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EIRE MOD

A DSGE Model for Ireland

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Non-Technical Summary

This paper describes the development of a core DSGE model for Ireland, ÉIRE Mod (Elementary Irish Real Economy Model). The model's theoretical foundation is the New Open Macroeconomics synthesis, with additional features added to account for Ireland's membership of European Monetary Union (EMU). The framework is a small open economy with two sectors, tradable and non-tradable. Agents in the economy are households, firms and retailers who import goods from abroad for sale on the domestic market. Monetary policy is exogenous and is determined at the euro area. New Keynesian features, such as sticky prices and wages, are included. This means the model dynamics can replicate the sluggish reaction of prices, wages and other economic variables found in the empirical literature. The model is calibrated in order to match key observed ratios in the Irish data.

To highlight the usefulness of the model for policy analysis, we examine the impact that various structural reforms could have on the Irish economy. The simulation of these shocks highlight the transmission channels through which such reforms would affect the economy. Structural reforms have been on the Irish policy agenda since the beginning of the decade, as the financial crisis exposed the loss of competitiveness suffered during the excesses of the housing boom. Successive policy documents, from Europe 2020 to the Financial Assistance Programme, the Programme for Government and the Medium-Term Economic Strategy (MTES) all call for the introduction of structural reforms to boost the sustainable growth potential of the Irish economy. These documents emphasise that a series of measures designed to reform the Irish labour and product markets could deliver medium-term growth through productivity gains.

Our results show that although all the reforms boost aggregate output, they might have opposing implications for Ireland's employment and external competitiveness.

Given that the Medium-Term Economic Strategy 2014-2020 (MTES) commits to a strategy of export-led growth and full employment, the reforms implemented under this programme need to be carefully assessed in order to ensure that they do not lead to counter-productive effects for employment and the export sector.

However, our results must be interpreted with caution. The model does not feature either liquidity constraints or labour market frictions and hence might fail to capture some key aspects in the adjustment path of the economy following the implementation of these reforms. This work should be viewed as a first step toward the development of a suite of DSGE models for Ireland and as an attempt to illustrate how the core ÉIRE Mod can be used for simulating policy scenarios for economic analysis.

Therefore, although useful for policy analysis in its own right, the core ÉIRE Mod presented here will be extended in a number of ways. On the modelling agenda are more detailed analyses of the housing, fiscal and financial sectors, as well as the labour market. Each model extension will be specifically tailored to answer questions of vital interest to policymakers. Additionally, key aspects from the various extensions can be combined (e.g. the housing and financial sectors) to analyse important transmission channels between these sectors. Finally, the core model will be estimated using Bayesian techniques.

ÉIRE Mod: A DSGE Model for Ireland*

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Abstract

We develop ÉIRE Mod (Elementary Irish Real Economy Model), a core DSGE model suitable for policy analysis in Ireland. The model's underlying structure, with a distinction between the traded and non-traded sectors and an import content of exports component, is designed to replicate the highly open nature of the Irish economy. Ireland's membership of EMU is accounted for through exogenous nominal interest and exchange rates. New Keynesian features, such as sticky prices and wages, mean the model's dynamics can replicate the sluggish reaction of economic variables found in the empirical literature. The model is calibrated in order to match key observed ratios in the Irish data. The usefulness of the model as a policy tool is highlighted through the simulation of various structural reforms aimed at boosting efficiency and competitiveness. Our results show that overall, reforms aimed at boosting productivity and price and wage competitiveness lead to the desired increase in output. Nevertheless, particular care should be paid to the effect of domestic reforms on Ireland's external competitiveness and employment. This work is the first step towards the development of a suite of DSGE models for Ireland. Extensions of the core ÉIRE Mod will be necessary to fully capture key aspects of the economy's adjustment path following these reforms. Accordingly, the results presented in this initial paper should be treated with caution.

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1 Introduction

Dynamic Stochastic General Equilibrium (DSGE) models have become increasingly popular tools for policy analysis in Central Banks and other policy-making institutions. These models formalise the behaviour of economic agents on the basis of explicit microfoundations and rational forward-looking expectations. As a result, DSGE models are less prone to the Lucas critique (Lucas, 1976) than traditional macroeconometric models and therefore provide a powerful framework for conducting policy scenario analysis[1]. In this paper we develop a DSGE model for Ireland, ÉIRE Mod (Elementary Irish Real Economy Model). The models underlying structure is designed to replicate the highly open nature of the Irish economy. Moreover, the model is calibrated to match the key steady-state ratios of the key macroeconomic variables, using long-run averages from National Account data. To highlight the usefulness of the model for policy analysis, we examine the impact that various structural reforms could have on the Irish economy. This is in the spirit of existing work that examines the short and long-run macroeconomic effects of policy reforms using DSGE models[2].

The simulation of these shocks highlights the transmission channels through which such reforms would affect the economy. Structural reforms have been on the Irish policy agenda since the beginning of the decade, as the financial crisis exposed the loss of competitiveness suffered during the excesses of the housing boom. Successive policy documents, from Europe 2020 to the Financial Assistance Programme, the Programme for Government and the Medium-Term Economic Strategy (MTES) all call for the introduction of structural reforms to boost the sustainable growth potential of the Irish economy. These documents emphasise that a series of measures designed to reform the Irish labour and product markets could deliver medium-term growth through productivity gains. Specifically, we analyse the effect of increases in productivity (i.e. R&D investment) and competitiveness (i.e. limiting wage bargaining and reducing barriers

[1]For a more exhaustive discussion, see Tovar (2008) and Vetlov et al. (2010).

[2]See for instance the analysis in Everaert and Schule (2008) based on the IMF's Global Economy Model; Gomes et al. (2011), based on the ECB's EAGLE model; Arpaia et al. (2007), Roeger et al. (2008) or Hobza and Mourre (2010), based on the European Commission's QUEST model; Cacciatore et al. (2012)

to entry for new firms). Our results show that, although all the reforms boost aggregate output, differing transmission channels for the shocks have contrasting implications for Ireland's external competitiveness and employment. Given that the MTES commits to a strategy of export-led growth and full employment, the reforms implemented under this programme need to be carefully assessed to ensure that they do not lead to counter-productive effects in the export sector and employment.

However, our results must be interpreted with caution. The model does not feature either liquidity constraints or labour market frictions (i.e. search frictions, hiring and firing costs) and hence might fail to capture some key aspects in the adjustment path of the economy following these reforms. Blanchard and Wolfers (2000) argue that labour market frictions and the lack of employment-friendly institutions deepen and prolong the effect of adverse shocks and dampen the benefits of positive shocks. The work presented here has primarily been conducted as an attempt to illustrate how the ÉIRE Mod can be used for simulating Irish policy scenarios for economic analysis.

