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COSMO: A new COre Structural MOdel for Ireland

Adele Bergin[a,b], Niall Conroy[d], Abian Garcia Rodriguez[a,b], Dawn Holland[c], Niall McInerney[a,b], Edgar Morgenroth[a,b] and Donal Smith[e]

Abstract: COSMO is a new structural econometric model of the Irish economy, with a theoretically founded structure and specification. It is designed to be used for medium-term economic projections and policy analysis. This paper outlines the key mechanisms in the model and explores the behaviour of the model by examining a range of shocks. One of the key contributions of COSMO is the incorporation of financial frictions in a small open economy model. The behavioural equations in COSMO are estimated econometrically, and the second contribution of the model relates to how all available information at both annual and quarterly frequency is exploited in estimation, applying a novel technique to convert dynamics estimated at one frequency into the other.

**Corresponding author: adele.bergin@esri.ie*

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a The Economic and Social Research Institute (ESRI), Whitaker Square, Sir John Rogerson's Quay, Dublin 2, Ireland
b Department of Economics, Trinity College, College Green, Dublin 2, Ireland
c Department of Economic and Social Affairs, United Nations, New York, USA
d Irish Fiscal Advisory Council (IFAC), Whitaker Square, Sir John Rogerson's Quay, Dublin 2, Ireland
e Department of Finance, Upper Merrion Street, Dublin 2, Ireland

1. Introduction

COSMO (COre Structural MOdel of the Irish economy) is a new macro-econometric model of the Irish economy designed for both economic projections and policy analysis.[1] Similar to existing models for Ireland, we model the behaviour of the economy in a small open economy framework.[2] COSMO has a theoretically founded structure and specification, and in common with many recent macro-economic models, the short-term dynamics are Keynesian while a fully specified neoclassical supply side drives the long-run dynamics. The key innovations of COSMO are: (1) the inclusion of financial frictions in a small open economy model and (2) in estimating the model, we exploit all available information at both annual and quarterly frequencies, applying a novel technique to convert dynamics estimated at one frequency into the other.

Following the financial crisis, macroeconomic models were heavily criticised for paying little or no attention to financial frictions, the role of the banking sector and interrelationships (see, for example, Kenny and Morgan, 2011 for a review). The first significant contribution of COSMO is that it incorporates the interaction between credit markets, macroprudential policy and the property market into the model, thus linking the real and financial dimensions of economic activity. In particular, and as far as we are aware, COSMO is the first macroeconometric model that is capable of exploring macroprudential policy through restrictions on credit demand and the composition of liabilities. The Irish property bubble and bust represent the prototypical example of the destabilising spillovers between the real and financial dimensions of the economy. Indeed, the amplification of real volatility by financial distortions proved particularly calamitous in the Irish case and had dire consequences for the balance sheets of households, firms, banks and the Irish state (Honohan, 2010).

The financial crisis has led to a renewed interest in integrating financial frictions or models of the financial sector into general equilibrium macroeconomic models (Gerali et al, 2010; Brunnermeier and Sannikov, 2014). In the Irish context, several studies have examined the interaction between credit markets, macroprudential policy and the property market but have not addressed the nature of real and financial linkages in an estimated macroeconomic model.[3] One of the key innovations in COSMO is the integration of these partial equilibrium models of credit, and more general financial frictions concepts from the broader literature, into a framework that has the link between real and financial dimensions of economic activity at its core and, importantly, explicitly characterises the channels through which financial shocks are transmitted through the economy. For example, the price and quantity of mortgage and consumer credit extended by banks may have important implications for the intertemporal consumption decisions of households through their impact on

[1] Structural macroeconometric models are important tools for policy analysis and economic projections in many countries. Such models are used in countries including Austria (Baumgartner et al, 2004), France (Carnot, 2002), Denmark (Statistics Denmark, 2013), the Russian Federation (Basdevant, 2000) and Greece (Kasimati and Dawson, 2009). Structural econometric models for multiple countries such as the NiGEM model, (Barrell et al, 2010), the OECD model (see Herve et al 2011) and for the Euro Zone (Fagan et al, 2005) have also been constructed.

