\Phi(\overline{\omega_{b,t}}). \tag{7}$$

The first term in equation 7 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.

Finally, a bank's capital ratio, el_t, is defined as the ratio of equity to loans,

$$el_t = \frac{E_{b,t}}{L_t}. \tag{8}$$

2.2 Households

Utility and budget constraints. We assume a continuum of optimising households indexed by j. Household j derives utility from consumption $C_{j,t}$, real bank deposits $D_{j,t}/P_t$ and housing $H_{j,t}$, and disutility from the labour $N_{j,t}$ supplied by its worker-members:

$$\mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \left[\frac{\left(C_{j,t+i} - \chi C_{t+i-1}\right)^{1-\sigma}}{\left(1-\chi\right)^{-\sigma}\left(1-\sigma\right)} - \phi_N \frac{N_{j,t+i}^{1+\eta}}{1-\eta} + \varepsilon_{H,t}\frac{\zeta_{H,t} H_{j,t}^{1-\nu}}{1-\nu} + \zeta_D \frac{\left(\frac{D_{j,t+i}}{P_{t+i}}\right)^{1-\iota}}{1-\iota} \right], \tag{9}$$

where β and χ denote the household discount factor and the degree of habit formation, σ, η, ν and ι are curvature parameters and P_t denotes the price level of the consumption basket $C_{j,t}$. $\zeta_{H,t}$ captures exogenous disturbances in the household preference for housing. In Appendix K, we show that our results are robust against allowing for an additional motive for holding deposits in the form of a cash in advance constraint in the goods and housing market.

The household budget constraint is given by

$$P_t C_{j,t} + P_{I,t} I_{j,t} + P_{H,t} H_{j,t} - L_{j,t} + D_{j,t} \left[1 + \frac{1}{2} \xi_D \Omega_{D,t} \right] =$$

$$= W_t N_{j,t} \left[1 - \frac{1}{2} \xi_W \Omega_{W,t} \right] + R_{K,t} K_{j,t-1} + P_{H,t} H_{j,t-1} + (1 - \theta_b - \omega) R_{E,b,j,t} E_{b,j,t-1} - R_{L,t} L_{j,t-1}$$
$$+ R_t D_{j,t-1} + \Pi_{j,t} - \Omega_{N,t} - \Omega_{M,t} - \Omega_{E,t} - \Theta_{j,t}. \quad (10)$$

In quarter t, household j earns a rental rate $R_{K,t}$ on its physical capital $K_{j,t-1}$, an interest rate R_t on its deposits $D_{j,t-1}$ and profits $\Pi_{j,t}$ from the ownership of firms in the economy. It receives net worth of its retiring banker members $(1-\theta_b) R_{E,b,j,t} E_{b,j,t-1}$, and provides those of its members who become bankers with total start-up funds $\omega R_{E,b,j,t} E_{b,j,t-1}$. Households may raise additional funds by selling part of their housing stock $H_{j,t-1}$ at price $P_{H,t}$ and by taking out bank loans $L_{j,t}$.[3] They pay an interest rate $R_{L,t}$ on the bank they took out in period t-1. $\Theta_{j,t}$ denotes lump sum taxes, while terms denoted by Ω denote quadratic adjustment costs.[4]

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.[5] Capital accumulation in the non-tradable sector is subject to investment adjustment costs:

$$K_{N,t} = (1 - \delta) K_{N,t-1} + I_t \left(1 - \frac{1}{2} \xi_I \Omega_{I,t} \right), \quad (11)$$

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

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

[3] As the aggregate housing stock is fixed, it holds that $P_{H,t} \int_0^1 H_{j,t} dj = P_{H,t} H$.

[4] Specifically, this term includes deposit adjustment costs and price adjustment costs in the tradable and non-tradable sector, which we assume to consist of consumption and non-tradable goods, respectively. Nominal wage and investment adjustment costs are assumed to consist of labour and investment goods units, respectively. 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.

[5] See subsection 2.3 for details.

$$\exp\left(\omega_{h,j,t}\right) H_{j,t-1} P_{H,t} < L_{j,t-1} R_{L,t-1}, \tag{12}$$

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

$$\overline{\omega_{h,j,t}} = \log(L_{j,t-1} R_{L,t-1}/(H_{j,t-1} P_{H,t})), \tag{13}$$

$$J_t = \Phi\left(\frac{\overline{\omega_{h,j,t}}}{\sigma_h}\right), \tag{14}$$

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.[6] 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.

Combining equations 13, 14, and the banks' participation constraint 6 yields a closed form relationship between the loan interest rate the household faces on the one hand, and its borrowing and housing on the other:

$$R_{L,t} = \frac{\mathbb{E}_t \widetilde{R_{t+1}}}{\left(1 - \lambda \mathbb{E}_t \left(\Phi\left(\log(L_t R_{L,t}/(H_t P_{H,t}))\sigma_h\right)\right)\right)} \tag{15}$$

This relationship represents the menu of choices offered to the household by the bank from which it chooses the optimal combination of these variables. In that respect, our modelling approach is similar to Clerc et al. (2015).[7] It is simpler than Clerc et al. (2015)

[6] 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 behaviour.

[7] Note that in Clerc et al. (2015) cast the optimization problem such that the household chooses its loan-to-value ratio LTV_t instead rather than the lending rate by substituting out the lending rate using the equation $LTV_t = L_t R_{L,t}/(H_t P_{H,t})$. This is a purely notational choice with no effect on the results.

in that our assumption of a fixed loss given default λ allows to solve explicitly for the lending rate.

First order conditions. We denote the Lagrange multiplier associated with the budget constraint (equation 10) with Λ_t, and the Lagrange multiplier associated with the interest rate faced by the borrowing households (equation 6) as $\Lambda_{R_L,t}$. The first order conditions with respect to C_t, L_t, $R_{L,t}$, D_t, $H_{j,t}$, I_t, and $K_{N,t}$ are

$$\Lambda_t P_t = (1-\chi)^{\sigma} (C_t - \chi C_{t-1})^{-\sigma}, \tag{16}$$

$$\Lambda_t = \beta \Lambda_{t+1} R_{L,t} + \Lambda_{R_L,t} \lambda \frac{\phi(\overline{\omega_{h,t+1}})}{\sigma_h L_t}, \tag{17}$$

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

$$D_t^{-\iota} P_t^{\iota-1} \zeta_D \frac{1}{\Lambda_t} = 1 - \beta R_t \frac{\Lambda_{t+1}}{\Lambda_t} + \xi_D \Omega'_{D,t}, \tag{19}$$

$$P_{H,t} = \varepsilon_{H,t} \zeta_{H,t} \frac{H_t^{-\nu}}{\Lambda_t} + \beta \frac{\Lambda_{t+1}}{\Lambda_t} P_{H,t+1} + \frac{\Lambda_{R_L,t}}{\Lambda_t} \lambda \frac{\phi(\overline{\omega_{h,t+1}})}{\sigma_h H_t}, \tag{20}$$

$$P_{I,t} = P_{K,t} \left[1 - \frac{\xi_I}{2} \Omega_{I,t} - \xi_I \Omega'_{I,t}\right] + \beta \frac{\Lambda_{t+1}}{\Lambda_t} P_{K,t+1} \xi_I \Omega'_{I,t} \frac{I_{t+1}}{I_t}, \tag{21}$$

$$P_{K,t} = \beta \frac{\Lambda_{t+1}}{\Lambda_t} \left((1-\delta) P_{K,t+1} + R_{K,t+1}\right). \tag{22}$$

In the equations above, $\phi(\bullet)$ denotes the probability density function of household default.[8] It is through this term and through the associated terms in equation 18 that

[8] This is the derivative of $\Phi(\bullet)$ in equation 14.

households take into account that their borrowing and investment decisions affect the probability of repaying the loan, and therefore the lending rate of the bank. Note that in equilibrium, $H_{j,t} = H$. Households also choose labour supply and set wages under standard assumptions regarding monopolistic competition and wage adjustment costs (see Appendix C for details). We assume that wage adjustment costs consist of hours worked.

2.3 Firms

There are four sectors in the model, as in 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 labour. Importers sell imported goods to final goods firms at a markup over the world price. The export sector generates output using domestic capital and labour, as well as imported intermediate goods. The latter feature accounts for the fact that small open economies typically have substantially higher import content of exports 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. In line with this, we 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 and tradable sectors also face nominal rigidities in the form of price adjustment costs, paid in terms of goods goods produced by the respective sector. See Appendix D for details.

2.4 International capital flows

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

$$R_t = e_t R_{W,t} \tag{23}$$

$$e_t = \theta_B \left(\frac{B_t}{Y_t} - \zeta \right) \tag{24}$$

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

$$B_t = R_{t-1}B_{t-1} - TB_t + \Gamma_t, \tag{25}$$

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

$$TB_t = P_{X,t}X_t - P_{M,t}M_t, \tag{26}$$

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.

2.5 Shocks

We assume that the economy is subject to four different shocks, namely to housing preference (housing demand), $\widehat{\zeta}_{H,t}$, to world interest rate, $\hat{R}_{W,t}$, to export demand, $\widehat{XD}_t$, and productivity in the tradable and non-tradable sector, $\hat{A}_t$. The shock processes are:

$$\widehat{\zeta}_{H,t} = \rho_H \hat{\zeta}_{H,t-1} + e_{H,t} \tag{27}$$

$$\widehat{R}_{W,t} = \rho_{R_W} \hat{R}_{W_{t-1}} + e_{R_W,t} \tag{28}$$

$$\widehat{XD}_t = \rho_X X\hat{D}_{t-1} + e_{XD,t} \tag{29}$$

$$\widehat{A}_t = \rho_A \hat{A}_{t-1} + e_{A,t} \tag{30}$$

where a hat above a variable denotes a percentage deviation of the variable from its steady state and the $e_{i,t}$ shocks are i.i.d. random variables.

3 Estimation and model validation

We bring the model to the data using a combination of calibration and estimation. We begin by dividing model 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 is estimated by matching model impulse-responses to the responses obtained from an estimated structural VAR model.

In the first group of parameters, we set the inverse of the Frisch elasticity of labour supply, η, to 2, assume log utility ($\sigma = 1$), and set the curvature of the utility function with respect to housing services, ν, to 1.[9] 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.[10] We calibrate the demand elasticities of the individual varieties in the labour, non-tradable, tradable and import CES baskets to 11, implying a steady state markup of 1.1. 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 (2012) 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 in Ireland, λ, covers 2014 and 2015, and is based on the EBA stress test. We set λ equal to the 2014 value for mortgages.[11]

The second set of parameters, and in particular those pertaining to the various financial frictions and household preferences over asset holdings, are 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

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

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

[11] 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%.

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.[12] Most of the other targets were calculated from multi-year averages of the relevant empirical counterparts of these variables, while some are econometric estimates.

Parameter values implied by calibration 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 (see Appendix I). All values in Table 1 are computed based on annual levels and model values are reported on annual levels.[13]

The third group of model parameters (Table 3) affects model dynamics, but not the steady state of the model, and include the habit formation, 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 shocks. We estimate these parameters by matching the impulse-responses (IRFs) of the model with the impulse-responses of an identified BVAR model, following the idea of Altig et al. (2011). The variables included in the VAR are real loans to the non-financial sector, real house prices, real exports, a measure of domestic real activity and the corresponding deflator, and the EONIA.[14] The sample period is 1999Q1-2016Q4. We identify four shocks (supply, housing demand, export demand, and monetary policy) by placing the minimum set of sign restrictions necessary to achieve distinct responses to each shock. The sign restrictions are listed in Table 4, where each row refers to a shock and each column to a variable.[15]

[12]Without loss of generality, we first assume $P_N = P_M$. 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 M for details.

[13]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.

[14]The measure of domestic real activity is the modified final domestic demand, and its corresponding price index is the modified final domestic demand deflator. The reason why we do not use the standard GDP is that due to the substantial amount of redomiciling, Irish GDP grew by more than 26% in 2015. Because of this, the Central Statistics Office constructed the "Modified domestic final demand" measure, which is arguably a better measure of domestic real activity (see also Lane (2017)) and the corresponding price index. We use the latter to deflate loans and house prices. The real export series is corrected for the jump in 2015.

[15]We leave two shocks unidentified. Importantly, the qualitative responses of the variables to the unidentified shocks do not correspond to the sign restrictions of any of the identified shocks. Moreover,

For the estimation we use the BEAR toolbox (Dieppe et al., 2016), and assume that the EONIA is block-exogenous with respect to the Ireland-specific variables.[16]

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 variance of each point of the IRF. This matrix attaches a higher weight to the more precisely estimated points of the IRF when calculating the criterion.[17] We compute the model IRFs under the assumption of a constant minimum capital requirement g_t, since there was no CCyB in place during the sample period.

Figure 2 displays the response of the model and the VAR to the four identified shocks. Importantly, typically respond procyclically, but not always. In particular, after a positive export demand shock, output expands, while loans essentially remain stable, especially in the short and medium run, implying that the credit gap decreases when GDP increases. An acyclical response of loans to demand side shocks is not an unusual finding. For instance, Fornari and Stracca (2012) estimate a panel VAR for 21 advanced economies and find that after a non-financial demand shock that increases GDP, credit to the private sector barely moves (and then decreases), implying that the credit gap falls.[18] den Haan

they fluctuate around zero and are not statistically significant, and their contribution to the variance of the variables is essentially zero.