The following section provides an overview of the model, while Section 3 describes the calibration process. Section 4 details the simulations of various structural reforms aimed at improving the efficiency and competitiveness of the Irish economy. These are used to illustrate the policy analysis capabilities of the model, as well as the channels through which shocks are transmitted through the economy. The final section summarises and concludes the main results and outlines several ways in which the model framework can be developed upon.

2 The model

We consider a two-sector small open economy[3] within a monetary union. Two types of goods are produced: non-tradable goods and export goods, with the price of the latter fixed on the world market. Agents in the economy are households, firms and retailers who import goods from abroad for sale on the domestic market. Nominal interest rates

[3]See Devereux et al. (2006) and Merola (2010) for further analytical details on two-sector small open economy models, and Lane (2001) for a survey of the New Open Economy Macroeconomics Synthesis, which is the theoretical foundation behind this model.

are set exogenously by the European Central Bank. The government raises revenues via taxes to finance exogenous public spending and pursues a balanced budget policy. The model is calibrated in order to match key observed ratios in Irish data. This is discussed in detail in the calibration section. A flow-chart of the model economy is depicted in Figure 1, while a glossary of terms used in the model is provided in the Appendix.

2.1 Households

Households gain utility from consumption C_t and disutility from labour N_t. They maximise their lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\chi) \log(C_t - \chi C_{t-1}) - \frac{1}{1+\eta} N_t^{1+\eta} \right] \tag{1}$$

where β is the discount factor, χ is the degree of habit persistence in consumption, $(1-\chi)$ is a scale factor which guarantees that the marginal utility of consumption in the steady state is independent from the habit parameter and η is the labour supply elasticity. Maximisation of the utility function is subject to a budget constraint:

$$\begin{aligned} B_t + P_t C_t + P_t^I I_t \left[1 - \frac{1}{2}\xi^I \left(\Omega_t^I\right)^2 \right] + P_t^N Y_t^N \left[\frac{1}{2}\xi^N \left(\Omega_t^N\right)^2 \right] + P_t^M M_t \left[\frac{1}{2}\xi^M \left(\Omega_t^M\right)^2 \right] \\ + P_t^X X_t \left[\frac{1}{2}\xi^X \left(\Omega_t^X\right)^2 \right] = R_t B_{t-1} + R_t^K K_{t-1} + W_t N_t \left[1 - \frac{1}{2}\xi^W \left(\Omega_t^W\right)^2 \right] + \Pi_t - \Theta_t \end{aligned} \tag{2}$$

where B_t are bond holdings, R_t is the nominal (risk-free) interest rate on these assets, Π_t are profits from firms (whom the households are assumed to own) and Θ_t are lump-sum taxes paid to the fiscal authority. The budget constraint requires that households' bond holdings, tax liabilities and purchase of consumption goods (at price P_t) and investment goods I_t (at price P_t^I) must be covered by labour income $W_t N_t$, capital income $R_t^K K_t$ and dividends from firms Π_t. Factor inputs are paid at the wage rate W_t and the rental rate of capital R_t^K. Households resources in the budget constraint

are net of adjustment costs. These costs are used to introduce New Keynesian features such as sticky prices and wages and thus accurately replicate the sluggish reactions of economic variables, such as inflation and output, found in the empirical literature[4]. In ÉIRE Mod adjustment costs arise from deviations in non-tradable good price inflation $\Omega_t^N = \log \frac{\pi_t^N}{\pi_{t-1}^N}$, import sector price inflation $\Omega_t^M = \log \frac{\pi_t^{P^M}}{\pi_{t-1}^{P^M}}$ and quantity adjustment in the export sector $\Omega_t^X = \log \frac{X_t}{X_{t-1}}$. In addition, households face adjustment costs in investment $\Omega_t^I = \log \frac{I_t}{I_{t-1}}$ and in wage inflation $\Omega_t^W = \log \frac{\pi_t^W}{\pi_{t-1}^W}$. In all cases, the size of these costs are controlled by adjustment cost parameters ξ^I, ξ^N, ξ^M, ξ^X and ξ^W. Households also take into account a law of motion for capital:

$$K_t = (1 - \delta)K_{t-1} + I_t. \tag{3}$$

This equation states that the capital stock available at the beginning of period t, K_t, is equal to the capital stock available at the end of period *t-1*, net of capital stock depreciation δK_{t-1}, where $0 < \delta < 1$ is the capital depreciation rate, plus the amount of capital accumulated during period t, which is determined by the investment made during period t, I_t. The first order conditions for B_t, I_t and K_t respectively are:

$$\Lambda_t = \beta \mathbb{E}_t \Lambda_{t+1} R_t, \tag{4}$$

$$P_t^K = P_t^I + \xi^I P_t^I \left(\Omega_t^I - \beta \mathbb{E}_t \Omega_{t+1}^I\right) \tag{5}$$

$$P_t^K = \beta \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} (R_{t+1}^K + (1 - \delta) P_{t+1}^K). \tag{6}$$

where ξ^I is a cost parameter for deviations in investment $\Omega_t^I = \log \frac{I_t}{I_{t-1}}$ and Λ_t is the multiplier associated with the budget constraint. The first order condition with respect

[4]See Woodford (2003) or Gali (2008) for a textbook treatment of New Keynesian theory and its incorporation in modern macroeconomic models.

to consumption is:

$$\frac{1-\chi}{C_t - \chi C_{t-1}} = \Lambda_t P_t. \tag{7}$$

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

$$N_{i,t} = \frac{W_{i,t}}{W_t}^{-\frac{\theta^W}{\theta^W - 1}} N_t, \tag{8}$$

where θ^W is the elasticity of the demand and $\mu_t^W = \frac{\theta^W}{\theta^W - 1}$ is a mark-up over the marginal cost of labour, which follows an autoregressive process:

$$\mu_t^W = (1-\rho^W)\mu_{t-1}^W + \rho^W \mu_{t-1}^W + \epsilon_t^W \tag{9}$$

where ρ^W is the persistence of the process and ϵ_t^W is a shock to the wage mark-up. The first order condition for labour, by which households choose the optimal wage, is:

$$\frac{\mu_t^W N_t^\eta}{W_t \Lambda_t} = 1 + (\mu_t^W - 1)\xi^W \Omega_t^W - (\mu_t^W - 1)\xi^N \beta \mathbb{E}_t \Omega_{t+1}^W \tag{10}$$

where ξ^W is a cost parameter for deviations in wage inflation $\Omega_t^W = \log \frac{\pi_t^W}{\pi_{t-1}^W}$.

