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ÉIRE Mod: A DSGE Model for Ireland

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Abstract: We present ÉIRE Mod, a quarterly DSGE model developed for macroeconomic policy analysis in Ireland. We simulate productivity and wage and price mark-up shocks to mimic the impact of various structural reforms aimed at improving the efficiency and competitiveness of the Irish economy. We find that all the structural reforms lead to an increase in aggregate output. However, depending on the source of the shocks, there are important differences in the transmission channels and the effect on employment and external competitiveness. This work is the first step towards the development of a suite of DSGE models for Ireland. Extensions of the core ÉIRE Mod detailed here will further enhance its analytic capabilities.

I INTRODUCTION

Dynamic Stochastic General Equilibrium (DSGE) models have become increasingly popular tools for policy analysis in Central Banks and other policymaking institutions. These models formalise the behaviour of economic

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agents based on 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] We develop a quarterly DSGE model for Ireland, ÉIRE Mod (Elementary Irish Real Economy Model). We design the model's underlying structure to replicate the highly open nature of the Irish economy. Moreover, we calibrate the model to match the steady-state ratios of key macroeconomic variables, using long-run averages (1960-2010) from National Account data. To highlight the usefulness of the model for policy analysis, we examine the impact of various structural reforms on the Irish economy. This is in the spirit of existing work that examines the short- and long-run macroeconomic effects of structural reforms using DSGE models.[2]

The simulation of these shocks highlights the transmission channels through which such reforms would affect the Irish 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 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 the MTES commits to a strategy of export-led growth and full employment, a careful assessment of the reforms implemented under this programme is necessary to ensure that they do not lead to counter-productive effects in the export sector and employment.

The following section provides an overview of the model, while Section III describes the calibration process. Section IV details the simulations of various structural reforms aimed at improving the efficiency and competitiveness of the Irish economy. These illustrate the transmission channels through which

[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; and Cacciatore *et al.* (2012).

structural reforms affect the Irish economy. The final section summarises the main results and briefly discusses planned extensions to the model framework.

II THE MODEL

We consider a two-sector small open economy within a monetary union.[3] Agents in the economy are households, firms producing non-tradable goods and exports, and retailers who import goods from abroad for sale on the domestic market. We include 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] Formally, we assume that labour and goods markets are characterised by a monopolistically competitive structure. Households and firms use their bargaining power to set their wages and prices as a mark-up over their respective marginal costs, subject to the (downward sloping) demand curves for their produce. We follow Beneš *et al.* (2014) and assume that the locus of the demand curve, determined by the aggregate price and quantity, is not internalised by the optimising (representative) agent but set equal to its individual counterpart in symmetric equilibrium.[5]

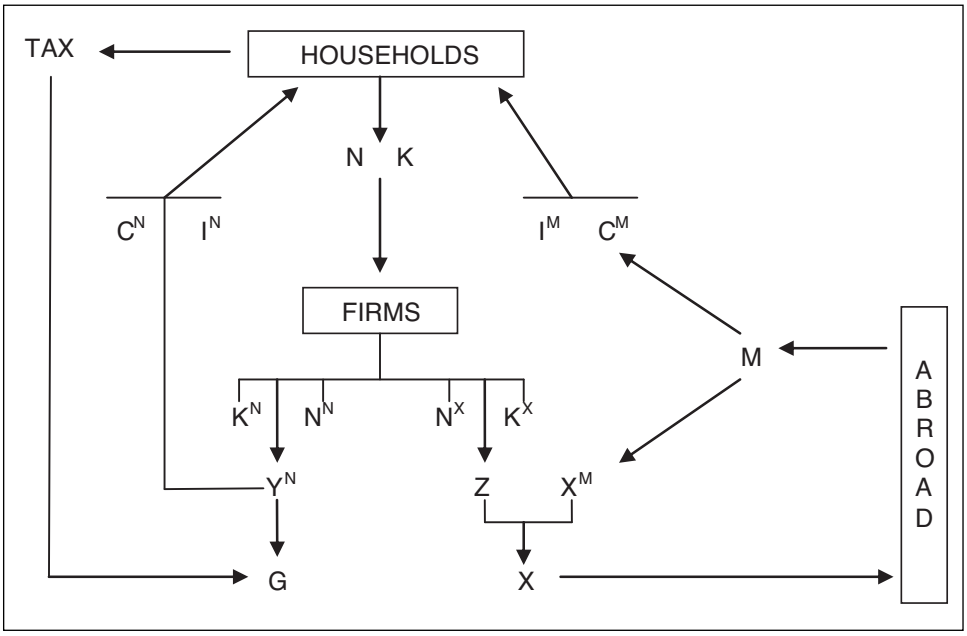
Variables not internalised (i.e., taken as given) by optimising agents, such as external habit formation in consumption, are marked with a bar. Deviations from steady-state wages and prices are subject to quadratic adjustment costs, modelled à la Rotemberg (1982). As a result, wages and prices adjust only gradually in response to a shock to demand or marginal cost. We introduce real rigidities via external habit formation in consumption and investment adjustment costs. We account for Ireland's membership in the European Monetary Union in a number of ways. We assume the European Central Bank exogenously sets the nominal interest rate, which therefore does not react to domestic economic developments. The government raises revenues via taxes to finance exogenous public spending, and pursues a balanced budget policy. A flow-chart of the model economy is depicted in Figure 1, and we provide a glossary of the model variables and parameters in the Appendix.