[16] We use the independent normal-Wishart prior, which is less restrictive than the Minnesota prior (we have experimented with several settings and priors and the results are robust). We assume the prior values close to those typically found in the literature as reported by Dieppe et al. (2016). In their notation, we assume: $\lambda_1 = 0.2$, $\lambda_2 = 0.5$, $\lambda_3 = 1$, $\lambda_4 = 100$, and impose a zero mean and a tight variance on the prior for coefficients on interest rate that govern block-exogeneity ($\lambda_5 = 100$).

[17] We identify four shocks and exclude from the calculation of the criterion the interest rate response to those shocks where it is zero by assumption. Hence $\Psi(\zeta_{par})$ is a (4x5+1)xT vector of IRFs stacked on top of each other, where T denotes the number of time periods from the IRF we attempt to match. The first T nonzero elements of V are equal to the variance of each element of the first IRF in $\hat{\Psi}$, the second T elements are equal the variance of each element of the second IRF in $\hat{\Psi}$, etc. We set T=20.

[18] The results in Fornari and Stracca (2012) are robust, both for stochastic pooling and for the simple average across countries, as well as for the sample using only pre-crisis data, exclusion of the EA countries, conditioning on whether credit-to-GDP ratio in countries is high or low, conditional on financial openness and on stock market capitalisation.

et al. (2017) find that commercial and industrial loans strongly and peristently increase in response to a monetary tightening.

The model IRFs are broadly in line with the VAR. Regarding the estimated parameters, we find that export prices are much more flexible than non-tradable goods prices, in line with the Euro Area estimates by Coenen et al. (2013), a moderate degree of investment adjustment costs and significant external habit formation.

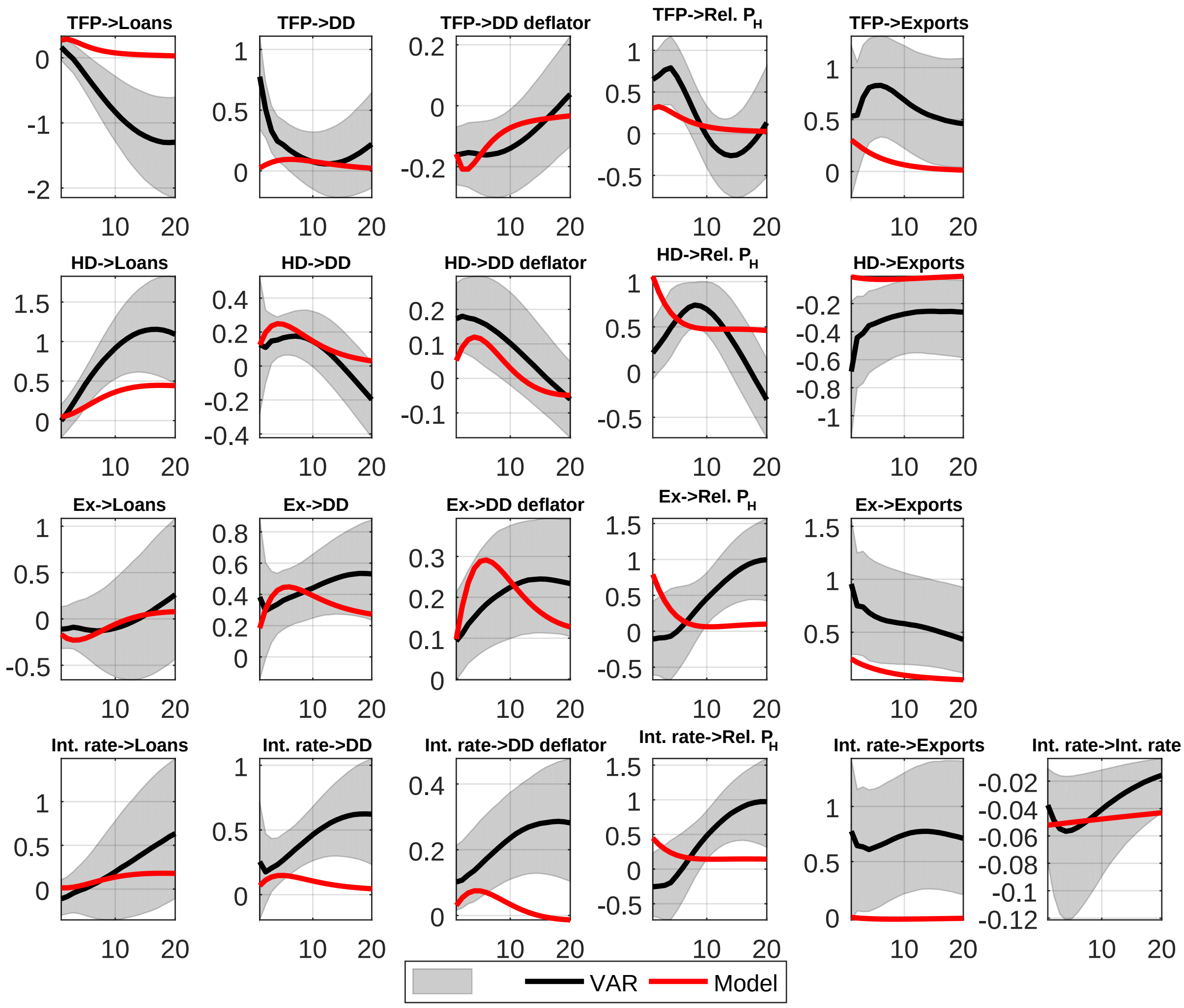
In Appendix B, we show that with the parameters estimated in this fashion, the model is also able to replicate the second moments of a number of important variable not included in the VAR. Furthermore, we show that the preference of households in the form of bank deposits is important for replicating the procyclicality of non-financial sector credit observed in the data.

The mechanism at the heart of the assessment of different rules for the CCyB is the effect of a change in the capital requirement on domestic demand and GDP. To verify the calibration of the model, we simulate the effect of a permanent 1 percentage point increase in the regulatory minimum capital requirement and compare it to the studies which investigated this issue as part of the design of the Basel regulatory framework.[19]

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 widens (Figure 3). As a consequence, the banks find themselves closer to paying the cost of breaching the minimum capital requirements, cut their supply of loans, and increase lending rates. The increase in the lending rate depresses domestic consumption and investment, causing a decline of GDP of 0.23% 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. House prices decline as the current and future utility from owning a house is discounted more heavily. The resulting house price decline results in a lower value of collateral, which increases the share of nonperforming loans.

[19]Ideally, we would like to compare the effect of a transitory shock to the minimum capital requirement in our model to a range of estimates, but the literature has typically looked at permanent shocks.

Figure 2. VAR and model IRFs



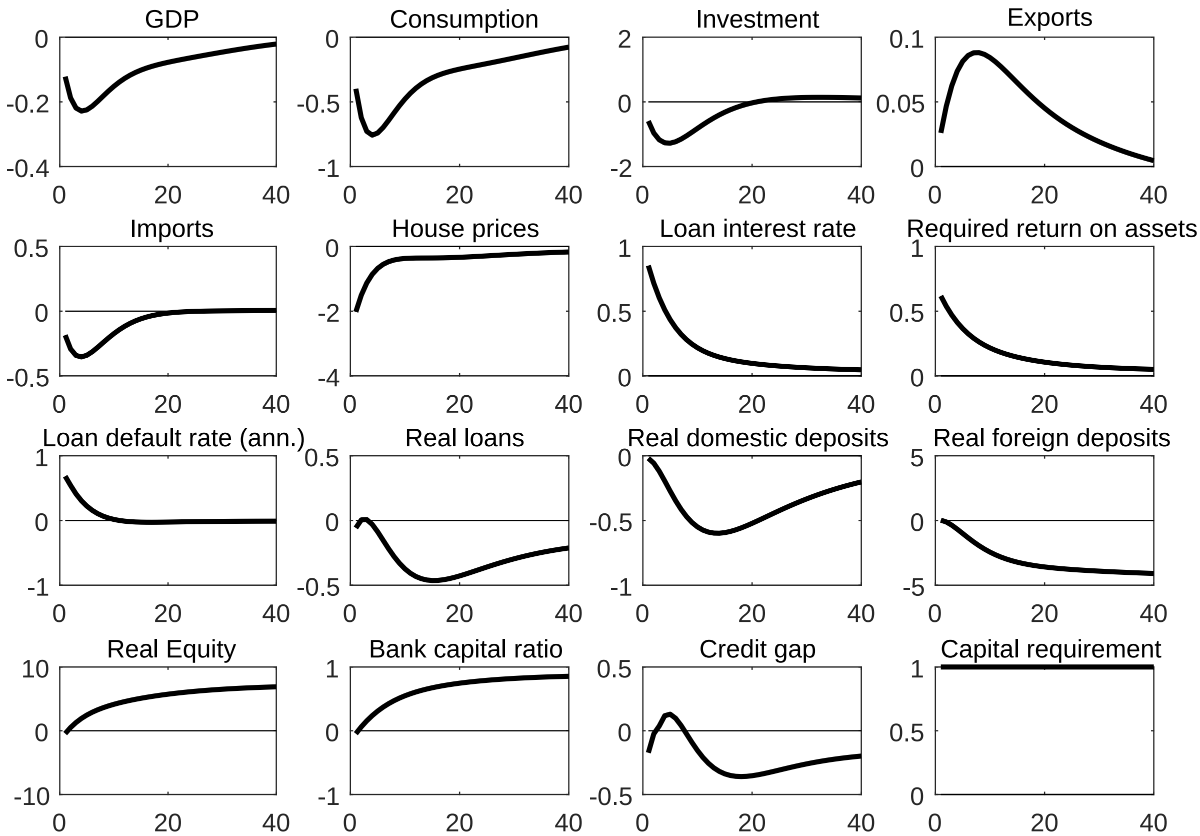
Notes: Impulse response functions of the model and the impulse responses in the VAR to the identified shocks. Shaded areas denote 68% confidence intervals. In the figure, DD denotes modified domestic demand.

The decline in house prices lowers domestic demand and economic activity, which in turn leads to an improvement in the current account. This is reflected both in lower borrowing of households from banks and in lower borrowing of banks from abroad. The increase in the lending rate increases the revenues of banks and thus gradually raises their equity.[20] The bank capital ratio slowly approaches the new higher regulatory ratio

[20]Note that in our model, banks can increase their capital only through retained earnings, as in Beneš et al. (2014).

and the marginal cost of lending declines, allowing domestic demand and house prices to recover.

Figure 3. Permanent increase in minimum capital requirements



Notes: Impulse responses to a permanent increase in minimum capital by 1 p.p.. All variables are in percentage deviations from the steady state, except interest rates, default rate, and required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

Importantly, our simulated GDP response to an increase in capital requirements is in line with the literature. The response of output in our model is of similar magnitude as that considered in Slovik and Cournède (2011), and close to the median of the range of model responses considered in BCBS (2010).[21]

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

4 Optimal simple rule

We consider a simple linear rule which relates the minimum capital requirement faced by banks, g_t, to the credit gap, gap_t, and the house price gap, $price\ gap_t$:

$$g_t = 8\% + \psi_L \cdot gap_t + \psi_{P_H} \cdot price\ gap_t, \tag{31}$$

$$gap_t = \left(\frac{L_t}{Y_t + Y_{t-1} + Y_{t-2} + Y_{t-3}} - \frac{\overline{L}}{4 \cdot \overline{Y}} \right), \tag{32}$$

$$price\ gap_t = \frac{P_{H,t}/P_t - \overline{P_H}/P}{\overline{P_H}/P}. \tag{33}$$

The definition of the credit gap follows the recommendation of the ESRB. [22]

We perform a gridsearch for a simple policy rule that maximises the unconditional expectation of household welfare (eq. 9). Following Schmitt-Grohé and Uribe (2007), we take a second-order approximation to both household welfare and the model's solution.[23] The grid is given by the intervals $\psi_L, \psi_{P_H} \in [0\ 2]$. We exclude policies for which the probability that g_t hits its zero lower bound exceeds 5%. We express the welfare gain of a proposed policy over the no CCyB case as a percentage of quarterly consumption under the no CCyB case. The welfare gain, τ_C, is computed as (see Appendix H for details):

$$\tau_C = \frac{(1-\beta)}{(1-\chi)} \left(dV_{a,0} - dV_0 \right). \tag{34}$$

The optimal simple rule obtained in this way only responds to the real house prices and not to the credit gap (see Table 5, column OSR), with $\psi^*_{P_H} = 1.1$. The welfare gain under the optimal policy as compared to the absence of a CCyB amounts to 0.23% of consumption in the absence of the CCyB.[24]

[22] 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.

[23] Due to the presence of steady-state distortions in our model, a second order accurate approximation to household welfare requires a second order approximation to the model's solution.

[24] This welfare gain is mainly the result of lower average hours in the new stochastic steady state, which decline by 0.05% (see Table 5, column Comp. WGOSR). The remainder is caused by higher

Since the optimal simple rule does not involve a response to the credit gap, we also consider a restricted version of the optimal simple rule, where we set $psi_{P_H} = 0$ and optimize ψ_{P_H} conditional on this restriction. This restricted optimal simple rule (see Table 5, column ROSR) does involve a response to the credit gap, but the welfare gain it achieves is essentially zero.

Finally, we also investigate the rule recommended by the ESRB, given by

$$g_t = 8\% + \begin{cases} 0 & if\ gap_t \leq 2\% \\ 0.3125 \cdot gap_t - 0.625 & if\ 2\% < gap_t \leq 10\% \\ 2.5\% & if\ gap_t > 10\%. \end{cases} \tag{35}$$

Equation 35 requires that g_t responds to the credit gap in an asymmetric and piece-wise linear fashion, as 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.