2.2 Firms

There are three types of firms. While one locally produces non-tradable goods, another produces exports goods for sale on the international market. A final type imports foreign goods for sale on the domestic market. Firms producing domestic goods and firms importing foreign goods are assumed to face a small direct cost of adjusting their prices[5], modelled *à la* Rotemberg (1982). Firms producing export goods face quadratic adjustment costs if they want to change the level of their output. As a result, firms will only adjust prices gradually in response to a shock to demand or marginal cost.

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

2.2.1 Non-tradable good producers

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

$$Y_t^N = A_t^N \left(K_{t-1}^N\right)^{1-\gamma^N} \left(N_t^N\right)^{\gamma^N} \tag{11}$$

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

$$\log A_t^N = \rho^A \log A_{t-1}^N + \epsilon_t^A \tag{12}$$

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

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^N Y_t^N \left[1 - \frac{1}{2} \xi^N \left(\Omega_t^N\right)^2 \right] - W_t N_t^N - R_t^K K_{t-1}^N \right] \tag{13}$$

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

$$\gamma^N MC_t^N Y_t^N = W_t N_t^N \tag{14}$$

$$(1 - \gamma^N) MC_t^N Y_t^N = R_t^K K_{t-1}^N \tag{15}$$

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

$$Y_{i,t}^N = \left(\frac{P_{i,t}^N}{P_t^N} \right)^{-\frac{\theta^N}{\theta^N - 1}} Y_t \tag{16}$$

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

$$(\mu_t^N - 1)\xi^N \Omega_t^N = (\mu_t^N - 1)\xi^N \beta \mathbb{E}_t \Omega_{t+1}^N + \left(\frac{\mu_t^N MC_t^N}{P_t^N} - 1 \right) \tag{17}$$

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

$$\mu_t^N = (1 - \rho^N)\mu_{t-1}^N + \rho^N \mu_{t-1}^N + \epsilon_t^N \tag{18}$$

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

2.2.2 Importers

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

$$\left(\frac{\mu_t^M MC_t^M}{P_t^M} \right) = 1 + (\mu_t^M - 1)\xi^M \Omega_t^M - (\mu_t^M - 1)\xi^M \beta \mathbb{E}_t \Omega_{t+1}^M \tag{19}$$

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

an autoregressive process:

$$\mu_t^M = (1-\rho^M)\mu_{t-1}^M + \rho^M \mu_{t-1}^M + \epsilon_t^M \tag{20}$$

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

2.2.3 Tradable good producers

Competitive local exporters combine domestic labour and fixed capital $\overline{K}_{t-1}^X$ [6] using a Cobb-Douglas technology:

$$Z_t = A_t^X \left(\overline{K}_{t-1}^X\right)^{1-\gamma^X} \left(N_t^X\right)^{\gamma^X} \tag{21}$$

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

$$\log A_t^X = \rho^X \log A_{t-1}^X + \epsilon_t^X \tag{22}$$

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

$$X_t = \min\left\{\frac{Z_t}{(1-\alpha)}, \frac{X_t^M}{\alpha}\right\}. \tag{23}$$

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

The large size of the multinational sector in Ireland makes this import content of exports channel very relevant for policy analysis[7]. By considering the international fragmentation of the tradable goods production process, this features can account for the reliance of exports in Ireland on imported components. For any given level of output, the inputs in the final export good X_t are combined in proportions fixed by the parameter α:

$$Z_t = (1-\alpha)X_t \tag{24}$$

$$X_t^M = \alpha X_t. \tag{25}$$

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

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^X X_t - W_t N_t^X - R_t^K \overline{K}_{t-1}^X \right]. \tag{26}$$

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

$$\gamma^X MC_t^Z Z_t = W_t N_t^X. \tag{27}$$

The exporters marginal cost of production is:

$$MC_t^X = (1-\alpha)MC_t^Z + \alpha P_t^M \tag{28}$$

[7]See Hummels et al. (2003) for an estimate of the importance of this channel in a panel of OECD and emerging market countries, including Ireland

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

$$\frac{P_t^X}{MC_t^X} = 1 + \xi^X \Omega_t^X - \beta \mathbb{E}_t \Omega_{t+1}^X \tag{29}$$

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

2.3 Net foreign asset position

The domestic interest rate, R_t, is assumed to be tied to the euro area interest rate $R_t^\star$:

$$R_t = R_t^\star \frac{E_t S_{t+1}}{S_t} e^F \tag{30}$$

where e^F is a debt elastic risk premium used to close the model, as in Schmitt-Grohe and Uribe (2003). This premium is defined as:

$$e^F = p\left(\frac{B_t}{Y_t} - \log \zeta\right) \tag{31}$$

where ζ is a parameter used to calibrate the steady-state debt-to-GDP, $B_t = \zeta Y_t$, and p is a parameter governing how quickly debt returns to its steady-state level. The balance of payments for the country as a whole evolves according to:

$$B_t = B_{t-1} R_{t-1} - (P_t^X X_t - P_t^M M_t) \tag{32}$$

with the interest households earn from bond holdings defined by R_{t-1} since savings accrue a nominal amount with certainty (i.e. a zero coupon bond)[8].

[8]See Adolfson et al. (2007) for further details.

2.4 Policy authorities

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

$$G_t = g\bar{Y} \tag{33}$$

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

$$P_t^N G_t = \Theta_t. \tag{34}$$

2.5 Market clearing conditions

The final consumption good C_t and investment good I_t are an aggregate of locally produced non-tradables and imports, bundled in fixed proportions[9]:

$$C_t = \omega^C C_t^M + \left(1 - \omega^C\right) C_t^N \tag{35}$$

$$I_t = \omega^I I_t^M + \left(1 - \omega^I\right) I_t^N \tag{36}$$

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

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

$$P_t C_t = P_t^N C_t^N + P_t^M C_t^M \tag{37}$$

$$P_t I_t = P_t^N I_t^N + P_t^M I_t^M. \tag{38}$$

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

$$Y_t^N = C_t^N + I_t^N + G_t \tag{39}$$

$$M_t = C_t^M + I_t^M + X_t^M \tag{40}$$

$$N_t = N_t^N + N_t^X \tag{41}$$

$$K_t = K_t^N + \overline{K}_t^X \tag{42}$$

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

$$Y_t = P_t^N C_t^N + P_t^M C_t^M + P_t^N I_t^N + P_t^M I_t^M + P_t^N G_t + P_t^X X_t - P_t^M M_t. \tag{43}$$

3 Calibration

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

We assume that the economy starts out in a steady state with zero consumption growth. Thus, the interest rate must equal the rate of time preference. We set the discount factor so as to be consistent with a (annualised) interest rate of 3%. The nominal output shares of government expenditures (16.8%) and investment (17.8%) are set to the respective domestic demand shares of public consumption and gross capital formation[10]. In the steady state, the trade balance simply covers net foreign interest payments. We therefore calibrate private sector debt to replicate a steady state trade surplus (0.5%). We then set the share of consumption (64.9%) equal to the residual of the sum of the remaining output shares.