[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.

[4] See Woodford (2003) and Galí (2008) for textbook treatments of New Keynesian theory and its incorporation in modern macroeconomic models.

[5] An alternative assumption is the existence of a continuum of differentiated households or firms, aggregated using, for example, a constant elasticity of substitution (CES) function. Beneš *et al.* (2014) note that the results from this assumption are identical to those from a model with the direct incorporation of Dixit-Stiglitz CES indices into production and utility functions.

Figure 1: *Structure of the Model Economy in ÉIRE Mod*



2.1 *Households*

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

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

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:

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

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 their 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. Adjustment costs, not internalised by households but instead rebated in lump-sum form, arise from deviations in non-tradable good price inflation $\Omega_t^N = \log \frac{\pi^N}{\pi_{t-1}^N}$, 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 $\Omega_t^X = \log \frac{X_t}{X_{t-1}}$.[6] 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:

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

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

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

[6] The inclusion of these terms in the household budget constraint means that they are considered private, not social costs. These costs therefore affect the distribution, but not the quantity, of the economy's real resources. The model solution and simulations are robust to this assumption. See Edwards and Vegh (1997) for a discussion in the context of banking sector intermediation costs.

where Λ_t is the multiplier associated with the budget constraint and the $\approx$ sign indicates the omission of second- or higher-order terms from the equation.[7] In symmetric equilibrium $C_t = \overline{C}_t$, and so the first order condition with respect to consumption is:

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

2.1.1 Labour supply and wage determination

Households use their monopoly power to set their wages so as to maximise the intertemporal objective function subject to both the budget constraint and a downward-sloping demand curve for their labour:

$$N_t = \left(\frac{W_t}{\overline{W}_t}\right)^{-\frac{\mu^W}{\mu^W - 1}} \overline{N}_t \tag{8}$$

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

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

where μ^W is the steady state of the mark-up over the marginal cost of labour, 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:

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

and $W_t = \overline{W}_t$, $N_t = \overline{N}_t$ in symmetric equilibrium. The equilibrium condition, Equation (10), represents the New Keynesian wage Phillips curve.[8] Under full price flexibility (i.e., $\xi^W = 0$), households would always set wages as a mark-up

[7] Similar to Beneš *et al.* (2014), we are only interested in the first-order dynamic effects of adjustment costs. We therefore simplify the notation by dropping higher order terms relating to adjustment costs. Since we linearise our model around a first-order approximation of the non-stochastic steady state, this simplification has no effect on the model solution or simulations. Naturally, a desire to examine higher-order approximations of the model would necessitate the inclusion of these additional terms.

[8] We have derived all the New Keynesian Phillips curves in the context of the Rotemberg (1982) model of price stickiness. However, similar dynamics emerge under another commonly used model of nominal rigidity due to Calvo (1983).

over the marginal rate of substitution between consumption and labour. Equation (10) implies that wages are set in a forward-looking manner, and are inversely related to both current employment and its expected future path.

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. As a result, these firms will only adjust prices gradually in response to a shock to demand or marginal cost. As exporters are assumed to be price takers on the world market, they face quadratic adjustment costs if they want to change their output levels.

2.2.1 Non-tradable good producers

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

$$Y^N_t = A^N_t (K^N_{t-1})^{1-\gamma^N} (N^N_t)^{\gamma^N} \tag{11}$$

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

$$\log A^N_t = \rho^A \log A^N_{t-1} + \varepsilon^A_t \tag{12}$$

with ρ^A the persistence of the process and ε^A_t 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:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P^N_t Y^N_t \left[1 \frac{1}{2} \xi^N (\Omega^N_t)^2 \right] - W_t N^N_t - R^K_t K^N_{t-1} \right] \tag{13}$$

The optimal choice of labour and capital, respectively, is:

$$\gamma^N MC^N_t Y^N_t = W_t N^N_t \tag{14}$$

$$(1 - \gamma^N) MC^N_t Y^N_t = R^K_t K^N_{t-1} \tag{15}$$

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

$$Y_t = \left(\frac{P_t^N}{\overline{P}_t^N}\right)^{-\theta^N} \overline{Y}_t \tag{16}$$

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. Given that $P_t^N = \overline{P}_t^N$ in symmetric equilibrium, the optimal price is set according to:

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

where $\mu_t^N = \dfrac{\theta^N}{\theta^N - 1}$ measures the monopolistic mark-up in this sector, which follows an autoregressive process:

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

where μ^N is the steady state of the mark-up in the non-tradable sector, ρ^N represents the persistence of the process and ε_t^N is a shock to the non-tradable price mark-up. The equilibrium condition, Equation (17), represents the New Keynesian Phillips curve, which describes how prices are set depending on current inflation, expected future inflation and the current deviation of marginal cost from marginal revenue. Under full price flexibility (i.e., $\xi^N = 0$), the firm would always set prices as a mark-up over the marginal cost (which equals the marginal revenue). However, with quadratic costs of changing nominal prices, this practice is costly. Current inflation is increasing in expected future inflation, because in the presence of nominal price adjustment costs, a firm expecting higher inflation in the future may want to smooth the necessary price adjustments over time by beginning to raise prices in the current period.