5 Simulations

This section discusses the response of the economy to two variants of a housing demand shock, a decline in export demand, a productivity shock and a decrease in the cost of foreign borrowing, all for the alternative rules described by equations 31 to 35. The magnitude of the shocks we assume in the simulations below equals one standard deviation.[26]

average consumption (+0.05%) and a lower volatility of all contributors to household utility (+0.1%). The decline in hours worked is in turn caused by a reduction in the variance of wage inflation (see the final row of Table 5), which lowers average wage adjustment costs. As we assume that wage adjustement costs consist of hours worked, the decline in wage inflation volatility allows hours worked to decline while leaving the labour input in goods production unchanged.[25] Note that the welfare gain associated with the CCyB might be higher still if we had assumed nominal rigidities in the form of Calvo (1983) pricing instead of quadratic adjustment costs, as the costs of inflation volatility tend to be higher with the former than with the later (see Lombardo and Vestin (2008) and Damjanovic and Nolan (2010)).

[26]This implies that the two percent threshold for the credit gap in the ESRB rule is never exceeded. We provide a simulation where this is the case and discuss its implications in Appendix L. We solve the model using the solver of Adjemian et al. (2011) to account for the non-linearity of the ESRB rule.

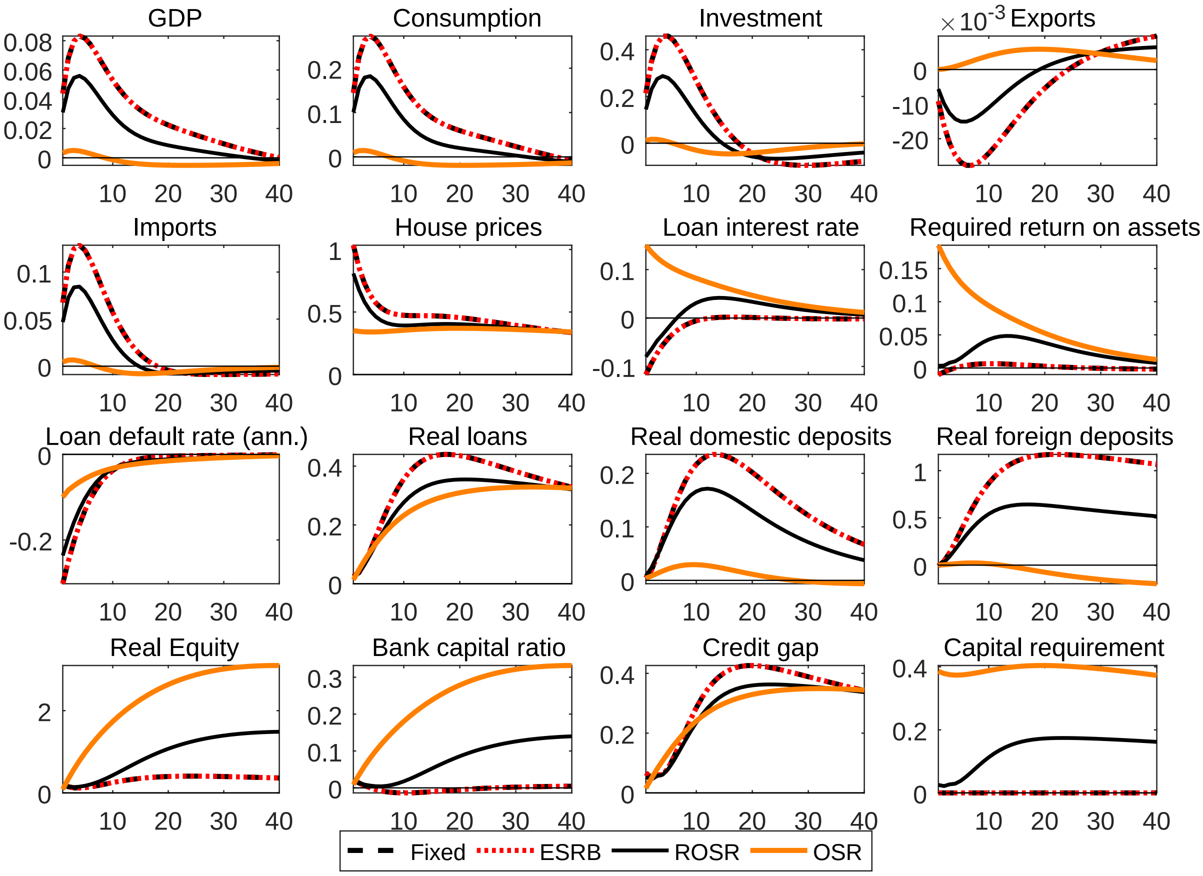
5.1 Positive housing demand shock

A positive housing demand shock is modelled as a temporary increase in preferences for housing, which increases the house price on impact (Figure 4). Our baseline is the constant bank capital requirement of 8% (dashed black line). With the supply of housing fixed, the increase in housing demand increases house prices, reduces households' loan-to-value ratios and thus the default rate. Banks pass lower expected losses from non-performing loans to households by reducing the loan rate, which stimulates consumption and investment. Lower interest rates and higher consumption further increase house prices, which can be interpreted as a financial accelerator mechanism. Wages and goods prices increase, worsening the country's competitiveness. Exports decrease and imports increase, implying that borrowing from abroad in the form of foreign deposits rises, and is intermediated to the non-financial sector as loans.

Total loans to households increase in response to the housing demand shock because the increase in households' expenditure relative to their revenue requires an increase in borrowing. Furthermore, the decline in the spread between the loan and deposit interest rate and the increase in consumption increases the demand for deposits by domestic households. 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 CCyB rules. The ESRB rule (dotted red line) performs exactly as the constant minimum capital requirement, because the credit gap opens by less than 2 p.p. and the rule does not kick in. As we show in Appendix L, a 10-standard-deviation shock is necessary to move the ESRB rule enough to have a meaningful effect on output. Both the optimal simple rule (OSR, full orange line) and the restricted optimal simple rule (ROSR, full black line) require an increase in the minimum capital requirement, as the credit gap and real house prices increase in response to the shock. With a higher minimum capital requirement, banks' capital buffer is smaller and the risk of ending up undercapitalised in period $t+1$ and having to pay a fine increases. This effect is reflected in a higher required expected return on assets ($\widetilde{R_{t+1}}$). Banks pass this increase in their expected cost of lending on to households, requiring higher interest rates for loans. As a result, the increase in consumption, investment and house prices is lower compared to the case of a constant minimum capital requirement. The OSR achieves a substantially higher attenuation than the ROSR because the increase in the real house price exceeds the increase in the credit gap, which leads to higher capital buffer requirements.

FIGURE 4. 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 required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

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), which ultimately does not materialise.[27]

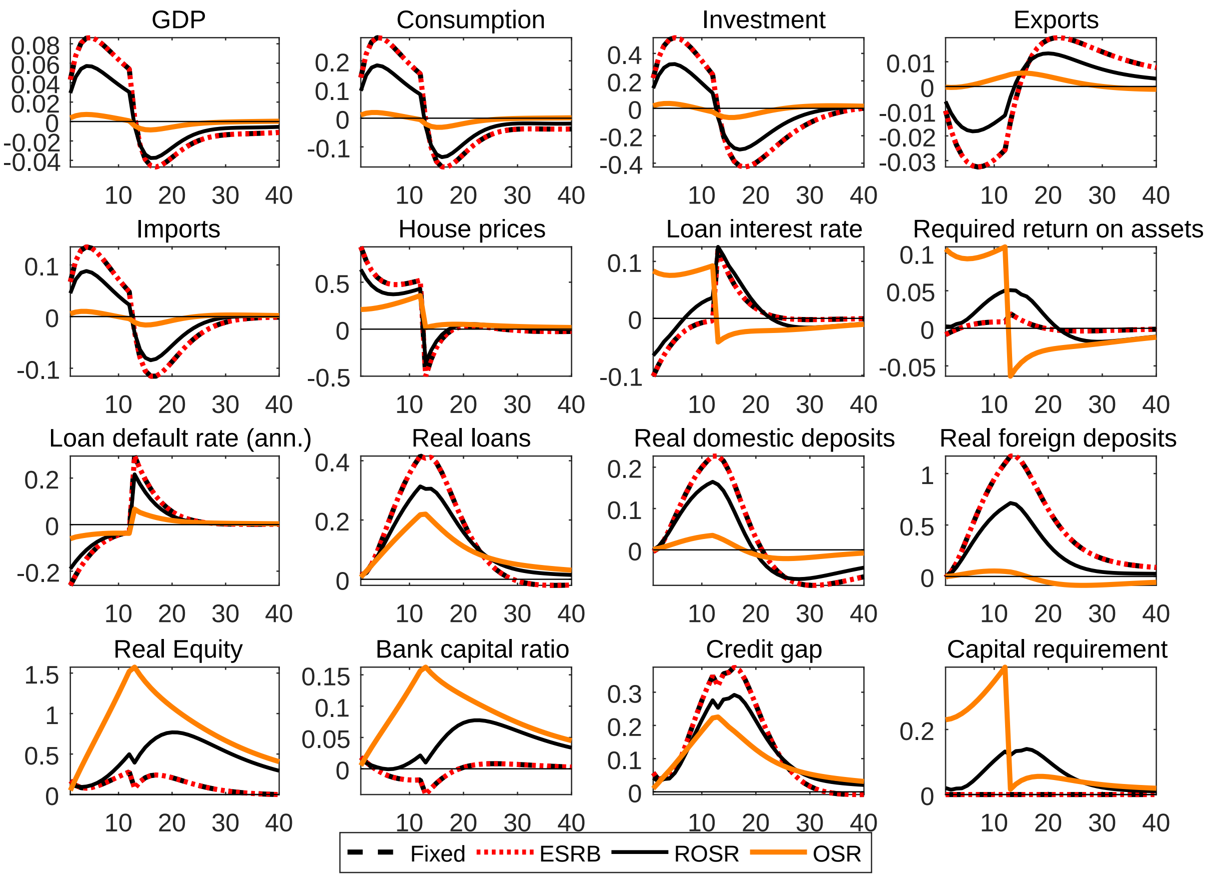
Expectations of a future increase in housing demand cause an immediate increase in house prices (Figure 5), which transmit across the economy in a qualitatively similar manner as the housing demand shock. The main difference is that when quarter 13 arrives, the demand for housing *does not increase*. This disappointment leads to a recession because the economy now has a too high physical capital stock, too much (foreign) debt and too low collateral value due to the collapse in house prices. The latter leads to a substantial increase in default rates. In the baseline case with constant minimum capital requirements there is only a tiny decrease in the required expected return on assets after the bubble bursts (and even this happens with a substantial delay), which implies that the increase in the default rate dominates. This is why fixed capital requirements are not able to prevent the increase in the loan interest rate after the burst of the bubble, which amplifies the recession.

The ESRB rule again performs identically to the fixed minimum capital requirements because the credit gap does not open sufficiently before and after the housing bubble bursts. Unlike the ESRB rule, the OSR and the ROSR provide more stabilisation. The distinction is that the OSR stabilises the economy both during the boom and during the bust, while the ROSR does it mostly during the boom phase. Under both rules, the increase in real house prices or the credit gap during the boom causes an increase in the regulatory capital requirement. Higher minimum capital requirements increase the risk of breaching the regulatory minimum capital and result in higher required return on assets. This results in higher lending rates, which dampen the increase in domestic demand and help to increase bank equity. During the bust, house prices decline strongly,

[27]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 second simulation without any actual or anticipated shocks.

implying that the OSR allows a decline in the minimum capital requirement almost to its steady state level. Importantly, this happens immediately after the expected increase in housing demand does not materialise, which immediately releases the accumulated capital buffer. This lowers the required expected return on bank assets sufficiently to dominate the increase in lending rates due to higher defaults, and as a result the loan interest rate *decreases*. The period of elevated loan rates during the boom is followed by a period of lower rates during the bust, which stimulates domestic demand and helps to stabilise the economy. For the ROSR, the stabilizing effect during the bust is absent. The reason is that even though the credit gap drops during the bust from its boom-level, it still remains above its steady-state for several years. This is because part of the boom-related increase in borrowing was used to increase spending on goods and services above disposable income, and the repayment requires a reversal of the household balance. Because households would like to smooth their consumption, they prefer a gradual reduction of their borrowing by maintaining a positive balance for an extended period. The minimum capital requirement under the ROSR does not decline as much relative to the actual bank capital ratio as under the OSR. Moreover, because it declines more gradually and from lower levels, the capital buffer release is neither timely nor large, which leads to a higher trajectory for the required expected return on assets and thus a higher loan rate. Note that this applies to any credit-gap-based rule, because the credit gap remains positive throughout the simulation.