However, data averaged over the very long-run may not be as useful in capturing Ireland's international trade relations. Therefore, the imported intermediate inputs in exports is set at 50%, in line with OECD estimates using input-output (I/O) tables for

[10]In order to accurately calibrate the steady-state investment to GDP ratio, the parameter value for depreciation had to be set to a higher level (0.04) than is standard in the literature (0.025). The sample period in question was a time of large growth in the Irish economy, and therefore it is reasonable to assume that the depreciation rate could be higher than in the more developed economies on which the DSGE literature has tended to focus.

the period 1995-2010. The share of imports in the aggregate consumption (29%) and investment (48%) baskets are based on the latest available (2008) final use breakdown of imports from the Central Statistics Office I/O tables. These latter features ensure that the model captures the highly open nature of the Irish economy. The factor-intensity parameters are important in determining the dynamics of the model. As only labour is mobile between the non-tradable and export sectors, the impact of productivity and terms of trade shocks will depend on the differing labour intensity of these sectors. Several Irish studies (e.g. Bermingham, 2006) have found that the non-traded sector is more labour intensive than the export sector. Following these studies, as well as sectoral data from the ESRI macroeconomic database, the labour share of export and non-tradable goods is set to 40% and 70% respectively. Accordingly, the total share of labour in GDP is approximatively 50%.

Following the New Keynesian tradition, the model uses real and nominal rigidities in order to match the sluggish reaction of prices, wages and other economic variables found in macroeconomic data. However, data on such features is limited or non-existent in the case of Ireland. Therefore, the matching process involved identifying values common in the literature and recursively updating them when the impulse response functions did not correspond to well-known macroeconomic theory regarding the business cycle (see, for example, King and Rebelo, 1999).

Druant et al. (2009) identified a relatively high degree of friction in the Irish goods and labour markets, implying a lower level of competition. However, Keeney et al. (2010) and Keeney and Lawless (2010) note that this may be due to the boom in Ireland during the period in which the survey used by Druant et al. (2009) took place. Keeney and Lawless (2010) find that, despite the lack of wage decreases during the period, Irish firms had the least issue with regulations of all euro area countries surveyed. This finding, coupled with evidence of wage decreases since the onset of the financial crisis, suggests greater flexibility in the labour market. In light of such offsetting evidence for goods and labour market flexibility, it was decided to keep price and wage mark-ups at standard values found in the literature (e.g. Ireland, 2001; Devereux et al., 2006; Keen

and Wang, 2007).

4 Simulation exercises

The conditions of the EU/IMF Financial Assistance Programme required a restructuring of the banking sector and a period of fiscal consolidation to put public finances back on a sustainable path. In addition, the programme advocated the implementation of structural reforms aimed at restoring competitiveness and boosting the sustainable growth prospects of the Irish economy.

Having exited this programme while meeting the fiscal and banking sector targets, the Government's MTES emphasised the need for structural reforms in order to generate sustainable growth for the Irish economy. With a focus on export-led growth, key components of the strategy will be reforms aimed at boosting competition and innovation. Such reforms are to be the basis on which necessary productivity improvements are made and medium-term economic growth ensured. The MTES re-confirms the commitment made under the EU/IMF Programme to remove restrictions to trade and competition in sheltered sectors, such as the legal, medical and pharmaceutical professions. This would notionally increase price and wage competitiveness in these sectors. Increased innovation is to be encouraged through tax credits for R&D spending. This research should manifest itself in the improved productivity of Irish based firms, thereby boosting their external competitiveness.

To highlight the usefulness of the core ÉIRE Mod for policy analysis, we examine the impact that such structural reforms could have on the Irish economy. However, the core ÉIRE Mod is too stylised to explicitly model some of the nuanced measures proposed in these policy documents. Instead, these simulation exercises have to been taken as an illustrative example of how ÉIRE Mod can be used for policy analysis. In order to proxy the beneficial effect of an increase in innovation, an exogenous productivity improvement shock is implemented through an increase in the production function efficiency term. To replicate the macroeconomic impact of pro-competition

policies, we simulate shocks that reduce the mark-up of wages and non-tradable prices over their marginal costs. The last two simulations mimic an increase in wage competitiveness, and a reduction in the barriers to entry for new firms.

The model is simulated using Dynare (Adjemian et al., 2011). Shocks are temporary and hit the economy at the initial time $t = 1$, with the persistence of the shock equal to 0.90 in all cases.

4.1 Effects of increased innovation

The effects of an exogenous shock to productivity in the non-tradable sector is considered in Figure 2. The shock is simulated as a 1% increase in the TFP component of the non-tradable good production function. An increase in the level of efficiency with which factor inputs are used has a positive impact on output in both sectors. The decrease in the marginal cost feeds into lower prices, with a lower inflation rate pushing up the real wage. As the monetary union nominal interest rate has a minimal reaction to Irish inflation, the real interest rate increases. However, consumption increases as result of higher labour income and the lower price of domestic goods. Higher efficiency reduces labour demand and, as a result, hours worked shifts downwards. This matches empirical evidence on the labour response to technology shocks first provided by Galí (1999) and later replicated by Francis and Ramey (2005) amongst others.

The productivity shock, by making domestic non-tradable goods less expensive, induces households to substitute imported goods with domestic goods. The change in relative prices discourages imports and improves the trade balance on impact. However, imports rebound relatively quickly, as they represent a large component of final export goods. There is increased production in the export sector as lower domestic costs (from reduced competition for factor inputs by non-tradable sector firms) make exporters more competitive.