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), $MC_t^M = P_t^{M*} S_t$, where P_t^{M*} 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*} is taken as given. Import firms then use their market power, represented by a downward sloping demand curve for imports:

$$M_t = \left(\frac{P_t^M}{\overline{P}_t^M}\right)^{-\theta^M} \overline{M}_t \tag{19}$$

to charge a mark-up $\mu^M = \dfrac{\theta^M}{\theta^M - 1}$ over this price, with θ^M representing the elasticity of demand for imported goods. The monopolistic mark-up in this sector follows an autoregressive process:

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

where μ^M is the steady state of the mark-up in the import sector, ρ^M is the persistence of the process and ε_t^M is a shock to the import price mark-up. Assuming $P_t^M = \overline{P}_t^M$ in symmetric equilibrium, these goods are then sold on the domestic market at price P_t^M:

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

with this price setting mechanism following the same rationale to that described previously for the non-tradable good sector. 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 Export good producers

Competitive local exporters combine domestic labour and fixed capital $\overline{K}_{t-1}^X$ to create a tradable good using a Cobb-Douglas technology:[9]

$$Z_t = A_t^X (\overline{K}_{t-1}^X)^{1-\gamma^X} (N_t^X)^{\gamma^X} \tag{22}$$

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:

$$\log A_t^X = \rho^X \log A_{t-1}^X + \varepsilon_t^X \tag{23}$$

[9] The capital input decisions of export 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, export firms concentrate solely on the minimisation of labour costs and capital follows an autoregressive process $\log \overline{K}_t^X = \rho^K \log \overline{K}_{t-1}^X + \varepsilon_t^K$, 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 into the Irish export sector by the parent branch of a multinational corporation, for example.

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 the locally produced tradable goods Z_t to produce final export goods using a Leontief production function:

$$Xt = \min\left\{\frac{Z_t}{(1-\alpha)}, \frac{X_t^M}{\alpha}\right\}. \tag{24}$$

The large size of the multinational sector in Ireland makes this import content of exports channel very relevant for policy analysis.[10] By considering the international fragmentation of the export goods production process, this feature 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 a parameter α:

$$Z_t = (1-\alpha)X_t \tag{25}$$

$$X_t^M = \alpha X_t. \tag{26}$$

This assumption of fixed proportions in the export bundle means 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:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[P_t^X X_t - W_t N_t^X - R_t^K \overline{K}_{t-1}^X \right]. \tag{27}$$

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:

$$\gamma^X MC_t^Z Z_t = W_t N_t^X. \tag{28}$$

The exporters marginal cost of production is:

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

$$MC_t^X = (1 - \alpha)MC_t^Z + \alpha P_t^{M*} S_t \tag{29}$$

where MC_t^Z is the marginal cost of locally-produced tradable goods used in the final export good production process, while $P_t^{M*} S_t$ is the world import price defined previously. In line with our small open economy assumption, Irish exporters are assumed to be price takers on the world market (i.e., P_t^X is taken as given). Export firms, therefore, only decide on the quantity to produce at a given price. 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:

$$\frac{P_t^X}{MC_t^X} \approx 1 + \xi^X \Omega_t^X - \beta \mathbb{E}_t \Omega_{t-1}^X \tag{30}$$

which again contains a forward-looking component relating current output changes to underlying marginal costs and expected future adjustment costs. Consistent with the small open economy assumption, foreign inflation is exogenously given and an increase in Irish exports does not influence world prices. Therefore, endogenous changes in Ireland's external competitiveness are driven by domestic factors.

2.3 *Net Foreign Asset Position*

Given the small weight of Ireland in the euro area (approximately 1 per cent), domestic developments are too small to affect area-wide macroeconomic aggregates. Therefore, the domestic interest rate, R_t, is assumed to be tied to the exogenously set euro area interest rate R_t^*:[11]

$$R_t = R_t^* \frac{E_t S_{t+1}}{S_t} e^F \tag{31}$$

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:

$$e^F = p\left(\frac{B_t}{Y_t} - \log \zeta\right) \tag{32}$$

where ζ is a parameter used to calibrate the steady-state external debt-to-GDP ratio, $B_t = \zeta Y_t$, and p is a parameter governing how quickly debt returns to its

[11] This assertion is consistent with empirical evidence provided by Honohan and Leddin (2006), who found that nominal interest rates in Ireland were substantially lower than those implied by a standard Taylor rule, with responses insufficiently small to be stabilising.

steady-state level. The implication of this model feature is that households have as much access to (foreign) funds as they desire, but the more they borrow the greater the premium they will be charged. This ensures that debt will not explode, as households will eventually try to reduce their debt back to the steady-state level to ensure they will not be charged this additional premium. This feature ensures the model is stationary (i.e., the model returns to the steady state following a temporary shock), a notoriously difficult task in small open economy models.

Consistent with the small open economy assumption that the rest of the world is taken as given and not modelled explicitly, the country's net foreign assets (NFA) evolve according to:

$$B_t = B_{t-1}R_{t-1} - (P_t^X X_t - P_t^M M_t) \tag{33}$$

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).[12] The evolution of NFA of the home country is determined by the aggregate stock of last period's NFA times the interest rate, plus (minus) the trade surplus (deficit). Since both importers and exporters are assumed to be price takers on the world market, and the the nominal exchange rate is fixed in line with Ireland's small weight in euro area aggregates, we abstract from valuation effects and implicitly assume that the trade balance is equal to the current account balance.