FIGURE 5. Stylised boom and bust in the housing market



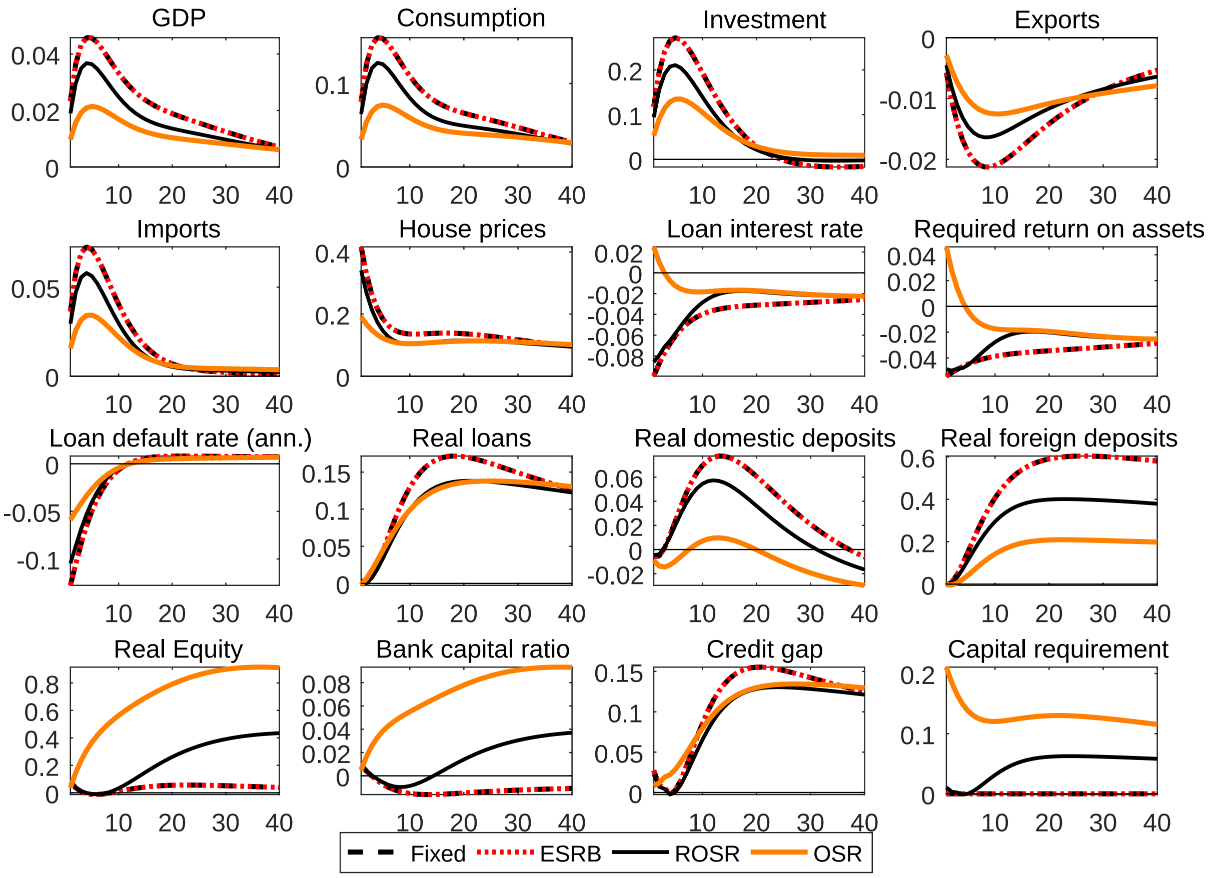
Notes: Responses to an anticipated increase in housing demand in the future, which does not materialise. All variables are in percentage deviations from the steady state, except interest rates, default rate, and required return on assets, which are in annualised percentage-point deviations, and the bank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

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. We simulate this scenario as a decline in the foreign deposit rate. Under the baseline scenario with fixed minimum capital requirements banks pass the reduction in their borrowing costs to households through a lower lending rate (Figure 6), 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, and lower exports, which increases foreign borrowing.

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 and its performance is identical to that of the constant minimum capital requirement. By contrast, the OSR and the ROSR rules do react. The main difference is that because of the muted and delayed response of the credit gap, the tightening of the minimum capital requirements is very small under the ROSR and so are the resulting impacts on the lending rate and the economic activity. In contrast, the OSR reacts strongly and immediately because house prices increase. As a result, the loan interest rate does not decrease as much as under other rules (it even increases slightly on impact), which dampens consumption and reduces the peak of GDP by about a half.

FIGURE 6. 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 required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

5.4 Temporary decline in export demand

In this scenario, foreign demand for domestic goods temporarily declines (Figure 7). The fall in foreign demand has a direct negative effect on GDP, and and an indirect negative effect vial lower domestic demand. The decline in domestic demand comes about for the following reasons. Lower production means lower real wages and marginal costs in both the tradable and the non-tradable sector, and thus lower inflation and a higher real loan rate. At the same time, the decline in export revenue and the desire of households to smooth their consumption tends to increase the paths of household borrowing from banks and the borrowing of banks from abroad. The associated increase in foreign deposits tends to increase the risk premium banks have to pay on their deposits via equations 23 and 24 and thus the loan rate faced by households (see equations 5 and 6). Finally, the increase in household borrowing and the house price decline result in an increase in the risk of household default and thus also increase the lending the lending rate (see equation 6).[28]

Under the baseline scenario with fixed minimum capital requirement the temporary increase in loans and the decrease in GDP leads to an increase in the credit gap. This increase is not sufficient to activate the ESRB rule, so that the results under the ESRB rule and under the fixed minimum capital requirements are the same.

Under the ROSR, the increase in the credit gap causes a sufficiently large *increase* in the minimum capital requirement to worsen the downturn caused by the shock (bottom-right panel of Figure 7).[29] Higher capital buffer results in higher probability for banks of having to pay the penalty, which is why they require higher return on assets. The lending rate increases by more than under the fixed capital requirements and this aggravates the recession. Note that because the credit gap opens in the wrong direction, any capital rule that responds positively to the credit gap worsens the downturn under this shock. Furthermore, note it appears that we would observe an increase of the credit gap even if we substituted say domestic demand for GDP in the denominator of the credit gap definition equation, as domestic demand declines even more than GDP.

By contrast, under the OSR, 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. This is sufficient to offset the increase in the default rate, allowing the lending rate to *decrease*. This enables households to borrow

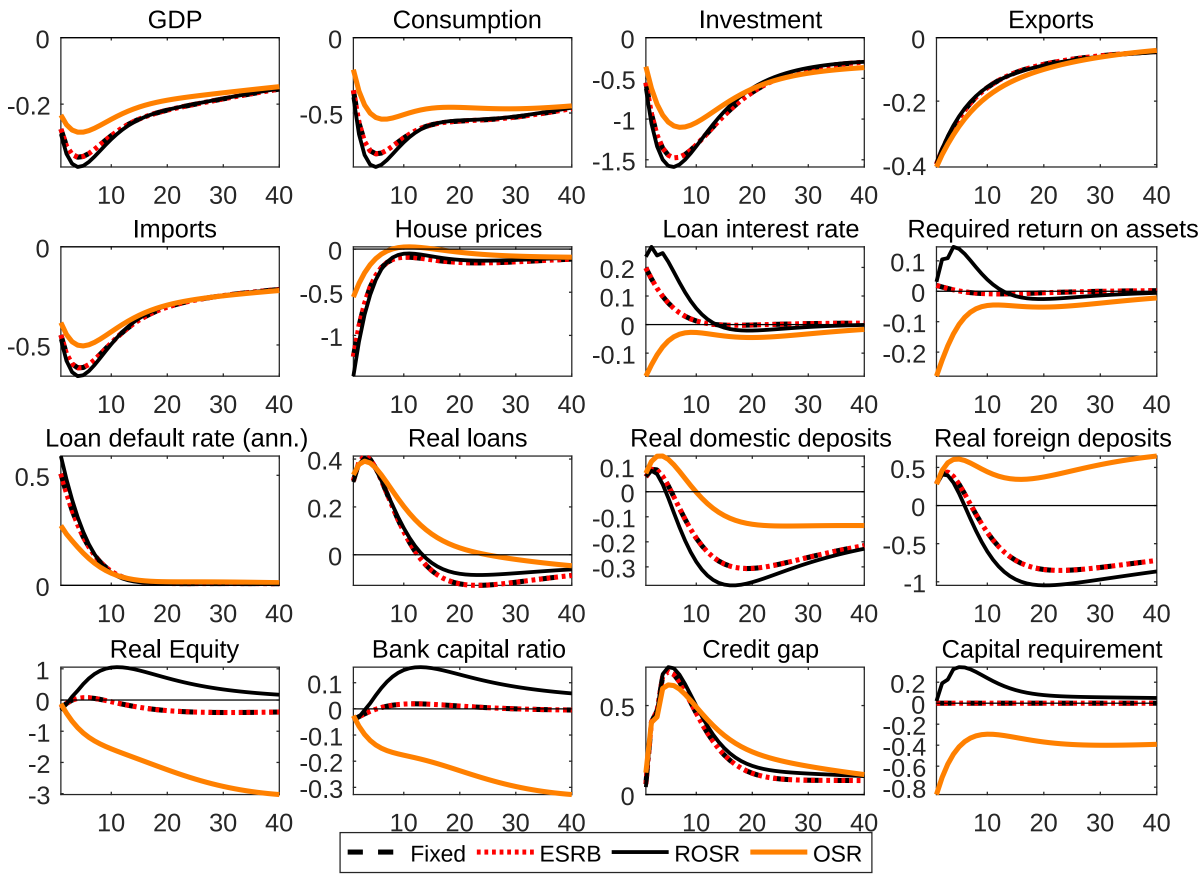
[28] In general equilibrium, foreign borrowing turns negative after six quarters, as the cumulative effect of the drop in imports for domestic consumption and investment purposes overcompensates the cumulative effect of lower export revenues. The strong effect on of domestic demand is partly driven by the high persistence of the shock ($\rho_X = 0.99$) and the associated effect on households' expectations. For instance, for $\rho_X = 0.95$, we observe a much more persistent increase in the foreign borrowing of banks and thus domestic lending.

[29] The small short-term oscillations in the required return on assets occur because the credit gap is defined as a moving average.

more from abroad in order to smooth consumption, which substantially alleviates the decline in consumption, investment and GDP.

Note that the model may actually understate the increase in the credit gap and thus the tightening prescribed by rules based on the credit gap. The reason is that the model does not have import content adjustment costs that can 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, 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.

FIGURE 7. 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 required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

These results suggest 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 temporary decline in foreign demand. The reason for such an adverse outcome is that the credit gap is countercyclical in this case. Policy rules based on the credit gap therefore 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.

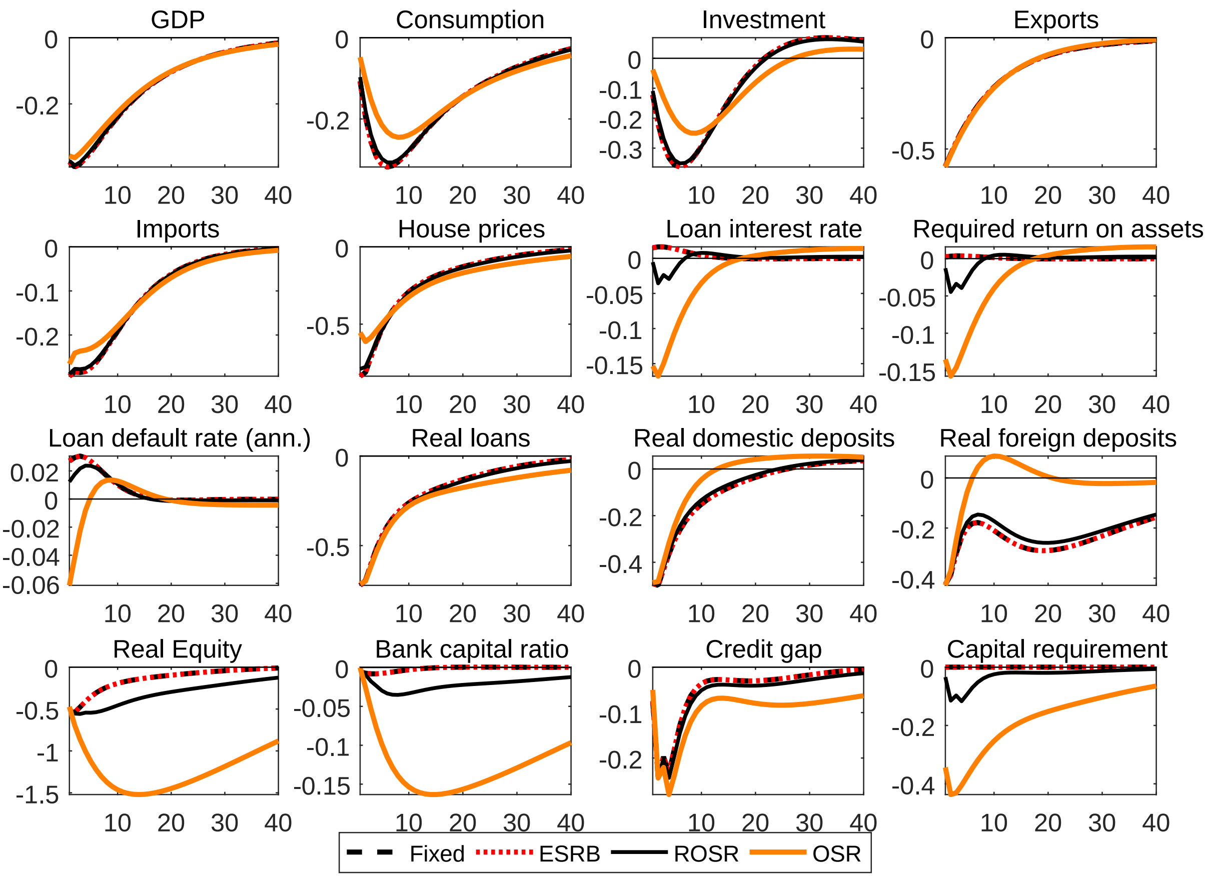
5.5 Productivity shock

We model the productivity shock as a temporary decrease in the productivity in non-tradable goods and export sectors (Figure 8). Under the baseline with constant minimum capital, the decrease in productivity immediately decreases output. Because households are now poorer, they demand less housing and deleverage by reducing borrowing. House prices drop initially by more than loans, which leads to a temporary increase in the default rate and a small increase in the lending rate.[30]. Foreign debt drops on impact due to the reduction in demand for imports, which is a consequence of the drop in domestic consumption and investment, but also due to the drop of exports, which contain a substantial fraction of imports.