4.2 Effects of labour market reforms: increased wage competitiveness

Figure 3 shows the implications of increasing wage competitiveness. This scenario is modelled as a transitory negative 1% shock to the wage mark-up. A decrease in the wage mark-up results in lower production costs through lower wages. These gains are then passed-on to consumers in the form through lower prices for non-tradable goods, and hence in higher demand in both sectors[11]. To produce this extra output, firms increase their labour demand and hours worked increase.

Despite lower real wages, the extra hours worked to satisfy the higher labour demand improves labour income. This helps to stimulate consumption, offsetting the effect of higher real interest rates. These higher real interest rates materialise due to the fact that the monetary union's nominal interest rate is unresponsive to changes in Irish prices. Compared to the case of a productivity gain, consumption and output increase to a lesser extent. This is due to the reduced bargaining power of households putting downward pressures on nominal wages. CPI inflation decreases on impact as result of lower labour costs, but then eventually overshoots in the medium run due to the higher import prices. This increase in imports is necessary in order to satisfy the boost in the export sector output which employs intermediate imported goods as inputs.

Our results on the effects of a increase in wage competitiveness are consistent with those obtained in Callaghan et al. (2014) using the ESRI HERMES model (Bergin et al., 2013). The authors find that a decrease in wage competitiveness adversly affects exporters, who as price-takers are unable to pass the increase in costs on to international customers. The loss of competitiveness reduces output and labour demand. Given that the HERMES model is symmetric, the opposite should hold for the reverse case where wage competitiveness improves, as is the case in our simulation.

[11] As we assume labour mobility, nominal wages are equalised across the two sectors.

4.3 Effects of product market reforms: reducing barriers to entry

Product market reforms reducing barriers to entry for new non-tradable firms increases competitiveness in this sector. The effects of product market reforms in the non-tradable sector are detailed in Figure 4. The shock is modelled as a temporary negative 1% shock to the price mark-up in the non-tradable sector.

Firm entry boosts investment, labour demand and output. By reducing the price mark-up and inflation, product market reforms also raise the real wage and thus consumption. Although CPI inflation decreases on impact due to lower mark-ups, it overshoots in the medium run as higher wages raise the costs of production. Therefore, labour demand begins to decrease in the medium run due to higher real wage costs. However, the expansion in the production of non-tradable goods leads to higher demand for factor inputs and hence mitigates the negative effect of higher real wages on employment. Overall, product market reforms support higher employment.

The real interest rate increases, as the inflation rate decreases and the monetary union nominal interest rate has a minimal reaction to Irish inflation. Despite the increase in real interest rates, consumption increases as result of the lower relative prices of non-tradable goods and higher labour income from higher wages and employment. These two effects dominate the negative effect that higher real interest rates have on consumption[12].

As resources are partially reallocated to meet the higher demand for non-tradable goods, output in the tradable sector increases but to a lesser extent compared to the case of a decrease in the wage mark-up. This is unsurprising given that this price mark-up shock is specific to the non-traded sector whereas the wage mark-up shock affects the entire economy. The increased demand for factor inputs leads to an increase in the cost of producing export goods, given that export firms are price-takers and hence are unable to adjust their prices to reflect the increase in input costs. This loss

[12]The expansionary effect of higher employment dominates the contractionary effect of real wages on consumption when employment adjusts freely, i.e. without frictions. In the presence of hiring costs, product market policies may not be sufficient to stimulate employment to the same extent and the total effect on consumption may be negative. Therefore, the results in this paper must be treated with caution as the model does not explicitly model labour market behaviour in the presence of these frictions. This will be the focus of future work in the Macro Modelling Project.

of competitiveness therefore dampens the increase in exports. Imports decrease as foreign goods are now relatively more expensive than domestic non-tradable goods.

5 Conclusions and further extensions

We describe ÉIRE Mod, the core DSGE model developed for policy analysis at the Central Bank of Ireland and the ESRI. We then simulate productivity and wage and price mark-ups shocks to mimic the impact of various structural reforms aimed at improving the efficiency and competitiveness of the Irish economy.

We find that both productivity and competitiveness gains lead to an increase in total output. However, there are important differences in the transmission channels and in the effect on employment and exports. An increase in productivity in the non-tradable sector also benefits the tradable sector and supports export-led growth. Moreover, real wage income increases because of the large decline in inflation. Facing a relaxed budget constraint, households increase their consumption spending. However, the higher efficiency with which factors are used reduces labour demand and employment.

For both the mark-up shocks, we find that, differently from the case of productivity gains, employment expands. However, some differences emerge between the price and wage shocks. A reduction in the monopoly power of non-tradable firms makes tradable-good firms relatively less competitive. This is unsurprising given that this price mark-up shock is specific to the non-traded sector. A reduction in the bargaining power of households in wage negotiations benefits both the tradable and the non-tradable sector, boosts exports and supports the opportunities for export-led growth. Overall, our analysis suggests that, given that the MTES commits to a strategy of export-led growth and full employment, the reforms implemented under this programme need to be carefully assessed to ensure that they do not lead to counter-productive effects for Irish exports and employment.

However, the policy implications of our results need to be interpreted with caution, as the core ÉIRE Mod still does not entail labour market frictions and hence might fail

to capture some key aspects in the adjustment path of the economy following these reforms. For instance, it does not take into account that labour market frictions, such as high hiring and firing costs due to strict employment protection, might downsize the potential growth and employment-enhancing effects of product and labour market reforms[13].

This work has primarily to been taken as a first step toward a suite of DSGE models for Ireland and as an attempt to illustrate how the core ÉIRE Mod can be used for simulating policy scenarios for economic analysis. Therefore, although useful for policy analysis in its own right, the core ÉIRE Mod will be extended in a number of ways. Already on the agenda are a financial sector (for details see Clancy and Merola, 2014), a labour market with involuntary unemployment and labour market frictions, a housing supply sector and a detailed fiscal sector. The development of these extensions on a relatively simplistic and consistent core will help with the tractability of the models. Additionally, key aspects from the various extensions could be combined (e.g. the housing and financial sectors) to analyse important transmission mechanisms between these sectors. A further step will be the estimation of ÉIRE Mod. This will allow for the model to be taken to the data more forcefully. It will also permit a historical decomposition of the shocks which drive the Irish business cycle. Finally, the model may eventually be used to forecast key economic variables, as DSGE models have been shown to have a strong forecasting performance in recent work (e.g. Del Negro and Schorfheide, 2012).

We finally emphasise the complementary nature of this tool with existing models at the ESRI and the Central Bank of Ireland, such as the HERMES (Bergin et al., 2013) and COSMO (Bergin et al., 2014). These developments will boost the policy analysis capabilities of the two institutions at a time when key decisions designed to facilitate sustainable economic growth are being made.