2.4 *Policy Authorities*

With monetary policy exogenous, instead of a Taylor rule we assume that a fixed exchange rate is maintained (i.e., the nominal exchange rate equals one). 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, g, of steady-state nominal output $\overline{Y}$:

$$G_t = g\overline{Y} \tag{34}$$

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):

$$P_t^N G_t = \Theta_t. \tag{35}$$

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

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:[13]

$$C_t = \omega^C C_t^M + (1 - \omega^C) C_t^N \tag{36}$$

$$I_t = \omega^I I_t^M + (1 - \omega^I) I_t^N \tag{37}$$

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

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

$$P_t^I I_t = P_t^N I_t^N + P_t^M I_t^M. \tag{39}$$

In equilibrium, the final goods markets clear when the demand from households and the rest of the world 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 (i.e., a trade surplus is necessary to pay down borrowings from abroad). The clearing conditions for the non-tradable goods, import, labour and capital markets are, respectively:

$$Y_t^N = C_t^N + I_t^N + G_t \tag{40}$$

$$M_t = C_t^M + I_t^M + X_t^M \tag{41}$$

$$N_t = N_t^N + N_t^X \tag{42}$$

$$K_t = K_t^N + \overline{K}_t^X \tag{43}$$

where capital in the export sector is fixed. Given that all households choose identical allocations in equilibrium, the aggregate quantities are expressed in domestic per capita terms. Adding the budget constraint of households and the entrepreneurs in each sector would allow us to derive the aggregate consolidated balance of payments condition for the economy. The economy's aggregate resource constraint is therefore:

$$Y_t = P_t C_t + P_t^I I_t + P_t^N G_t + P_t^X X_t - (P_t^M C_t^M + P_t^M I_t^M + P_t^{M*} S_t X_t^M). \tag{44}$$

[13] Kee *et al*. (2008) provide empirical evidence on the relatively low degree of substitution between imported and domestically produced goods in Ireland.

III CALIBRATION

We model the specific nature of the Irish economy within the context of the EMU. The calibration process involves the specification of values for steady-state (long-run) ratios, and model parameters that govern the model's dynamic adjustment to shocks. These values are provided in Tables 1 and 2. We target key steady-state ratios in order to resemble the underlying structure of the Irish economy. However, given the large fluctuations in the Irish economy since the foundation of the state, the elicitation of appropriate steady-state values is difficult. We choose a calibration based on the long-run averages (1960-2010) from the national accounts statistics, as gathered from the Economic and Social Research Institute (ESRI) model database. This data allows for the longest possible time horizon to be used.[14]

Table 1: *Calibrated Model Steady-States (as Percentage of GDP)*

	Per Cent
Private Consumption	64.0
Private Investment	17.4
Public Expenditure	16.8
Exports	69.7
Imports Total	67.9
Imports for Consumption	23.2
Imports for Investment	9.8
Imports for Re-export	34.9
Net exports	1.8

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

[14] The results of our simulations are qualitatively robust to alternative calibrations based on averages from the sub-periods 1970-2010, 1980-2010, 1990-2010 and 2000-2010. The major differences between the sub-periods is a secular decline in the GDP share of consumption, offset by a rise in the share of net exports. The investment and government expenditure shares have remained remarkably constant throughout time. The results from these alternative calibrations are available from the authors upon request.

Table 2: *Calibrated Model Parameters (Contd.)*

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

We assume 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 household's subjective discount factor consistent with an (annualised) interest rate of 3 per cent. The nominal output shares of government expenditures (16.8 per cent) and investment (17.4 per cent) are set to the respective domestic demand shares of public consumption and gross capital formation.[15] In the steady state, the trade balance simply covers net foreign interest payments. We therefore calibrate external debt to replicate steady state net exports to GDP of 1.8 per cent. We then set the share of consumption (64.0 per cent) 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 per cent, in line with OECD estimates using input-output (I/O) tables for the period 1995-2010. The share of imports in the aggregate consumption (29 per cent) and investment (48 per cent) 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

[15] In order to accurately calibrate the steady-state investment-to-GDP ratio, the parameter value for depreciation is 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.

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 examining sectoral data from the ESRI macroeconomic database, the labour share of export and non-tradable goods is set to 40 per cent and 70 per cent respectively. Accordingly, the total share of labour in output is 55.4 per cent.

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 calibration process involved identifying common values in the literature and recursively updating them when the impulse response functions (IRFs) 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, we 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).

IV SIMULATION EXERCISES

The conditions of the EU/IMF Financial Assistance Programme required a restructuring of the banking sector, a period of fiscal consolidation to put public finances back on a sustainable path, and 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 continued need for structural reforms to generate sustainable growth for the Irish economy. Although ranked as the 15th easiest country in which to do business, the OECD (2013) note that there is scope to further improve the business environment. Barriers to entry appear to be high, with

low firm birth and death rates indicating the Irish enterprise sector is not as dynamic as other OECD countries. Cumbersome licence and permit regulations, the use of market power by large firms to dictate long credit periods to SME suppliers and a high-cost legal system are cited as factors reducing enterpeneurship. Product market reforms reducing barriers to entry for new non-tradable firms could increase competitiveness in this sector. With a focus on export-led growth, 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. These should notionally increase price and wage competitiveness in these sectors. Increased innovation is 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 ÉIRE Mod for policy analysis, we examine the impact that such structural reforms could have on the Irish economy. However, DSGE models are too stylised to explicitly feature some of the nuanced measures proposed in these policy documents. Instead, these simulation exercises are an illustrative example of the use of ÉIRE Mod for policy analysis. In order to proxy the beneficial effect of an increase in innovation, we implement an exogenous productivity improvement shock 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. These last two simulations mimic an increase in wage competitiveness, and a reduction in the barriers to entry for new firms respectively. We then compare the dynamic reaction of our model to these structural reforms to those found in the Irish theoretical and empirical literature. This benchmarking of the model results against the empirical evidence is a particularly important component in assessing a model's suitability for policy analysis.