The ESRB rule again performs exactly the same as the constant minimum capital requirement because the credit gap drops and the rule does not allow reductions of minimum capital. The ROSR, in contrast, allows for an immediate reduction in minimum capital requirements, which moves banks away from the regulatory constraint and allows them to reduce the required return on assets and thus the lending rate. However, because the credit gap closes relatively quickly, this provides only a limited dampening of consumption and the business cycle. The OSR performs somewhat better in terms of the reduction in the lending rate, because the decrease in real house prices is more persistent than the reduction in the credit gap. Because the reduction in minimum capital requirements under the OSR is more persistent, lending rates remain lower for longer. Households anticipate this and reduce consumption by less. In addition, lending decreases faster than house prices under the OSR, resulting in an initial decrease in the default rate, which further helps the initial reduction in lending rates.

[30]In this case, the financial friction between the bank and the household amplifies the effect of the shock, unlike in Christiano et al. (2014).

FIGURE 8. Decrease in non-tradable and export goods productivity



Notes: Impulse responses to a decrease in productivity for non-tradable goods and for export goods. All variables are in percentage deviations from the steady state, except interest rates, default rate, and required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

6 Conclusion

We investigate the performance of several countercyclical capital buffer rules based on the credit gap and the real house prices as indicator variables, conditional on a set of structural shocks that are typically considered important for small open economies. To do so, we use an estimated medium-scale DSGE model of the Irish economy. We take as benchmark the case where the minimum capital requirement is fixed at 8%. Against this benchmark we compare the performance of CCyB rules where the regulatory capital ratio is positively linked to the credit gap, including the rule recommended by the ESRB, as well as a simpler and more reactive linear policy rule, optimised to give the best performance in terms of welfare (restricted optimal simple rule). Moreover, we consider specifications where the CCyB rule is based on both the credit gap and real house prices. If such a rule is optimised, it is positively linked to real house prices only (optimal simple rule).

Our main finding is that the CCyB rules based on the credit gap are able to dampen the fluctuations of the economy to housing demand shocks as well boom and bust cycles driven by expectations. The reason is that in such cases the credit gap is procyclical, implying that the regulatory capital is tightened when GDP increases. This limits the development of foreign debt overhang, and creates a bank capital cushion which can be released once the economy and borrowing contract. For shocks of realistic magnitudes, the ESRB rule does not act stabilising, because the credit gap threshold of 2 p.p. is never exceeded. In addition, it does not allow for a response to negative credit gap values, which limits the scope for stabilisation when the credit gap becomes negative.

Most importantly, CCyB rules based on the credit gap not only fail to attenuate the response of the economy to shocks that cause an acyclical credit gap response, but even amplify their negative effects when shocks trigger a 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: If the macroprudential authority responds aggressively to the credit gap, it worsens the export-induced downturn by effectively making borrowing more expensive. Overall, 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. In 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 considered.

Our results indicate that policymakers should take seriously the part of the ESRB Recommendation that allows them to consider a wider set of indicators, in particular house prices, when setting CCyB rates. They also suggest that the prominence given to the credit-gap-based rules and CCyB thresholds should be taken with caution.

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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 (2015)
Deposit adjustment speed*	0.2	0.2	Gerlach and Stuart (2015)
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 (2016)

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 I. 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 deposit utility*	5
ξ_D	Deposit adjustment cost*	2
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
$\theta_b + \omega$	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
κ_W/ξ_W	Wage markup coefficient/ Wage adjustment cost	0.005/ 2000
κ_N/ξ_N	Non-tradable sector markup coefficient/ price adjustment cost	2.3/ 4.3
κ_X/ξ_X	Tradable sector markup coefficient/ price adjustment cost	100/ 0.1000
ξ_I	Investment adjustment cost	9.5
χ	Habit formation	0.83
ω^{P_N}	Non-tradable price indexation	0
σ_μ	Sd. productivity shock	0.0026
σ_H	Sd. housing demand shock	0.0073
σ_X	Sd. export demand	0.0057
σ_R	Sd. monetary policy shock	0.00013
ρ_A	AR(1) productivity shock	0.89
ρ_H	AR(1) housing demand shock	0.99
ρ_X	AR(1) export demand	0.989
ρ_{R_W}	AR(1) risk premium shock	0.99

Note: We imposed an upper bound on the AR(1) coefficients of 0.99 and a lower bound on the price markup coefficients of 0.005. The markup coefficient of a sector i κ_i is the coefficient on the percentage deviation of the markup from its steady state obtained after linearising the respective price (or wage) setting equation. The relationship between κ_i and sector i's price (or wage) adjustment cost ξ_i is given by $\xi_i = 1/(\kappa_i * (\mu_i - 1))$, where μ_i denotes the steady state markup in sector i.

Table 4. Matrix of sign restrictions

Shock in VAR (model)	Real NFC loans	GDP	GDP defl.	Real P_H	EX	EONIA
Supply (productivity)		+	-	+		0
Housing d. (prefer.)		+	+	+	-	0
Export d. (XD)		+	+		+	0
Monetary policy (R)		+	+			+

Note: In the estimation, the sign restriction is always applied to the fourth element of the IRF of the respective variable to the respective shock. An exception is the response of the EONIA, where restriction applies on impact.

TABLE 5. Optimal simple rule

	No CCyB	OSR	Comp. WGOSR (p.p.)	ROSR	Comp. WGROSR (p.p.)
ψ_L	0.00	0.00		0.48	
ψ_H	0.00	1.10		0.00	
WG (%)	0.00	0.23		0.00	
Means					
Consumption	0.01	0.05	0.03	0.01	-0.01
Labour	0.12	0.07	0.22	0.12	0.01
Domestic deposits	0.16	0.05	-0.13	0.14	-0.01
Variances					
Consumption	9.7	7.9	0.02	9.3	0.00
Labour	1.8	1.2	0.03	1.9	0.00
Domestic deposits	3.1	1.2	0.05	2.8	0.01
Wage inflation (APR)	0.3	0.2		0.3	

Notes: The table displays the results of the gridsearch for the optimal simple rule (OSR), with grid $\psi_L, \psi_{P_H} \in [0\ 2]$, and for a restricted optimal simple rule (ROSR), with grid $\psi_L \in [0\ 2]$ and $\psi_{P_H} = 0$, stepsize 0.02. We restrict attention to policies for which the probability of hitting the zero lower bound is less than 5%, i.e. for which $\sqrt{(}Var(g_t) * \Phi_{0.95} < E_t g_t$, where $\Phi_{0.95}$ denotes the 95 percentile of the standard normal distribution. The reported moments are theoretical moments calculated for the percentage deviation of the respective variable from its non-stochastic steady-state. Wage inflation is expressed as an APR. Variances are computed from the first order approximation to the model's solution. The means are based on the second order approximation to the models solution using first-order-accurate variances. The Welfare gain and its components are expressed as a percentage of consumption in the absence of the CCyB. For the variables entering the the household utility function, columns Comp. WGOSR and Comp. WGROSR display the percentage point contribution of the change in each first and second moment to the overall welfare gain associated with the OSR and the ROSR for the CCyB, respectively.

TABLE 6. Second Moments

	$\frac{\Sigma_{X_t}}{\Sigma_{GDP_t}}$			$Cor(GDP_t, X_t)$			$Cor(X_t, X_{t-1})$		
Variable	**Data**	**Model**	**Model no D_t**	**Data**	**Model**	**Model no D_t**	**Data**	**Model**	**Model no D_t**
Domestic Demand	1.0	1.0	1.0	1.0	1.0	1.0	0.79	0.99	0.99
Consumption	0.8	1.3	1.2	0.9	1.0	1.0	0.82	0.99	0.99
Non-tradable sector investment	3.3	1.6	1.7	0.8	0.9	0.9	0.87	0.99	0.98
Exports	1.2	0.3	0.3	0.4	0.6	0.6	0.65	0.91	0.91
Imports	5.2	0.7	0.7	0.2	1.0	1.0	0.94	0.98	0.98
Nominal wage growth	1.0	0.2	0.2	0.3	0.3	0.4	0.07	0.85	0.83
Inflation, DD deflator	0.8	0.5	0.5	0.2	0.0	0.0	0.14	0.36	0.45
Real house price	1.4	2.0	1.8	0.8	0.6	0.6	0.89	0.95	0.93
Real loans	1.4	1.6	1.4	0.5	0.4	0.2	0.96	1.00	1.00
$R_{L,t} - R_{w,t}$	0.2	0.1	0.2	-0.5	-0.4	-0.6	0.76	0.80	0.83
$R_{L,t} - R_{w,t}$, SME	0.1	0.1	0.2	-0.2	-0.4	-0.6	0.70	0.80	0.83

Notes: Σ_{X_t} and $Cor(...)$ denote the standard deviation of a variable and the correlation coefficient of the variables in brackets, respectively. The data was HP-filtered ($\lambda = 1600$), and, with the exception of interest and growth rates, logged. "DD deflator" denotes the deflator of modified domestic demand. We proxy non-tradable sector investment as residential investment. We proxy nominal wages as compensation of employees per employee. We report two proxies for $R_{L,t} - R_{w,t}$. The first is based on the mortgage interest rate, the second on the interest rate on loans to non-financial firms with a volume of one million Euro or less. The sample period is 1999Q1-2010Q3 since the interest rate data we use is not available after 2010Q3. The empirical moments are based on HP filtered data ($\lambda = 1600$). We report theoretical model moments based on the first order approximation to the solution of the model. The results in the columns labelled "Model" are based on the parameterisation reported in Tables 2 and 3, while column "Model no D_t" refers to a model where domestic deposit are constant ($\xi_D = 1000$).

We do not apply the HP filter to the model. First, the model variables are stationary and thus no trend needs to be removed before computing second moments. Furthermore, filtering the model results with the HP filter ($\lambda = 1600$) creates a spurious negative correlation between real loans and domestic demand, which may be due to the way the filter treats the response of domestic demand and loans to the export demand shock. As can be obtained from Figure 2, real loans initially decline following an expansionary export demand shock, but increase above their steady state value later, while domestic demand peaks much earlier and then slowly returns to its steady state. To the extend the HP-filter attempts to fit the trend to the later increase in loans, it enhances the negative deviation of loans from trend in the initial quarters after the shock. For domestic demand, HP-filtering tends to lower the domestic demand response in later quarters. Both of these mechanisms tend to lower the correlation of real loans and domestic demand.

B Second moments

Table 6 displays second moments of a number of important variables from the model and their closest counterparts in the data. The model performs well at matching the cyclicality of the variables as measured by their correlations with GDP, and in particular the cyclicality of house prices, real loans and $R_{L,t} - R_{w,t}$. The model also matches the relative volatility of loans, house prices and $R_{L,t} - R_{w,t}$. The model performs somewhat less well at matching the relative volatility of the remaining variables, though the deviations between the model and the data are mostly limited.

Table 6 also shows that variation in domestic deposits helps replicating the procyclicality of non-financial sector credit, by reporting results for a version of the model where household deposits remain constant over the business cycle (columns labelled ""Model no D_t"). In this version of the model, movements in non-financial sector credit are driven purely by the the difference between borrower spending and income. As a result, credit becomes less procyclical because borrowing increases less in response to expansionary housing demand and monetary policy shocks, and declines more persistently in response to a favourable export demand shock.

C Wage setting

Wage and price adjustment costs are specified in terms of deviations from past growth rate of prices and wages.[31] We allow for a degree of indexation, implying that only part of the deviation from previous-period price or wage inflation is subject to adjustment costs. For wages we have $\Pi^W_{t-1} = \left(\pi^W_{t-1}\right)^{\omega_W} (\pi)^{1-\omega_W}$, 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 $N\left(W_{i,t}\right) = (W_{i,t}/W_t)^{-e^W} N_t$, and wage adjustment costs $\Omega_{W,t} \equiv \xi_W/2(\log(W_{i,t}/W_{i,t-1} * 1/\Pi^W_{t-1}))^2$. The objective is given by

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

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

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

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

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

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

D 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.

D.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, $Y_{N,t+j} = A_{N,t+j}K_{N,t+j-1}^{1-\gamma_N}N_{N,t+j}^{\gamma_N}$, and faces quadratic price adjustment costs. Its objective is:

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

where $\Omega_{P_N,t} \equiv \xi_N/2(\log(P_{N,i,t+j}/P_{N,i,t+j-1} * 1/\Pi_{N,t}))^2$ are price-adjustment costs. Π_t^N denotes the price indexation scheme. As for wages, adjustment costs permit costless partial indexation. Each intermediate goods firm is a monopolistic supplier of its own product variety and takes a downward-sloping demand curve as a constraint:

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

Each firm chooses prices, capital, and labour. 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 $P_{N,i,t}/P_{N,i,t-1} = P_{N,t}/P_{N,t-1} \equiv \pi_t^N$:

$$\frac{\xi_N}{e^N - 1}\log\left(\frac{\pi_t^N}{\Pi_t^N}\right) = \beta\frac{\Lambda_{t+1}}{\Lambda_t}\pi_{t+1}^N\frac{Y_{N,t+1}}{Y_{N,t}}\left[\frac{\xi_N}{e^N - 1}\log\left(\frac{\pi_{t+1}^N}{\Pi_{t+1}^N}\right)\right] + \\ + \frac{MC_{N,t}}{P_{N,t}}\frac{e^N}{e^N - 1} - [1 - \Omega_{P_N,t}] \tag{39}$$

The optimality conditions w.r.t. capital and labour are given by $(1 - \gamma_N) MC_{N,t}Y_{N,t} = R_{K,t}K_{t-1}$ and $\gamma_N MC_{N,t}Y_{N,t} = W_tN_{N,t}$, respectively.