[13]Cacciatore et al. (2012) argue that structural policies would be more beneficial if implemented as a broad package of reforms. They find that, to exploit the interactions across different structural policies and make them more efficient, a broad reform package should be implemented. For instance, reducing entry barriers in product markets in parallel to labour market reforms reverses the wages losses that would result from the latter alone.

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Figures and tables

TABLE 1. Calibrated Model Steady-States (as % of GDP)

Private Consumption	64.9%
Private Investment	17.8%
Public Expenditure	16.8%
Exports	59.2%
Imports Total	58.7%
Imports for Consumption	20.4%
Imports for Investment	8.7%
Imports for Re-export	29.6%
Nominal Trade Balance (annual)	2.0%
Nominal Private Debt (annual)	250%

TABLE 2. Calibrated Model Parameters

Households	
Discount Factor	0.9926
Frisch Elasticity	1
Consumption Habit Persistence	0.80
Consumption Import Share	0.29
Investment Import Share	0.48
Capital Depreciation Rate	0.04
Wage Rigidity	25
Investment Rigidity	3
Debt Convergence	0.02
Export Sector Firms	
Labour Share	0.40
Capital Share	0.60
Output Rigidity	5
Non-tradable Sector Firms	
Labour Share	0.70
Capital Share	0.30
Price Mark-up	0.10
Price Rigidity	25
Import Sector Firms	
Price Mark-up	0.10
Price Rigidity	15