[2] Existing structural macroeconomic models of Ireland include HERMES (Bergin et al 2013) and HERMIN (Bradley et al, 1995, Bradley and Untiedt, 2008) while ÉIRE-Mod (Clancy and Merola, 2016) is an example of a DSGE model.

[3] See Gerlach-Kristen and McInerney (2014), Duffy et al (2016a,) and McInerney (2016) for an econometric analysis of the link between macroprudential policy, credit and the property sector. Clancy and Merola (2014) examine the impact of capital requirements on the property market in a DSGE model calibrated for Ireland.

house prices, housing wealth and net disposable income (Davis and Liadze, 2012). This change in consumption (or savings) behaviour has important implications for the trade balance, current account and net foreign asset position.

Moreover, COSMO facilitates an analysis of how macroprudential policy can influence the interaction between real and financial shocks in a structural macroeconomic model. Several macroprudential instruments have already been introduced by the Irish Central Bank in its capacity as the Irish macroprudential authority (Cassidy and Hallissey, 2016; McInerney, 2016). However, little is known about the macroeconomic impact and costs of macroprudential policy. For example, lowering the LTV and LTI ratios permitted on new mortgage lending may reduce leverage in the household and banking sector and thereby enhance the resilience of these sectors to real and financial shocks. However, the ensuing decline in house prices will, at least in the short term, lead to lower housing investment, consumption and employment. Therefore, COSMO provides scenario analyses that can allow policymakers to more precisely calibrate each macroprudential instrument.

From a financial stability perspective, COSMO highlights the exposure of banks' balance sheets to the two main assets classes that are used by banks and households as collateral- housing and commercial property. It can capture how the triggers of financial distress, such as a collapse in asset prices, can feedback into distress in the financial sector via mortgage arrears and corporate insolvencies and force the banking sector to raise additional capital.[4] The model thus embeds a bank capital accelerator as the central mechanism for raising capital is through raising the cost of credit to firms and households.

The behavioural equations in COSMO are estimated econometrically, and the second contribution of the model relates to how all available information at both the annual and quarterly frequency is exploited in estimation. This issue of a lack of long horizon time series data is an obvious problem for a macro-econometric model and has been noted in the modelling literature of other countries; see Andersen et al (2005), Basdevant (2000) and Olofin (2014). Andersen et al (2005), in particular, note that in constructing a quarterly model of Lithuania that the limited number of observations available implies that a number of the long-term parameters must be pre-fixed in the estimation and restricted to what the authors deem to be theoretically sound and or interpretable values. This is done, even though the ideal would be to have all long and short-run parameters estimated in practice, as estimating these parameters on short time series yields parameters with the wrong sign and or unreasonable magnitudes (Andersen et al 2005). While many models internationally use quarterly data, the coverage of variables that are available at a quarterly frequency for Ireland is quite limited and quarterly national accounts have only been published since 1997. However, utilising quarterly data as opposed to annual data is likely to improve the dynamics particularly of equations linking the financial markets to the real economy.

To deal with this, the model introduces a novel approach to incorporating both annual and quarterly data into the estimation process. As a first step, both a quarterly and an annual dataset are constructed and the model equations are estimated at both quarterly and annual frequencies. In constructing some of the quarterly series it is necessary to interpolate several variables for which

[4] As loans comprise the main expose of Irish banks to the real economy, the main source of risk facing the banking sector in COSMO is credit risk (McInerney, 2016). The latter is driven by fluctuations in collateral values, and changes in the income- and asset gearing of households and firms.