We simulate the model using Dynare (Adjemian *et al.*, 2011). The (stochastic) 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. As the model is quarterly, the impulse response functions represent the dynamic reaction of the model over 40 periods (i.e., 10 years).

4.1 *Effects of Increased Innovation*

The effects of an exogenous shock to productivity in the non-tradable sector are considered in Figure 2. The shock is simulated as a 1 per cent increase in the TFP component of the non-tradable good production function A_t^N, and proxies an increase in innovation driven by increased R&D spending. An increase in the level of efficiency with which factor inputs are used has a

positive impact on output in both the non-tradable and export sectors. Higher productivity implies lower marginal costs, which feed into lower prices. The lower inflation rate pushes up real wages. As the monetary union nominal interest rate has a minimal reaction to Irish inflation, the real interest rate increases. However, consumption increases as a result of higher labour income and the lower price of domestic goods. Higher efficiency reduces labour demand, with firms replacing labour with capital in the production process. As a result, employment (i.e., 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. Investment, which is more attractive following the shock due to the increased marginal product of capital, initially increases to facilitate the expansion in output. However, over the medium term, the income effect from a steady upturn in employment and the higher real wage rate means that consumption is brought forward at the expense of reduced investment.

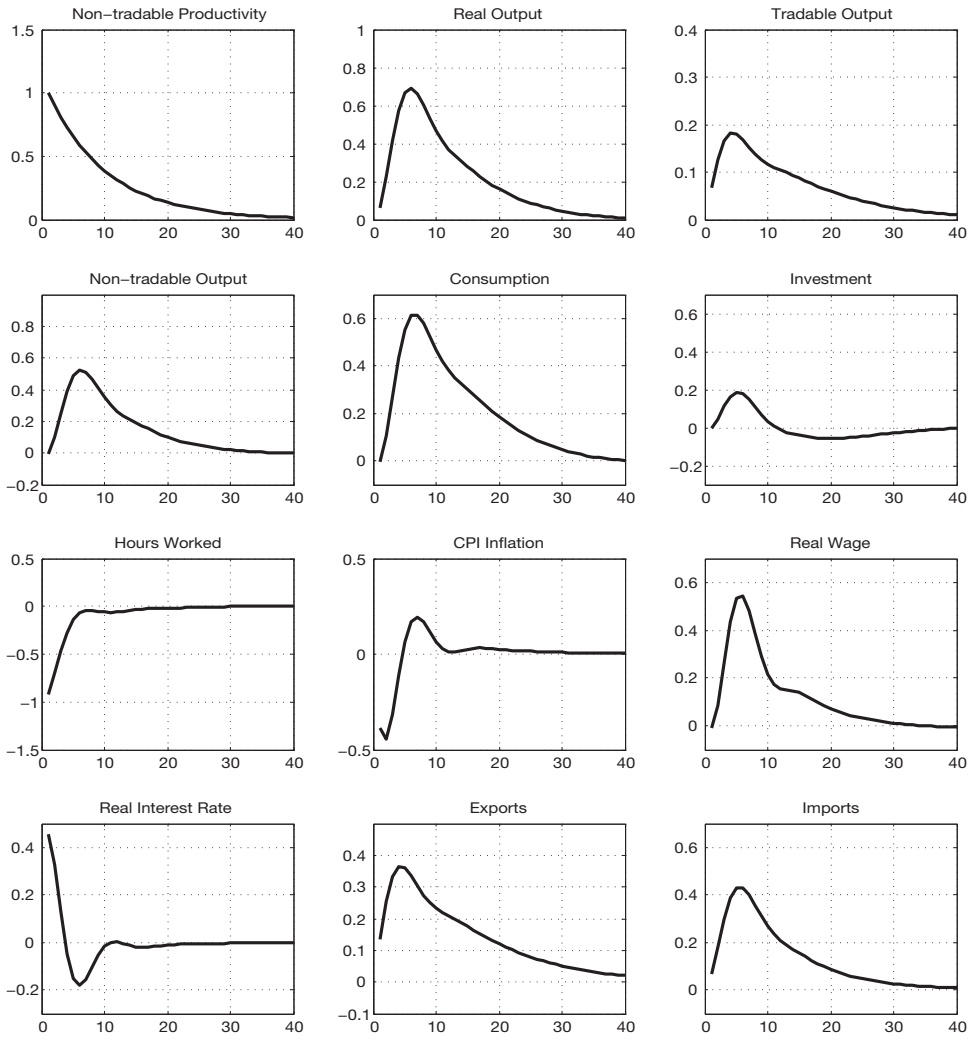
The productivity shock, by decreasing marginal costs in the non-tradable sector, makes domestically produced goods relatively less expensive and induces households to substitute imported goods with domestic goods. The change in relative prices discourages imports and improves the trade balance on impact. 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) increases the competitiveness of exporters.