FIGURE 1. Structure of the model economy in ÉIRE Mod

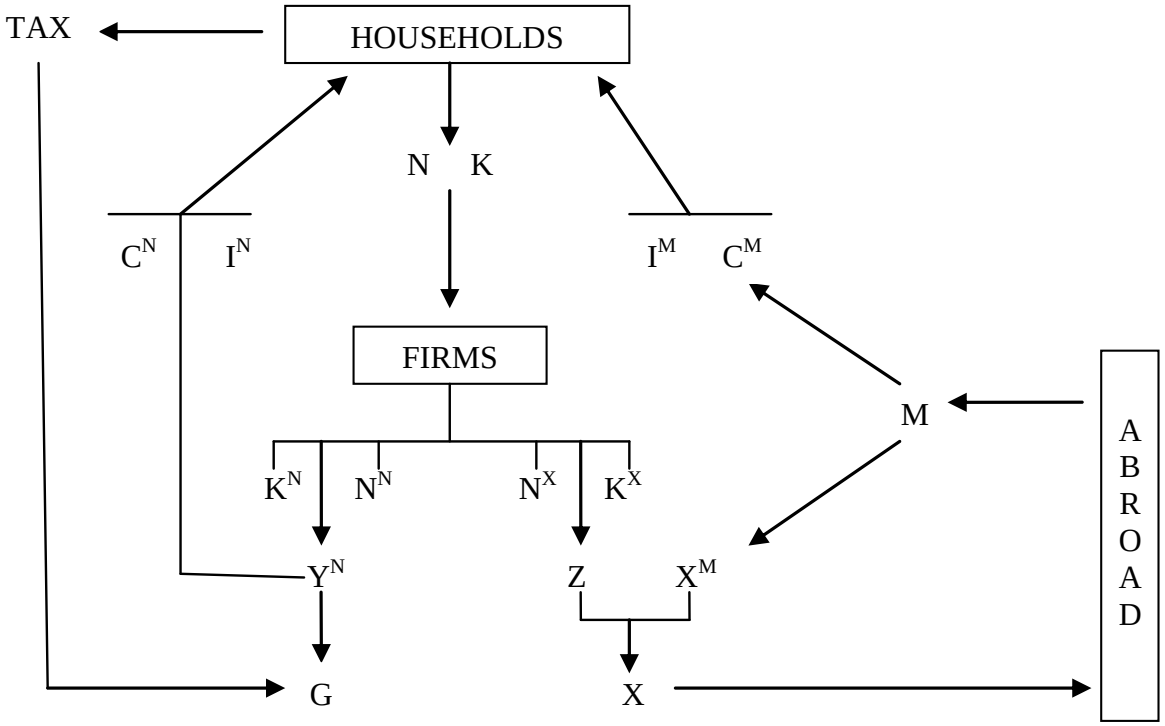


FIGURE 2. Increase in non-tradable sector productivity

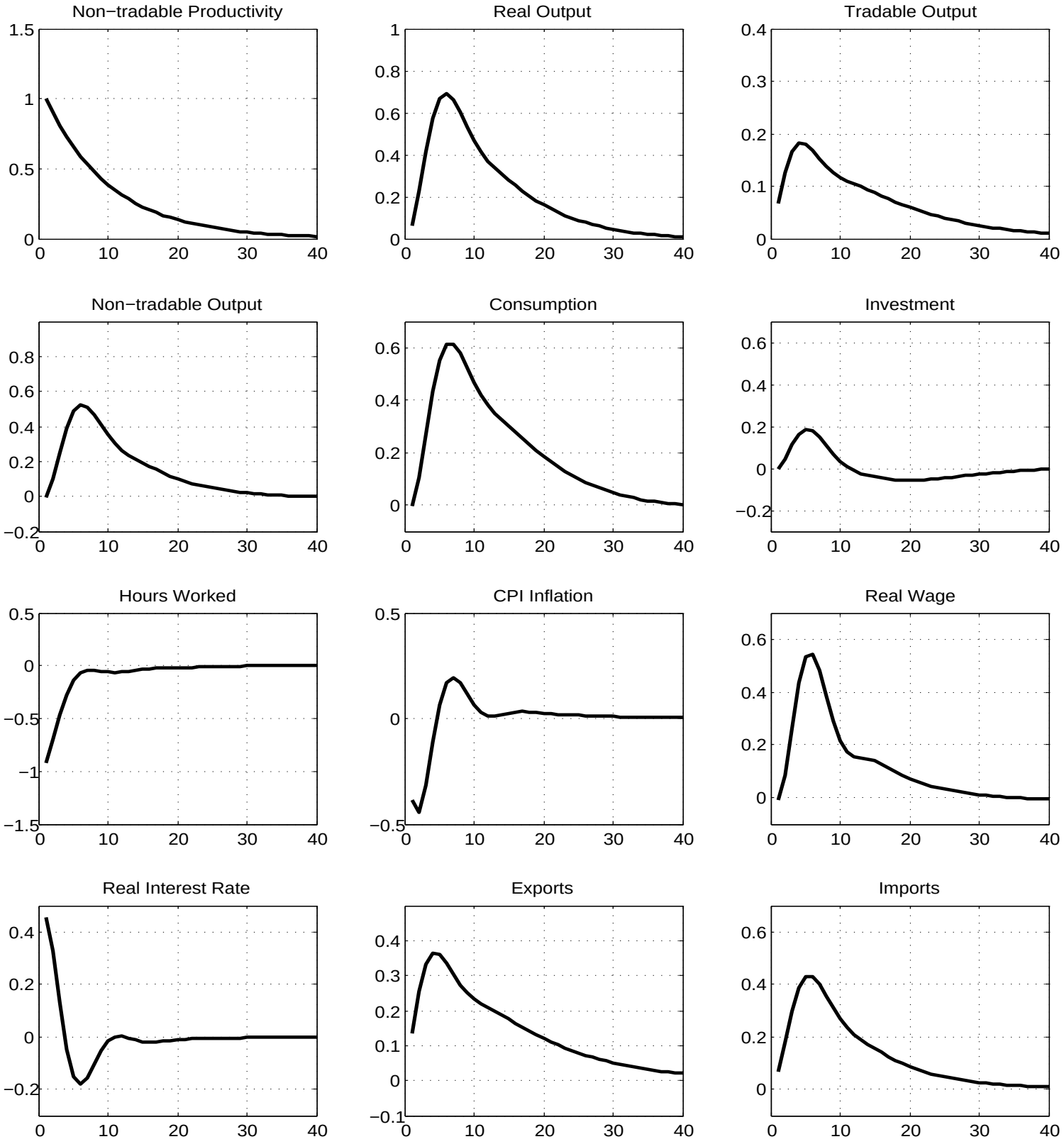


FIGURE 3. Increase in wage competitiveness

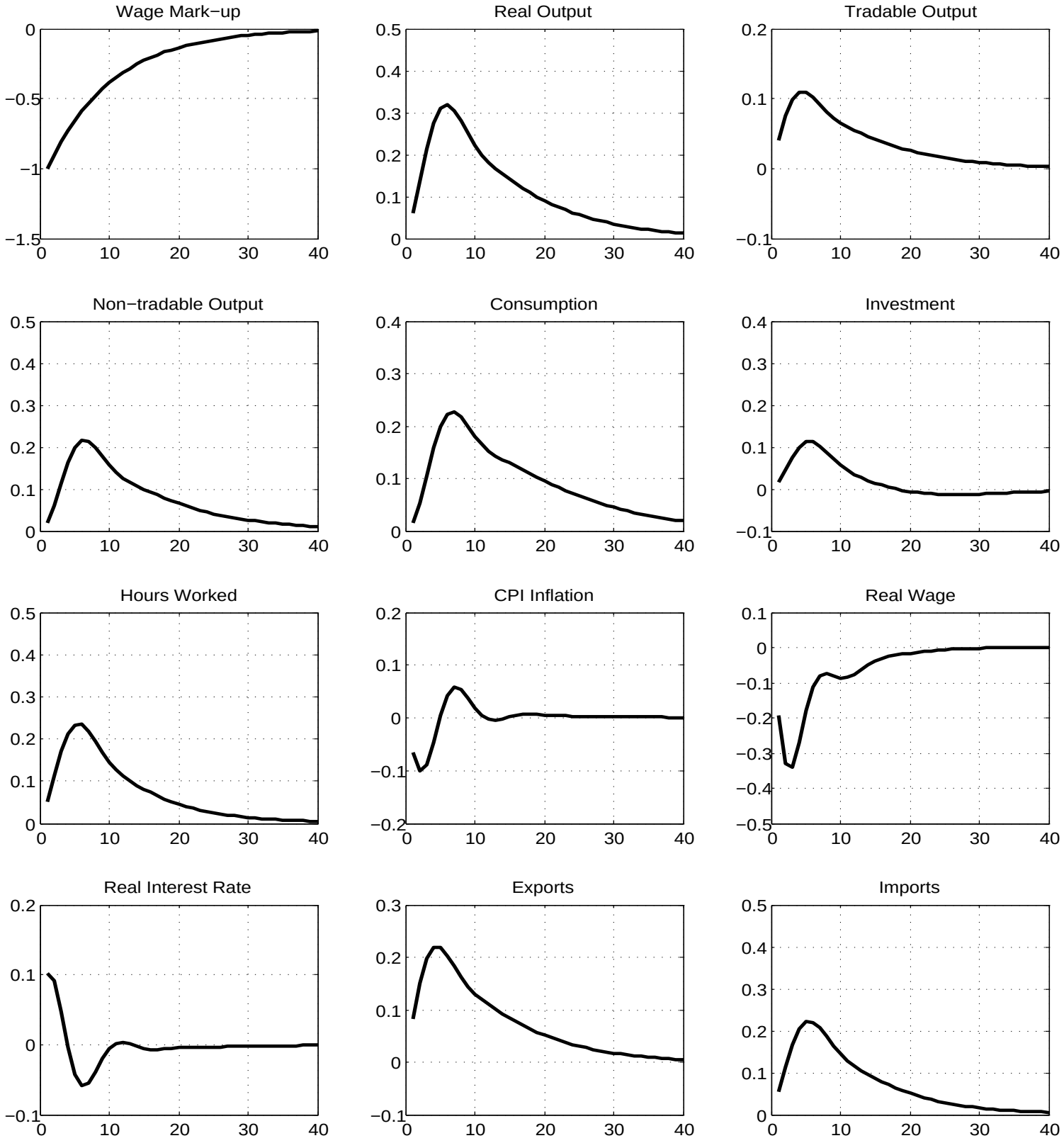
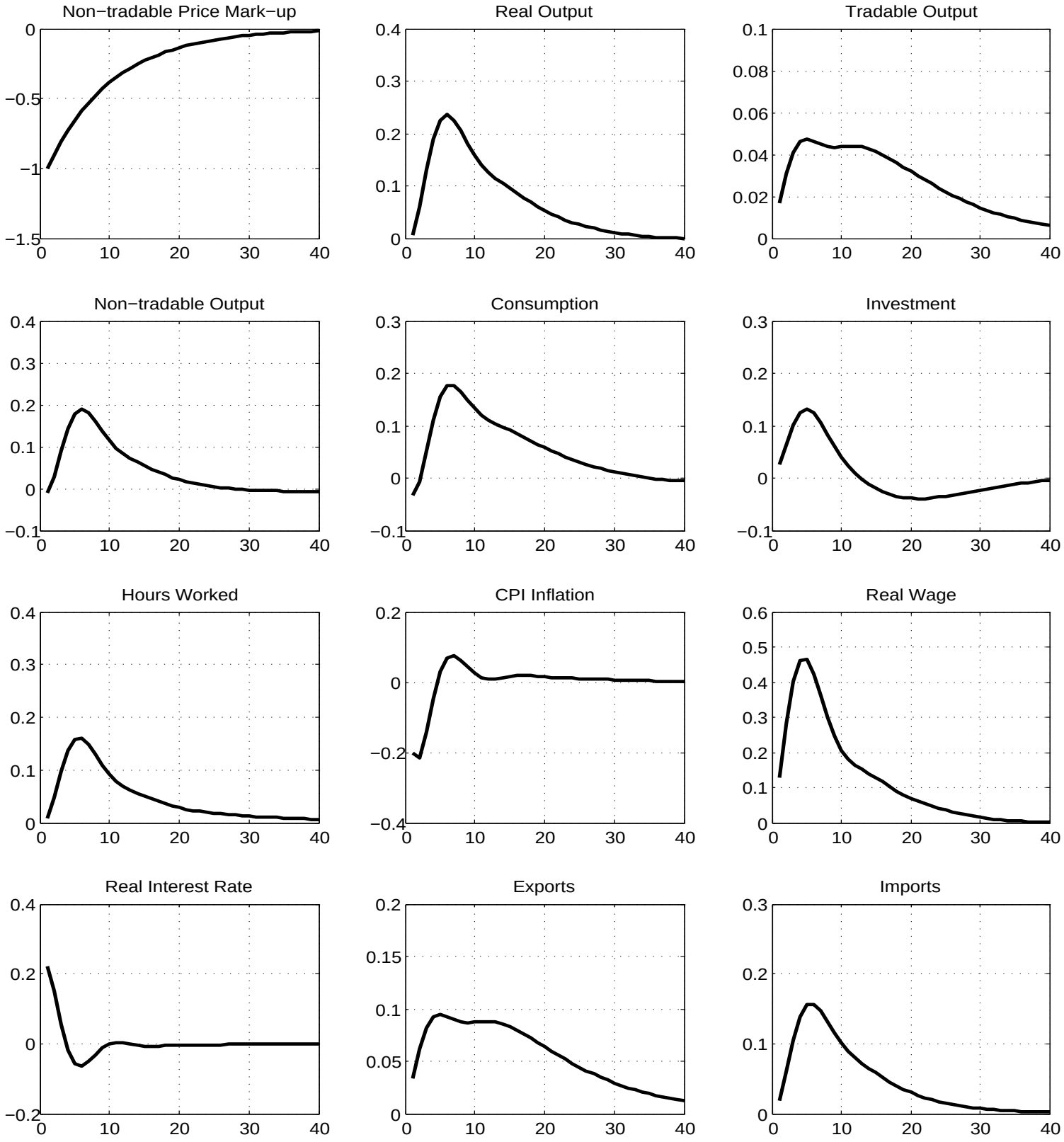