annual data are available. This approach has the advantage that it allows for the estimation of the quarterly dynamics of an equation even where only annual data is available or the use of the annual estimates where quarterly data is excessively noisy. The dynamic responses to shocks in both models are then tested. Of the two estimated long-run relationships, that which best conforms with prevailing national or international empirical estimates or with theoretical priors is selected and along with the estimated dynamics is imposed on the annual and quarterly equations, with the matching of the annual/quarterly relationship being achieved using calibration. As a final step the dynamic response to shocks in both models is tested again and from this the final model is selected and the matching quarterly/annual equation is calibrated. The use of data at two frequencies in COSMO thus allows for more of the parameters of the model to be estimated rather than calibrated, as is the ideal in a macroeconomic model. As a result both the annual and quarterly versions of the model will necessarily have the same long-run and dynamic properties.

The remainder of the paper is structured as follows: Section 2 outlines the main mechanisms in COSMO covering the supply and demand side of the model. Section 3 discusses the real-financial linkages. Section 4 outlines the estimation methodology including the technique used to incorporate both quarterly and annual data. Section 5 examines the behaviour of the model, by examining a range of exogenous and policy shocks and Section 6 concludes.

2. The Model Structure

In line with many macroeconomic models COSMO embodies the neoclassical synthesis.[5] This combines both short-run dynamics based on empirical evidence as well as theoretically founded long-run relationships which are static optimisation conditions (Fenz and Spitzer 2005). The long-run equilibrium is supply driven, determined by available factors of production and total factor productivity. The long-run properties of the model, as derived from optimisation, exert their influence through the error correction structure. This anchors the model and ensures that although there are short-run dynamics the variables do eventually converge to their long-run path as specified by theory.[6]

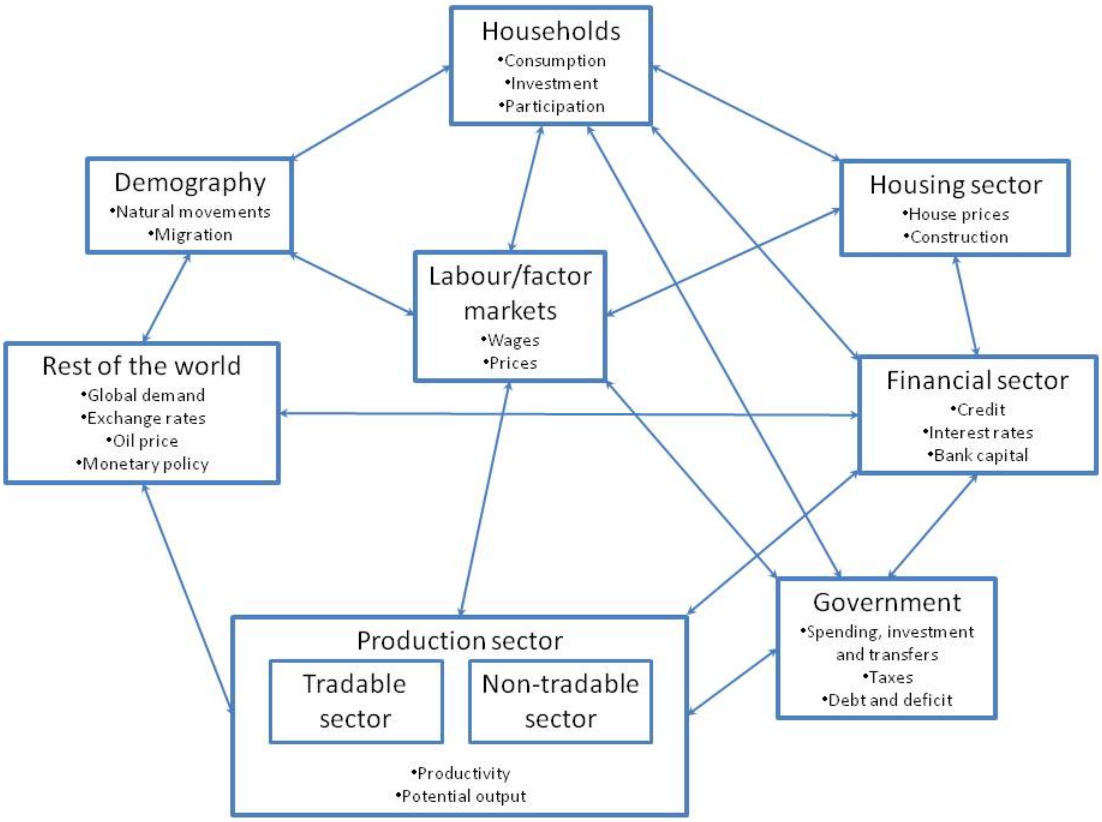
The model initially focuses on production relationships, and then examines the downstream expenditure and income consequences. As illustrated in Figure 1, the key mechanisms within the model can be summarised as follows:

- There are three sectors in the model: traded, non-traded and government.[7]
- There is an underlying production function for each sector that drives medium-term growth and a 'production gap' will feed back through prices to guide output towards capacity
- Output in the traded sector is driven by world demand and cost competitiveness.

[5] The most prominent example of this type approach is the NiGEM global macro econometric model. See Mitchell et al., (1998) for an overview.
[6] The short-run dynamics are not purely data driven as consistency with economic theory is given more importance.
[7] Although the potential output of the government sector is difficult to conceptualise, it is necessary to include a public sector component in a model for the whole economy; it broadly tracks the overall evolution of the rest of the economy.

- The non-traded sector is driven by domestic demand.
- The public sector is policy-driven, and includes the treatment of borrowing and debt accumulation.
- The labour market is open and through migration is influenced by conditions in alternative labour markets.
- Wages are determined in a bargaining model, and influenced by the factors that affect the supply and demand for labour – e.g. prices, taxes.
- Households make consumption decisions based on current income and net holdings of wealth (financial and non-financial)
- Households and firms demand credit based on activity levels (including income), cost of credit and collateral values, while banks set interest rates as a variable mark-up over funding costs.

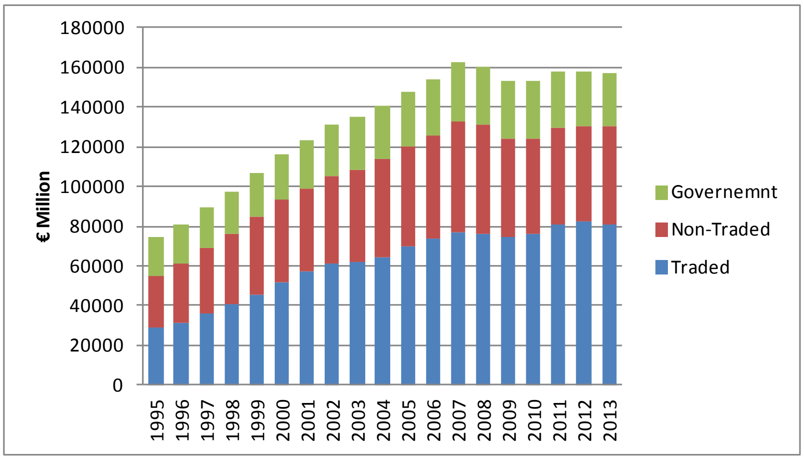
Figure 1: Main Mechanisms of COSMO



2.1. The Supply Block

On the production side, COSMO distinguishes between the traded sector, the non-traded sector and the government sector.[8] The disaggregation reflects the significant differences between firms/actors operating within the three sectors.[9] The traded sector has a high content of multinational firms operating within it, but is not exclusively multinational. It is constrained by global demand, a global user cost of capital and the state of technology in the traded sectors. The non-traded sector, by contrast, primarily contains firms operating in the national economy for which domestic conditions are of primary importance. The behaviour of the government sector is largely a policy choice but is constrained by the public sector capital stock in the short- to medium-term. Figure 2 shows the contribution of each sector to total gross value added (GVA).