D.2 Importers

Importers buy goods at the (exogenous) world price $P^*_{M,t}$, which, converted into domestic units through the exchange rate S_t, is their marginal cost, $MC_{M,t} = S_tP^*_{M,t}$. They use this good to transform it into varieties of a CES basket, facing demand curve $M_{i,t+j} = (P_{M,i,t+j}/P_{M,t+j})^{-e^M} M_{t+j}$ and price adjustment costs $\Omega_{M,t} \equiv \xi_M/2(\log(P_{M,i,t+j}/P_{M,i,t+j-1} * 1/\Pi_{N,t}))^2$. They maximise:

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

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

$$\frac{\xi_M}{e^M - 1} \log\left(\frac{\pi_t^M}{\Pi_t^M}\right) - \frac{MC_{M,t}}{P_{M,t}} \frac{e^M}{e^M - 1} + [1 - \Omega_{M,t}] = $$

$$= \beta \frac{\Lambda_{t+1}}{\Lambda_t} \pi_{t+1}^M \frac{M_{t+1}}{M_t} \left[\frac{\xi_M}{e^M - 1} \log\left(\frac{\pi_{t+1}^M}{\Pi_{t+1}^M}\right)\right]. \quad (40)$$

D.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 $X_t = \min\{Z_t/(1-\alpha), X_{M,t}/\alpha\}$, where $Z_t = A_{X,t}\overline{K}_{X,t-1}^{1-\gamma_X} N_{X,t}^{\gamma_X}$, 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 $P_{XI,t+j}$. They maximise:

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

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

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

$$= \beta \frac{\Lambda_{t+1}}{\Lambda_t} \pi_{XI,t+1} \frac{X_{t+1}}{X_t} \xi_X \log\left(\frac{X_{t+1}}{X_t}\right), \quad (41)$$

$$MC_{X,t} = \alpha P_{M,t} + MC_{Z,t} (1 - \alpha), \quad (42)$$

and $\pi_{XI,t+1} \equiv \frac{P_{XI,t+1}}{P_{XI,t}}$. The FOC w.r.t. labor is given by $\gamma_X MC_{Z,t} = W_t N_{X,t}$, and because of Leontief technology, the shares of domestic production in exports and the import-content of exports are $Z_t = (1-\alpha)X_t$ and $X_{M,t} = \alpha X_t$, respectively.

D.4 Final goods firms

Final goods firms combine intermediate and imported goods to create final goods used for consumption and investment, using a constant-elasticity-of-substitution (CES) technology:

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

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

$$C_{M,t} = \omega_C \left(\frac{P_{M,t}}{P_t} \right)^{-\mu_C} C_t \;\; and \;\; C_{N,t} = (1-\omega_C) \left(\frac{P_{N,t}}{P_t} \right)^{-\mu_C} C_t \tag{43}$$

where ω_C is the bias towards imported consumption goods, μ_C is 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 $P_t = (\omega_C P_{M,t}^{1-\mu_C} + (1-\omega_C) P_{N,t}^{1-\mu_C})^{(1/(1-\mu_C))}$. The equations for investment goods are analogous.

D.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 $X_{i,t+j} = (P_{X,i,t+j}/P_{X,t+j})^{-e^X} X_{t+j}$ and the price setting is determined as

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

$$= \beta \frac{\Lambda_{t+1}}{\Lambda_t} \pi_{t+1}^X \frac{X_{t+1}}{X_t} \frac{\xi_X}{e^X - 1} \log\left(\frac{\pi_{t+1}^X}{\Pi_{t+1}^X}\right) + \frac{P_{XI,t}}{P_{X,t}} \frac{e^N}{e^N - 1} - \left[1 - \frac{\xi_X}{2}\left(\log\left(\frac{\pi_t^X}{\Pi_t^X}\right)\right)^2\right] \quad (44)$$

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

$$X_t = X_{D,t} \left(\frac{P_{x,t}/S_t}{P_{W,t}T_t}\right)^{-e^{X,W}}, \quad (45)$$

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 in the rest of the Euro area declines when Euro area interest rates increase and reduce demand abroad. We therefore assume that $log(X_{D,t}) = (1 - \rho_{XD})log(\overline{X}) + \rho_{XD}log(X_{D,t-1}) - XD_{RW}(R_{W,t} - \overline{R})$, where ρ_{XD} is persistence of foreign export demand, XD_{RW} is the sensitivity of this demand to interest rates, $R_{W,t}$ is exogenous, and bars over variables denote steady-state values.

E Net foreign asset position

The domestic interest rate is linked to the Euro Area one via $R_t = e_t R_{W,t} * S_{t+1}/S_t$ and $e_t = \theta_B(B_t/Y_t - \zeta)$, where θ_B determines how the sensitivity of the interest rate on domestic debt depends 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

$$B_t = R_{t-1}B_{t-1} - TB_t + \theta_\Pi \left((P_{X,t} - \alpha P_{M,t})X_t - W_t N_{X,t}\right), \quad (46)$$

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

$$TB_t = P_{X,t}X_t - P_{M,t}M_t, \tag{47}$$

F Policy authorities

The exchange rate is fixed ($S_t \equiv 1$), and government spending is funded by lump sum taxes on optimising households ($P_{N,t}G_t = \Theta_t$).

G Market clearing conditions

$$P_tC_t = P_{N,t}C_{N,t} + P_{M,t}C_{M,t} \tag{48}$$

$$P_tI_t = P_{N,t}I_{N,t} + P_{M,t}I_{M,t} \tag{49}$$

$$Y_{N,t} = C_{N,t} + I_{N,t} + G_t \tag{50}$$

$$M_t = C_{M,t} + I_{M,t} + X_{M,t} \tag{51}$$

$$N_t = N_{N,t} + N_{X,t} \tag{52}$$

$$K_t = K_{N,t} + \overline{K}_{X,t} \tag{53}$$

$$Y_t = P_tC_t + P_{I,t}I_t + P_{N,t}G_t + P_{X,t}X_t - P_{M,t}M_t \tag{54}$$

H Welfare associated with different policy rules

To express the welfare effects of different CCyB rules as a percentage of consumption in the absence of the CCyB, we first write down welfare under the assumption that households receive a quarterly transfer $\tau_C \geq 0$ with certainty. This yields the following expression for the quarterly welfare flow $V_{f,t}$:

$$V_{f,t} = \frac{ln\left(\left(1+\tau_C\right)C_{r,t} - \chi\left(1+\tau_C\right)C_{r,t-1}\right)}{\left(1-\chi\right)^{-1}} - \frac{\phi_N N_{r,t}^{1+\eta}}{1+\eta} + \varepsilon_{H,t}\zeta_H ln\left(H_{r,t}\right) + \frac{\zeta_D}{1-\iota}\left(\frac{D_{S,r,t}}{P_{r,t}}\right)^{1-\iota}$$

We now take a a second order approximation around the non-stochastic steady state and $\tau_C = 0$ to this equation. The derivatives are given by

$$\begin{aligned}
\frac{dV_{f,t}}{dC_t} &= \frac{1}{(C_{r,t} - \chi C_{r,t-1})(1-\chi)^{-1}} = \frac{1}{C} \\
\frac{dV_{f,t}}{dC_{t-1}} &= \frac{-\chi}{(C_{r,t} - \chi C_{r,t-1})(1-\chi)^{-1}} = \frac{-\chi}{C} \\
\frac{d^2V_{f,t}}{(dC_t)^2} &= -\frac{1}{(C_{r,t} - \chi C_{r,t-1})^2 (1-\chi)^{-1}} = -\frac{1}{C^2(1-\chi)} \\
\frac{d^2V_{f,t}}{(dC_{t-1})^2} &= \frac{-\chi}{(C_{r,t} - \chi C_{r,t-1})^{-2} (1-\chi)^{-1}} = \frac{-\chi}{C^2(1-\chi)} \\
\frac{d^2V_{f,t}}{dC_t dC_{t-1}} &= \frac{\chi}{(C_{r,t} - \chi C_{r,t-1})^2 (1-\chi)^{-1}} = \frac{\chi}{C^2(1-\chi)} \\
\frac{dV_{f,t}}{d\tau_C} &= \frac{1}{(1+\tau_C)(1-\chi)^{-1}} = \frac{1-\chi}{(1+\tau_C)} \\
\frac{dV_{r,t}^2}{(d\tau_C)^2} &= -\frac{1-\chi}{(1+\tau_C)^2} = -(1-\chi) \\
\frac{dV_{f,t}}{dN_t U_{h,0}} &= -\phi_N N_{r,t}^{\eta} = -\phi_N N_r^{\eta} \\
\frac{d^2V_{f,t}}{(dN_t)^2} &= -\phi_N \eta N_{r,t}^{\eta-1} = -\phi_N \eta N_r^{\eta-1} \\
\frac{dV_{f,t}}{d\left(\frac{D_{S,t}}{P_t}\right)} &= \zeta_D \left(\frac{D_{S,t}}{P_t}\right)^{-\iota} = \zeta_D \left(\frac{D_S}{P}\right)^{-\iota} \\
\frac{d^2V_{f,t}}{\left(d\left(\frac{D_{S,t}}{P_t}\right)\right)^2} &= -\iota\zeta_D \left(\frac{D_{S,r}}{P_r}\right)^{-\iota-1}
\end{aligned}$$

where we evaluate the derivatives at the non-stochastic steady state and $\tau_C = 0$. The second order Taylor approximation to the deviation of $V_{f,t}$ from its non-stochastic steady state is then

$$\begin{aligned}
dV_{f,t} = {} & (1-\chi)\left[\tau_C - \tau_C^2\right] + \frac{dC_t - \chi dC_{r,t-1}}{C} - \frac{(dC_t)^2 + \chi (dC_{t-1})^2}{2C^2(1-\chi)} \\
& + \frac{2\chi dC_t dC_{t-1}}{2C^2(1-\chi)} - \phi_N N^{\eta} dN_t - \frac{\phi_N}{2}\eta N^{\eta-1} (dN_{r,t})^2 \\
& + \zeta_D \left(\frac{D_{S,r}}{P_r}\right)^{-\iota} d\left(\frac{D_{S,r,t}}{P_{r,t}}\right) - \frac{\iota\zeta_D}{2}\left(\frac{D_S}{P_r}\right)^{-\iota-1}\left(d\left(\frac{D_{S,t}}{P_t}\right)\right)^2
\end{aligned}$$

$$dV_{f,t} = (1-\chi)\left[\tau_C - \tau_C^2\right] + \hat{C}_t - \chi\hat{C}_{t-1} - \frac{\left[\hat{C}_t^2 + \chi\hat{C}_{t-1}^2 - \chi 2\hat{C}_t\hat{C}_{t-1}\right]}{2(1-\chi)} - \phi_N N^{\eta+1}\hat{N}_t$$
$$-\frac{\phi_N \eta}{2}N^{\eta+1}\left(\hat{N}_t\right)^2 + \zeta_D\left(\frac{D_S}{P}\right)^{1-\iota}\widehat{\frac{D_{S,t}}{P_t}} - \iota\frac{\zeta_D}{2}\left(\frac{D_S}{P}\right)^{1-\iota}\widehat{\frac{D_{S,r,t}}{P_{r,t}}}^2$$

The unconditional expectation of the second order approximation to V_0 is

$$\begin{aligned} dV_0 &= E_0\left\{\sum_{t=0}^{\infty}\beta^t\hat{V}_{f,t}\right\} = \\ &= \frac{(1-\chi)\tau_C}{1-\beta} + \frac{(1-\chi)E_0\hat{C}_t - \left[\frac{(1+\chi)E_0\left\{\hat{C}_t^2\right\} - 2\chi E_0\left\{\hat{C}_t\hat{C}_{t-1}\right\}}{2(1-\chi)}\right]}{1-\beta} \\ &\quad + \frac{-\phi_N N^{\eta+1}\left[E_0\left\{\hat{N}_t\right\} + \frac{\eta}{2}E_0\left\{\hat{N}_t^2\right\}\right]}{1-\beta} \\ &\quad + \frac{\zeta_D\left(\frac{D_{S,r}}{P_r}\right)^{1-\iota}}{1-\beta}\left[E_0\left\{\widehat{\frac{D_{S,t}}{P_t}}\right\} - \frac{\iota}{2}E_0\left\{\widehat{\frac{D_{S,t}}{P_t}}^2\right\}\right] \end{aligned}$$

where we use the fact that $E_t\left\{\tau_C^2\right\} = 0$ since τ_C is known with certainty. Note that the $E_t\left\{(..)^2\right\}$ terms may be approximated using a first order approximation to the model's solution (e.g. Lombardo and Sutherland (2007)). Since under the first order approximation $E_0\hat{X}_t = 0$, the $E_t\left\{(..)^2\right\}$ are simply the variances of the respective variables calculated using the first-order accurate solution of the model (the autocovariance in case of $E_t\left\{\hat{C}_t\hat{C}_{t-1}\right\}$).