4.2 *Effects of Labour Market Reforms: Increased Wage Competitiveness*

Figure 3 shows the dynamic impact of increasing wage competitiveness due to the reduction in the degree of monopoly power of workers or trade unions. This scenario is modelled as a transitory negative 1 per cent shock to the wage mark-up μ_t^W. A decrease in the wage mark-up results in lower production costs in both the non-tradable and export sectors through lower wages.[16] Non-tradable sector firms pass on these gains to consumers through lower prices. However, export firms are price takers and therefore cannot pass on these cost decreases. The higher demand for non-tradable goods means that firms increase their labour demand and employment increases to produce this extra output. Lower costs also enable export firms to produce more output. However, the effect is muted relative to the non-tradable sector who have now reduced their prices.

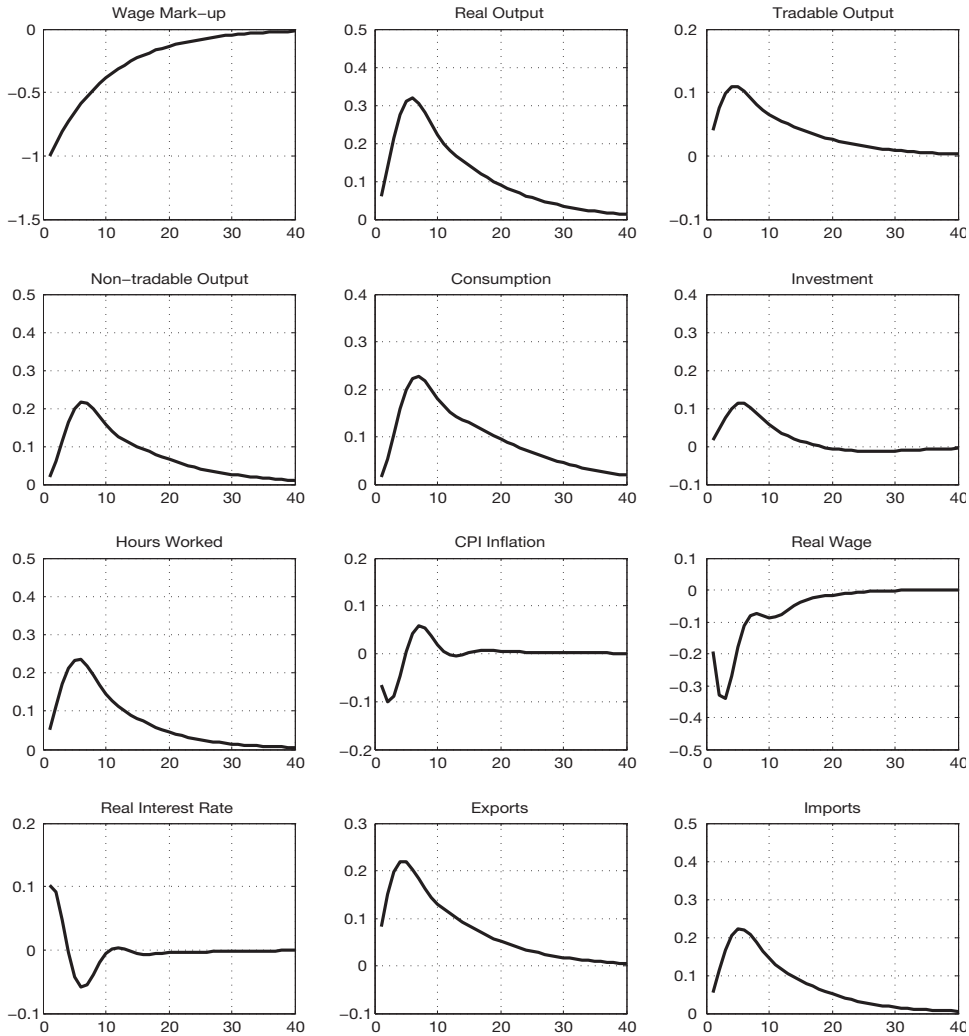
[16] As we assume full labour mobility, nominal wages are equalised across the two sectors.

Figure 2: *Increase in Non-Tradable Sector Productivity*



Despite lower real wages, the extra hours worked to satisfy the higher labour demand improves household's labour income. This helps to stimulate consumption, offsetting the effect of higher real interest rates. These higher real interest rates materialise as 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 pressure on nominal wages. Inflation decreases on impact as a result of the lower labour