FIGURE 4. Increase in non-tradable sector price competitiveness



Appendix: Glossary

TABLE 3. Model Variables

A_t^N	Non-tradable sector productivity
A_t^X	Export sector productivity
B_t	Private debt
C_t	Aggregate consumption
C_t^N	Consumption of non-tradable goods
C_t^M	Consumption of imported goods
G_t	Government spending
I_t	Aggregate investment
I_t^N	Investment in non-tradable goods
I_t^M	Investment in imported goods
K_t	Total capital
K_t^N	Non-tradable sector capital
$\overline{K}_t^X$	Export sector capital
Λ_t	Multiplier associated with the budget constraint
M_t	Total imports
MC_t^N	Non-tradable sector marginal costs
MC_t^M	Imports marginal costs
MC_t^X	Total exports marginal costs
MC_t^Z	Domestic export production marginal costs
μ^M	Time-varying import price mark-up
μ^N	Time-varying non-tradable price mark-up
μ^W	Time-varying wage mark-up
N_t	Total labour
N_t^N	Non-tradable sector labour
N_t^X	Export sector labour
P_t	Aggregate prices
P_t^I	Investment good prices
P_t^K	Price of capital
P_t^N	Non-tradable good prices
P_t^M	Import good prices
P_t^X	Export good prices
$P_t^{M\star}$	World import price (in foreign currency)
$P_t^{X\star}$	Export price (in foreign currency)
π_t^N	Gross rate of non-tradable good price inflation
π_t^M	Gross rate of imported good price inflation
π_t^W	Gross rate of wage inflation
R_t	Domestic gross rate of interest
$R_t^\star$	Gross rate of interest in the rest of the euro area
R_t^K	Rental price of capital
S_t	Nominal exchange rate
Z_t	Tradable good (domestically produced component)
Y_t	Total output
Y_t^N	Non-tradable good output

Θ_t	Lump-sum taxes (transfers)
W_t	Nominal wages
X_t	Total exports
X_t^M	Imported goods for re-export
Y_t	Nominal GDP
Y_t^N	Domestic non-tradable good production
Z_t	Domestic export good production

TABLE 4. Model Parameters

α	Import content of exports
β	Discount factor
χ	Habit persistence in consumption
δ	Depreciation rate of capital
η	Frisch labour elasticity
γ^N	Labour share in non-tradable good production
γ^X	Labour share in export good production
μ^M	Mark-up over import sector marginal costs
μ^N	Mark-up over non-tradable sector marginal costs
μ^W	Mark-up over labour market marginal costs
ω^C	Import share in consumption goods
ω^I	Import share in investment goods
p	Debt convergence
ξ^I	Investment adjustment cost
ξ^M	Import price adjustment cost
ξ^N	Non-tradable price adjustment cost
ξ^W	Wage adjustment cost
ξ^X	Export output adjustment cost
ρ^A	Persistence of non-tradable sector productivity shock
ρ^M	Persistence of import sector mark-up shock
ρ^N	Persistence of non-tradable sector mark-up shock
ρ^W	Persistence of wage mark-up shock
ρ^X	Persistence of export sector productivity shock
ζ	GDP proportion of private sector debt

TABLE 5. Model Shocks

ϵ_t^A	Non-tradable sector productivity shock
ϵ_t^M	Import sector mark-up shock
ϵ_t^N	Non-tradable sector mark-up shock
ϵ_t^W	Wage mark-up shock
ϵ_t^X	Export sector productivity shock