Assuming that a given policy a leads to (second order accurate) welfare level of $\hat{V}_{a,o}$, and that welfare in the absence of this policy equals dV_o, the quarterly transfer τ_C we need to make households as well off in the absence of policy as in its presence is determined by

$$dV_{a,0} = \frac{\tau_C(1-\chi)}{1-\beta} + dV_0 \quad or \quad \tau_C = \frac{(1-\beta)}{(1-\chi)}\left(dV_{a,0} - dV_0\right).$$

τ_C may be decomposed into the contributions of changes in the unconditional expectation of each variable and the variance terms as follows:

$$CON_{E_0\hat{C}_t} = E_0\hat{C}_{a,t} - E_0\hat{C}_t \tag{55}$$

$$CON_{E_0\{\hat{C}_t^2\}} = -\left[\frac{(1+\chi)\left[E_0\left\{\hat{C}_{a,t}^2\right\} - E_0\left\{\hat{C}_t^2\right\}\right] - 2\chi\left[E_0\left\{\hat{C_{a,t}}\hat{C}_{a,t-1}\right\} - E_0\left\{\hat{C}_t\hat{C}_{t-1}\right\}\right]}{2(1-\chi)^2}\right] \tag{56}$$

$$CON_{E_0\hat{N}_t} = -\frac{\phi_N N^{\eta+1}}{1-\chi}\left[E_0\left\{\hat{N}_{a,t}\right\} - E_0\left\{\hat{N}_t\right\}\right] \tag{57}$$

$$CON_{E_0\{\hat{N}_t^2\}} = -\frac{\phi_N N^{\eta+1}}{(1-\chi)}\frac{\eta}{2}\left[E_0\left\{\hat{N}_{a,t}^2\right\} - E_0\left\{\hat{N}_t^2\right\}\right] \tag{58}$$

$$CON_{E_0\left\{\widehat{\frac{D_{S,t}}{P_t}}\right\}} = \frac{\zeta_D\left(\frac{D_{S,r}}{P_r}\right)^{1-\iota}}{1-\chi}\left[E_0\left\{\widehat{\frac{D_{S,a,t}}{P_t}}\right\} - E_0\left\{\widehat{\frac{D_{S,t}}{P_t}}\right\}\right] \tag{59}$$

$$CON_{E_0\left\{\widehat{\frac{D_{S,t}}{P_t}}^2\right\}} = -\frac{\iota\zeta_D\left(\frac{D_{S,r}}{P_r}\right)^{1-\iota}}{2(1-\chi)}\left[E_0\left\{\widehat{\frac{D_{S,a,t}}{P_{a,t}}}^2\right\} - E_0\left\{\widehat{\frac{D_{S,t}}{P_t}}^2\right\}\right] \tag{60}$$

I Empirical target values for calibration

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

- **Imports:** Import content of private consumption, private investment and exports to calibrate ω_C, ω_I and α are from the CSO input output tables.
- **Flow shares (averages over the 2001-2014 period):**
  - Private investment I = private + gov. gross physical capital form. (GGPCF).
  - Government expenditure G = Gov. consumption (= final consumption expenditure of gov. + net expenditure by central and local gov. on current goods and services) + GGPCF.
  - Compensation of employees $W * N$ = wages and salaries + Employers contribution to social insurance.
- **Housing stock value and non-financial-sector loan to GDP ratios:**
  - L=Total notional non-financial private sector loans to Irish counterparts, see McElligott et al. (2011).
  - $P_H * H$: Internal CBI series.
- **Bank funding shares B/L and E/L:**

- 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)

All data for bank funding shares is taken from Tables A.4.1 – Assets and A.4.1 – Liabilities. The data is monthly. 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 (2016), 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%.

Domestic deposit demand long term interest elasticity and speed of adjustment Gerlach and Stuart (2015) 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 deposits $\epsilon_{D,R}$ to1.5. Their estimated speed of adjustment equals 0.2 (see their Table 5), which we denote as $Speed_A$. Linearising equation 19 yields

$$(\hat{D}_t - \hat{D}_{t-1}) = \frac{\iota(1-\beta R)}{\xi_D}(\frac{1-\iota}{\iota}\hat{P}_t + \frac{-\hat{\lambda}_t + \beta R(\hat{R}_t + \hat{\lambda}_{t+1})}{\iota(1-\beta R)} - \hat{D}_t), \tag{61}$$

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 determine $\iota = \frac{\beta R}{4\epsilon_{D,R}(1-\beta R)}$ and $\xi_D = \frac{4\iota(1-\beta R)}{Speed_A}$.

J Quarterly data used for VAR estimation and second moments

Where available, we have used seasonally adjusted data, and otherwise adjusted it ourselves.

- **Output**: As a proxy for real GDP we use real GNI*, which is defined as GNI less the effects of the profits of re-domiciled companies and the depreciation of intellectual property products and aircraft leasing companies. Source: CSO.
- **Price level**: The GNI* deflator.
- **Real loans to the non-financial sector**: Total notional non-financial private sector loans to Irish counterparts, quarterly data, deflated with the GNI* deflator. See McElligott et al. (2011).
- **Real house price**: Internal Central Bank of Ireland series, deflated with the GNI* deflator.
- **EONIA**: Quarterly averages of montly data. Source: Deutsche Bundesbank.
- **Consumption**: Real consumption expenditure of Households and non-profit organizations serving households. Source: Eurostat.

- **Imports**: Real imports. Source: Eurostat.
- **Nominal wage growth**: Growth rate of compensation of employees per employee. Source: Eurostat.
- $R_{L,t} - R_{w,t}$:
  - Spread between the interest rate on loans to non-financial firms with a volume of one million or less and the EONIA. Source: Internal CBI series.
  - Spread between the household mortgage interest rate and the EONIA. Source: Internal CBI series.

K Addition of transaction deposits

Some of the models for the analysis of macroprudential policies include deposits that are held for transaction purposes (see, for instance, Beneš et al. (2014), Jakab and Kumhof (2015) or Clancy and Merola (2017)). This appendix shows how the inclusion of such deposits alters the model in this paper and its optimality conditions. The key point is that the inclusion of transaction deposits does not materially alter our results.

When there are transaction deposits, banks supply deposits for transaction purposes (in addition to buffer stock deposits) and households hold additional deposits for transaction purposes $D_{T,j,t}$. As in Beneš et al. (2014), we assume that there is a cash-in-advance constraint associated with consumption, investment and housing related transactions:

$$D_{T,j,t} = \gamma_C \left(P_t C_{j,t} + P_{I,t} I_t \right) + \gamma_H P_{H,t} H_{j,t}, \tag{62}$$

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 consist of transaction deposits and saving deposits:

$$D_{j,t} = D_{T,j,t} + D_{S,j,t}. \tag{63}$$

When the household is subject to the deposits-in-advance constraint, there is an additional optimality condition due to the choice of transaction-related deposits, and there are modifications to other optimality conditions related to the additional constraint (equation62). We denote the Lagrange multiplier associated with transaction deposits as $\Lambda_{T,t}$ and list the modified optimality conditions of the household below:

$$\Lambda_t P_t \left(1 + \gamma_C \frac{\Lambda_{T,t}}{\Lambda_t}\right) = (1-\chi)^{\sigma} \left(C_t - \chi C_{t-1}\right)^{-\sigma}, \tag{64}$$

$$\frac{\Lambda_{T,t}}{\Lambda_t} = 1 - \beta \frac{\Lambda_{t+1}}{\Lambda_t} R_t, \tag{65}$$

$$P_{H,t}\left(1 + \gamma_H \frac{\Lambda_{T,t}}{\Lambda_t}\right) = \varepsilon_{H,t}\zeta_H \frac{H_{j,t}^{-\nu}}{\Lambda_t} + \beta \frac{\Lambda_{t+1}}{\Lambda_t} P_{H,t+1} + \frac{\Lambda_{R_L,t}}{\Lambda_t} \lambda \frac{\phi(\overline{\omega_{h,t+1}})}{\sigma_h H_{j,t}}, \tag{66}$$

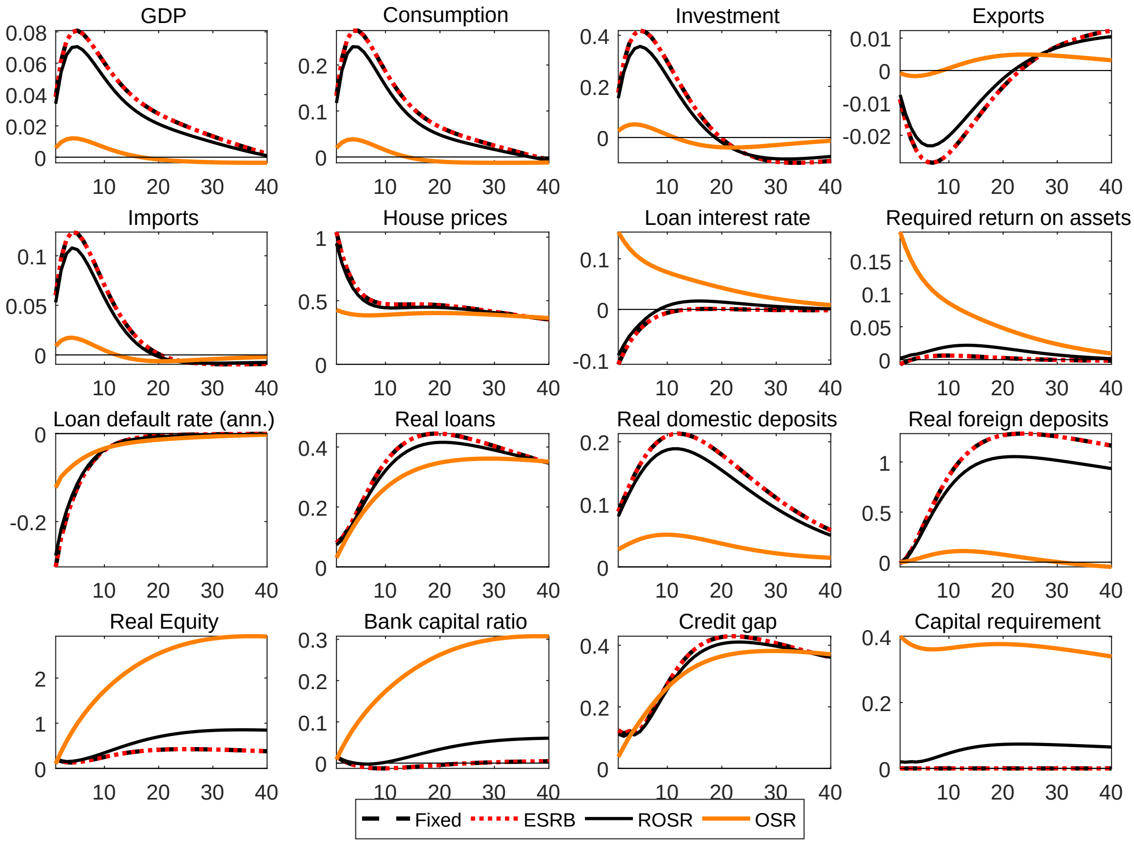
$$P_{I,t}\left(1 + \gamma_C \frac{\Lambda_{T,t}}{\Lambda_t}\right) = P_{K,t}\left[1 - \frac{\xi_I}{2}\Omega_{I,t} - \xi_I \Omega'_{I,t}\right] + \beta \frac{\Lambda_{t+1}}{\Lambda_t} P_{K,t+1} \xi_I \Omega'_{I,t} \frac{I_{t+1}}{I_t}, \tag{67}$$

Note that equations 22, 19, 18 in the main text are not directly affected by the inclusion of transaction deposits, while the consumption Euler equation (17) is affected through the marginal utility of consumption, equation 64. Equation 65 corresponds to the first-order condition with respect to transaction deposits, and equations 66 and 67 show how the constraint on transactions drives a wedge, represented by Λ_T, γ_C, and γ_H, into otherwise standard first order conditions for consumption, investment, and housing (standard equations reported in the main text are obtained by setting $\gamma_C = \gamma_H = \Lambda_T = 0$ for all t).

Calibration of transaction deposits. We assume that consumption and investment purchases are made using deposits and therefore set $\gamma_C = 1$. For housing transactions 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 equalled 4.1% (Coates et al., 2016).