Figure 3: *Increase in Wage Competitiveness*

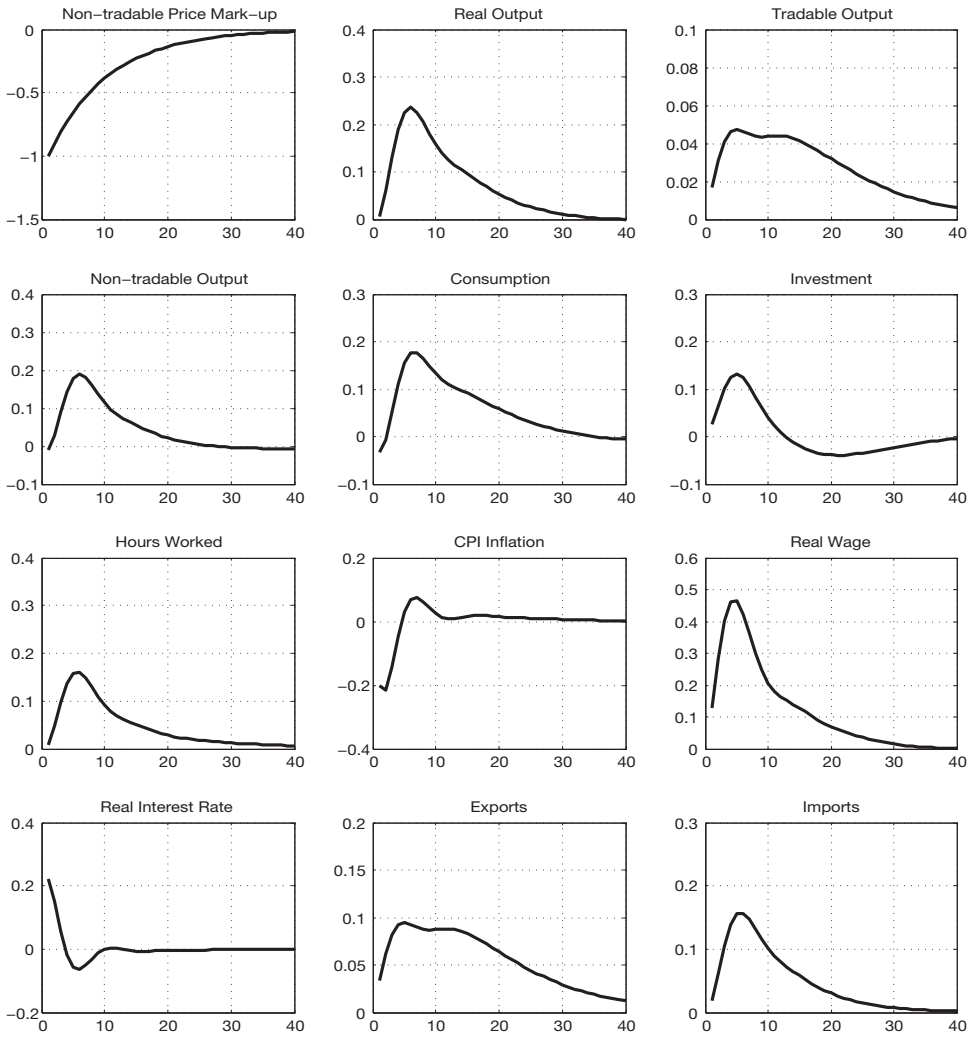


costs, but then eventually overshoots in the medium run due to the higher import prices. This increase in imports is necessary in order to satisfy the boost in the export sector output, which employs intermediate imported goods as inputs.

4.3 *Effects of Product Market Reforms: Reducing Barriers to Entry*

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 per cent

Figure 4: *Increase in Non-Tradable Sector Price Competitiveness*



shock to the price mark-up in the non-tradable sector μ_t^N, proxying decreased barriers to entry. Firm entry boosts investment, labour demand and output. By reducing firms' mark-up power, and hence the price mark-up and inflation, product market reforms lead to a rise in real wages and thus consumption. Although inflation decreases on impact due to the 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 the 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 monetary union nominal interest rate has a minimal reaction to the drop in Irish inflation. Despite this real interest rate increase, consumption increases as result of the lower relative prices of non-tradable goods and the higher labour income from higher wages and hours worked. These two effects dominate the negative effect that higher real interest rates have on consumption.[17] As resources are partially reallocated to meet the higher demand for non-tradable goods, output in the export 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 affected 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 of competitiveness dampens the increase in exports. Imports decrease, as foreign goods are now relatively more expensive than domestic non-tradable goods.

4.4 *Comparison with the Literature*

In order to assess the usefulness of ÉIRE Mod for the analysis of structural reforms in Ireland, we benchmark the model results against similar studies from the Irish theoretical and empirical literature. Our results on the effects of an increase in wage competitiveness are consistent with those obtained by Callaghan *et al.* (2014) using the ESRI's *HERMES* model (Bergin *et al.*, 2013). The authors find that a decrease in wage competitiveness adversely 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 basis for our simulation. While our results are qualitatively similar, a quantitative comparison is not possible given the differing approaches to modelling the shocks. While we introduce higher competition through a drop in the wage mark-up, Callaghan *et al.* (2014) model a change in wage competitiveness as a

[17] The expansionary effect of higher employment dominates the contractionary effect of real wage decreases on consumption when employment adjusts freely, i.e. without frictions. In the presence of hiring costs, product market policies may be insufficient to stimulate employment to the same extent and the total effect on consumption may be negative. Therefore, these results must be treated with caution as the core ÉIRE Mod 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.

change in wages not accompanied by a change in productivity. Barry and Devereux (2006) develop a neo-classical growth model to analyse the effects of a beneficial labour market shock that shifts the economy from an initial system of strong unions with monopoly power to a more centralised wage bargaining system. The authors find that this shock reduces wages and raises employment. Consistent with Barry and Devereux (2006), we also find that the productivity shock leads to a higher effect on GDP than the wage competitiveness shock.