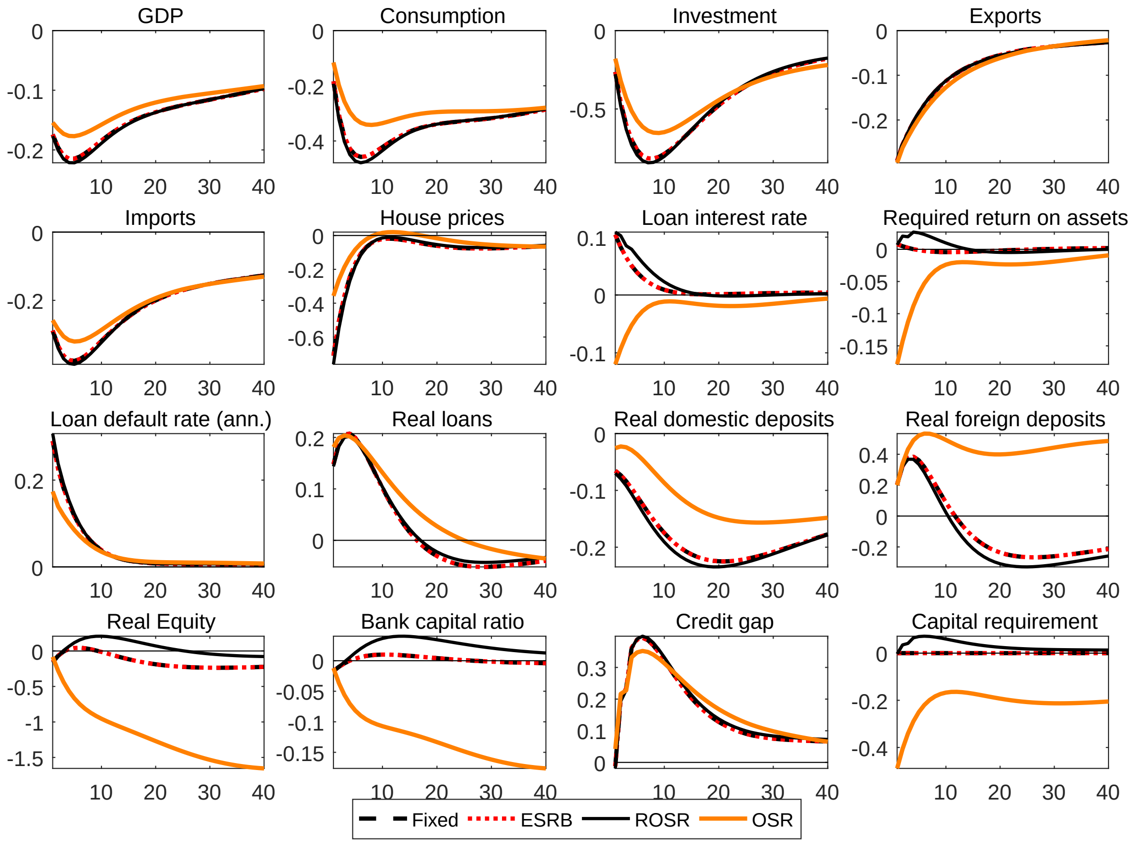
Responses to shocks with transaction deposits. The presence of transaction deposits alters somewhat the quantitative (but not qualitative) responses to shocks. The demand for transaction deposits follows the responses of consumption, investment, and housing (house prices), in line with the deposits-in-advance constraint, 62. For instance, after the housing demand shock, households' demand for deposits increases by more because both house prices and domestic demand increase, which requires more deposits for transaction purposes. Importantly, none of our results is materially affected by the inclusion of deposit-in-advance constraint and transaction deposits. This can clearly be seen in Figure 9, which shows the effects of a positive housing demand shock, and in Figure 10, which shows the effects of a negative export demand shock, in the model that includes transaction deposits.

Figure 9. Housing demand shock with transaction deposits



Notes: Impulse responses to a positive housing demand shock with transaction deposits. All variables are in percentage deviations from the steady state, except interest rates, default rate, and required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

Figure 10. Export demand shock with transaction deposits

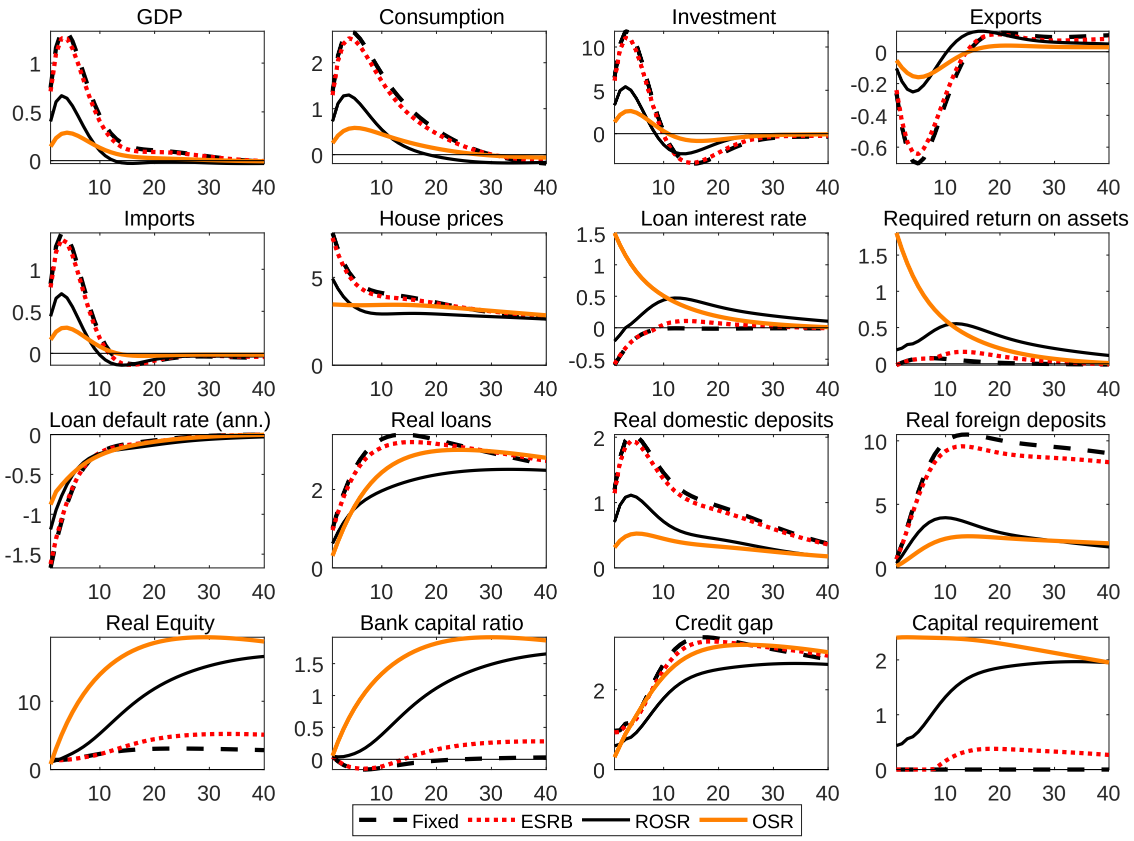


Notes: Impulse responses to a negative export demand shock with transaction deposits. All variables are in percentage deviations from the steady state, except interest rates, default rate, and required return on assets, which are in annualised percentage-point deviations, and the bank capital ratio, the credit gap, and the minimum capital requirement, which are in percentage-point deviations.

L Performance of the ESRB rule for a large shock

Here we briefly discuss the performance of the ESRB rule after a positive housing demand shock that is large enough to open the credit gap by more than 2 p.p. The only difference in Figure 11 compared to Figure 4 is that in the bottom-right panel, the ESRB rule leads to a mild increase in minimum capital requirements, and even this with a substantial delay. While this leads to an increase in the required return on bank assets and somewhat higher lending rates than under fixed minimum capital requirements, the increase is too small and to late to have a marked effect. This implies that the ESRB rule cannot help smoothing business cycle fluctuations even when shocks are so large that the credit gap opens sufficiently for the rule to kick in.

FIGURE 11. Large housing demand shock



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

M Steady state

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

Note first that

$$R_L = \frac{1}{\beta} \text{ from } (17)$$

Hence

$$\begin{aligned}
\widetilde{R} &= R_L (1 - \lambda J) \text{ from } (6) \\
\overline{\omega_b} &= \frac{R\left(\frac{1}{E/L} - 1\right)}{\left(\frac{(1-g)\tilde{R}}{E/L}\right)} \\
f(\overline{\omega_b}) &= \phi\left(log(\overline{\omega_b}) + \frac{1}{2}\sigma_b^2)\right) \\
R_E &= R + \frac{R_{L1} - R}{E/L} - \chi_b \frac{\Phi(\overline{\omega_b})}{E/L} \text{ from } (7) \\
J &= \frac{\left(1 - \frac{\widetilde{R}}{R_L}\right)}{\lambda} \text{ from } (14) \\
\frac{D}{Y} &= \frac{L}{Y}\left(1 - \frac{E}{L}\right) - \zeta \text{ from } (2) \\
\theta_b + \omega &= \frac{1}{R_E}
\end{aligned}$$

Recall that ϕ denotes the standard normal density function, which is equivalent to the derivative of Φ in our notation. Our calibration of the fraction of retained equity in the banking sector $\theta_b + \omega$, is necessary to ensure that bank equity is stationary in the long run.

M.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 price index definition, equations, 21, 22 and 39

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

This allows to rearrange non-tradable firm FOC w.r.t. capital to get

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

which allows to calculate

$$
\begin{aligned}
y_N &= A_N \left(k_N\right)^{1-\gamma_N} \text{ from (38)} \\
W &= \gamma_N MC_N A_N \left(k_N\right)^{1-\gamma_N} \text{ from non-tradable firm's FOC}
\end{aligned}
$$

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.

$$
\begin{aligned}
T &= 1 \text{ from calibration} \\
P_{X\_} &= P_M^* T \\
P_X &= S P_{X\_} \\
MC_X &= \frac{P_X}{\mu_X} \text{ from (44) and (41)}
\end{aligned}
$$

Then

$$MC_Z = \frac{(MC_X - \alpha P^W S)}{(1-\alpha)} \text{ from (42)}$$

This allows to compute

$$\begin{aligned}
k_X &= \frac{K_X}{N_X} = (W/(A_X \gamma_X MC_Z))^{\frac{1}{1-\gamma_X}} \text{ from tradable goods producers' labour FOC} \\
N_X &= \frac{K_X}{k_X} \\
Z &= A_X (K_X)^{1-\gamma_X} (N_X)^{\gamma_X} \text{ from tradable production function} \\
X &= \frac{Z}{1-\alpha} \text{ from tradable goods producers' optimality} \\
X_M &= \alpha X \text{ from tradable goods producers' optimality} \\
PTR &= \Theta_\Pi((P_X - \alpha P_M)X - WN_X),
\end{aligned}$$

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

$$B = \zeta Y$$

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

$$L = Y * L2GDP$$

$$TB = [(R-1)\zeta + J\lambda R_C * L2GDP](P_N Y_N + PTR) \text{ from } (46)$$

Furthermore, combining (47), the definition of imports and exporters' import share, it is possible to write

$$C_M + I_M = \frac{X(P_X - P_M^* S\alpha) - TB}{P_M^* S} \tag{68}$$

which can be written as

$$C_M + I_M = \frac{\begin{array}{c} X\left(P_X - P_M^* S\alpha - [(R-1)\zeta + J\lambda R_L * L2GDP](P_X - \alpha P_M)\right) - PTR \\ -[(R-1)\zeta + J\lambda R_C * L2GDP] P_N Y_N N_N \end{array}}{P_M^* S} \tag{69}$$

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 (43) and the equivalent for investment goods, (51), (11) , $k_N = \frac{K_N}{N_N}$ and $y_N = \frac{Y_N}{N_N}$ as

$$C_M + I_M = N_N \left[(Y_N - \delta(1-\omega_I) k_N) \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} + \omega_I \left(\frac{P_M}{P_I}\right)^{-\mu_I} \delta k_N \right] - \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N}\right)^{-\mu_C} G \tag{70}$$

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

$$G = \frac{(P_N Y_N + (P_X - \alpha P_M) X) * govsh}{P_N} \tag{71}$$

Hence we can write

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

Combining (69) and (71) and defining

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

allows to solve for N_N as

$$N_N = \frac{\frac{X\left(P_X - P^W S\alpha - [(R-1)\zeta + J\lambda R_C * L2GDP](P_X - \alpha P_M)\right) - PTR}{P_M^* S} + \frac{\omega_C}{1-\omega_C} \left(\frac{P_M}{P_N} \right)^{-\mu_C} \left[\frac{(P_X - \alpha P_M) X * govsh}{P^n} \right]}{Denominator} \tag{72}$$

Now the remaining real variables can be calculated easily:

$$
\begin{aligned}
N &= N_N + N_X \text{ using (53)} \\
K_N &= k_N N_N \\
Y_N &= y_N N_N \\
Y &= P_N Y_N + (P_X - \alpha P_M) X \\
G &= govsh * Y/P_N \\
K &= K_X + K_N \text{ using (54)} \\
I &= \delta K_N \text{ using (11)} \\
I_N &= (1-\omega_I)\left(\frac{P_N}{P_I}\right)^{-\mu_I} I \text{ (using the equivalent of (43) for investment)} \\
I_M &= \omega_I \left(\frac{P_M}{P_I}\right)^{-\mu_I} I \text{ (using the equivalent of (43) for investment)} \\
C_N &= Y_N - I_N - G \text{ using (51)} \\
C &= \frac{C_N}{(1-\omega_C)\left(\frac{P_N}{P}\right)^{-\mu_C}} \text{ using (43)} \\
C_M &= C\omega_C \left(\frac{P_M}{P}\right)^{-\mu_C} \text{ using (43)} \\
M &= X_M + C_M + I_M \text{ using (52)} \\
B &= \zeta Y \\
TB &= [(R-1)B + J\lambda R_C * L] \text{ using (46)} \\
\Theta &= G \text{ from government budget)} \\
L &= \left(\frac{L}{Y}\right) Y \\
\Lambda &= \frac{1}{PC^\sigma(1+(1-\beta R))} \text{ using (16)} \\
\Lambda_T &= \Lambda(1-\beta R).
\end{aligned}
$$

Using 37, we can back out ϕ_N as

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

M.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:

$$
\begin{aligned}
P_H &= \left(\overline{\frac{P_H H}{Y}}\right)\frac{Y}{H} \\
D_S &= \left(\overline{\frac{D}{Y}}\right) Y - D_T \\
D &= D_S \\
F &= P_H H \\
\overline{F} &= L R_L/\psi \text{ (using 12)}
\end{aligned}
$$

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:

$$
\begin{aligned}
\zeta_D &= \frac{(1-\beta R)}{D^{-\iota}\left(P\right)^{\iota-1}}\Lambda \text{ (using 19)} \\
\sigma_h &= \frac{\left(\log\left(\overline{F}-F\right)\right)}{\Phi^{-1}\left(\frac{J-\pi}{1-\pi}\right)} \text{ (using 14)}
\end{aligned}
$$

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:

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

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

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

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

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