Our results on price competitiveness are also consistent with those of Callaghan *et al.* (2014), who examine a 1 per cent increase in the price level to proxy for a decrease in competition in product markets. This shock is designed to proxy the impacts of policy choices or other adverse market developments such as the creation or facilitation of barriers to entry (regulatory and otherwise), or regulatory actions that act to limit retail price competition. The increase in prices raises firm's margins, and has a negative impact on consumption despite a rise in nominal wages. On the external side, price-taking manufacturing sector exporters are unable to pass on the increase in wage costs to international customers, and thus reduce their output and demand for labour in Ireland. As a result, GDP falls in real terms and unemployment rises. As with the wage competitiveness shock, the *HERMES* model's symmetry allows us to compare these results with ours. From a qualitative point of view, these results are consistent with ours. From a quantitative perspective, the Callaghan *et al.* (2014) analysis shows that the overall effect of this policy choice would be to reduce GDP in the long run by 0.3 per cent. Total employment falls by one-third of a percentage point in the long run, along with an increase in unemployment. Again, a comparison of the magnitude of our results is not possible, given the alternative approaches to modelling these shocks. While in Callaghan *et al.* (2014) reforms affecting competition are modelled through their "second-round effects" on the consumption price, we model a change in competition more directly though a change in firm's mark-up.

As Ireland is a small open economy, it is essential that the dynamic reaction of the trade balance is consistent with the empirical literature. The negative association between higher economic activity and external competitiveness is a common feature of empirical studies of the Irish economy (see, for example, Bergin *et al.*, 2013; Bermingham, 2006; Bermingham and Conefrey, 2014). In fact, Podstawski (2014) provides empirical evidence that this price competitiveness channel has been the most important driver of Irish current account deficits.[18] Overall, our model dynamics are in accordance with the Irish

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

theoretical and empirical literature, both in terms of direction and magnitude. We therefore consider our model well-tailored for the Irish economy and useful for counterfactual policy experiments.

V CONCLUSIONS AND FURTHER EXTENSIONS

We develop ÉIRE Mod, a quarterly DSGE model suitable for policy analysis in Ireland. We simulate productivity and wage and price mark-up shocks to mimic the impact of various structural reforms aimed at improving the efficiency and competitiveness of the Irish economy. We find that all the structural reforms lead to an increase in aggregate output. However, depending on the source of the shocks, there are important differences in the transmission channels and the effect on employment and external competitiveness. An increase in non-tradable sector productivity also benefits the tradable sector and supports export-led growth. Real wage income increases due to the large decline in inflation. Facing a relaxed budget constraint, households increase their consumption spending. The higher efficiency in factor input usage, however, reduces labour demand and employment.

This is not the case for the mark-up shocks, where employment expands following the reforms. A reduction in the monopoly power of non-tradable firms makes export-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 non-tradable sectors, boosts exports and supports opportunities for export-led growth. Given the MTES commits to a strategy of export-led growth and full employment, a careful assessment of the reforms implemented under this programme is necessary to ensure that they do not lead to counter-productive effects in employment and external competitiveness.

Our model does not feature either liquidity constraints or labour market frictions (apart from sticky wages), and hence may not capture some key aspects in the adjustment path of the economy following these reforms. For instance, it does not take into account that frictions, such as high hiring and firing costs due to strict employment protection, might reduce the potential growth and employment-enhancing effects of product and labour market 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. Cacciatore *et al.* (2012) suggest that structural policies would be more beneficial if implemented as a broad package of reforms. This facilitates the partial offsetting of any negative impacts from introduced reforms. For instance, reducing product markets

barriers to entry in parallel with labour market reforms reverses the wages losses that would result from the latter alone.

This work is a first step toward a suite of DSGE models for Ireland, and illustrates the transmission channels and policy analysis capabilities of ÉIRE Mod. However, there will be a number of extensions to the ÉIRE Mod. Already on the agenda are a financial sector (for greater 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 permit a historical decomposition of the shocks driving the Irish business cycle, and enable the model to forecast key economic variables. Del Negro and Schorfheide (2012), amongst many others, demonstrate that estimated DSGE models exhibit a strong forecasting performance. Comparing and contrasting the results from this suite of DSGE models with existing macroeconometric models, such as the *HERMES* (Bergin *et al.*, 2013) and *COSMO* (Bergin *et al.*, 2014), will facilitate greater analysis and discussion of the economic effects of contemporary Irish policy issues.

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APPENDIX

GLOSSARY

Appendix Table A1: *Model Variables*

A_t^N	Non-tradable sector productivity
A_t^X	Export sector productivity
B_t	External 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
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_t^M	Time-varying import price mark-up
μ_t^N	Time-varying non-tradable price mark-up
μ_t^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	Consumption good 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*}	World import price (in foreign currency)
P_t^{X*}	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^*	Gross rate of interest in the rest of the euro area
R_t^K	Rental price of capital

Appendix Table A1: *Model Variables (Contd.)*

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

Appendix Table A2: *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	Steady-state import price mark-up
μ^N	Steady-state non-tradable price mark-up
μ^W	Steady-state wage mark-up
ω^C	Import share in consumption goods
w^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
θ^M	Elasticity of demand for import goods
θ^N	Elasticity of demand for non-tradable goods
θ^W	Elasticity of demand for labour
ζ	External debt

Appendix Table A3: *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