Figure 2: Gross Value Added by Sector,€ million, basic 2012 prices



Source: CSO, National Accounts

The model underlying the supply-side for each of these sectors is a 3-factor normalised nested constant elasticity of substitution production function with labour augmenting technical progress. The estimation approach for each sector follows that of Barrell and Pain (1997). The nested CES production function for sector *i* is given as:

$$Y_i = \gamma_{1i}[\delta_{1i} Z_i^{-\rho_{1i}} + (1-\delta_{1i})(L_i e^{\lambda_{it}})^{-\rho_{1i}}]^{-1/\rho_{1i}} \qquad (1)$$

Where Y_i is output measured as each sector's gross value added, L_i is labour measured as total hours worked, λ_i is labour augmenting technological progress, δ_{1i} is the share parameter, γ_{1i} is a constant term that centres the function around the level of actual output, ρ_{1i} is the substitution

[8] Sectors are defined based on the Supply and Use Input-Output Tables from the Central Statistics Office. A sector is defined as traded if at least 50% of total final uses (excluding change in stocks) is exported. The government sector is defined as at least 50% of total final uses (excluding change in stocks) are used as government consumption. The non-traded sector comprises the remaining sectors.

[9] See Bradley and FitzGerald (1988) and Bradley, Fitz Gerald and Kearney (1993).

parameter and *Z* denotes a composite of capital, *K,* measured as the net productive capital stock and energy, *E,* measured as fossil fuel consumption. The composite of capital and energy is given by:

$$Z_i = \gamma_{2i}[\delta_{2i} K_i^{-\rho_{2i}} + (1-\delta_{2i}) E_i^{-\rho_{2i}}]^{\frac{-1}{\rho_{2i}}} \quad (2)$$

Using the profit maximising condition, which sets the marginal product of labour equal to the markup-adjusted real wage, we can derive a labour demand relationship of the form:

$$\ln L_i = c + \ln y_i - \frac{1}{1+\rho_{1i}} \ln \frac{w_i}{p_i} - \frac{\rho_{1i}}{1+\rho_{1i}} \lambda_{it} = c + \ln y_i - \sigma_{1i} \ln \frac{w_i}{p_i} + (\sigma_{1i} - 1)\lambda_{it} \quad (3)$$

Where c is a constant term and (w/p) is the real wage. This implies that in the long-run the demand for labour in each sector depends on the real wage, technological progress and level of output. The elasticity of substitution between labour and the capital energy composite is identified through the labour demand side and we test for differences across sectors. We also test that the constant returns to scale restriction holds across the three sectors. The long-run demand for capital in each sector follows a similar framework to that of labour. This long-run demand will move in tandem with the economy as a whole while also reacting to changes in its price, represented by the user cost of capital. The user cost of capital is in turn influenced by the interest rate on corporate credit, price changes as measured by the GVA deflator and, for the traded and non-traded sectors, the effective corporate tax rate.[10] The aggregate production function is the sum of the sectoral production functions and this determines the long run level of output. With the long-run level of output generated in the model an output gap can thus be calculated.

The long-run relationships among the variables as defined by first order conditions are used in the short-run equations to guide the error correction structure. This structure can be seen in the short-run dynamic equation for labour which is given as:

$$\begin{aligned} \Delta \log L_{it} &= \beta_1^l + \beta_2^l \sigma_{1i} (\log(w_{it-1}/p_{it-1}) + ((1-\sigma_{1i})/\sigma_{1i})\lambda_{it} - (1/\sigma_{1i}) \log(y_{it}/L_{it})) \\ &+ \beta_3^l \Delta \log L_{it-1} + \beta_4^l \Delta \lambda_{it} + \beta_5^l \Delta \log y_{it} + \beta_6^l \sigma_{1i} \Delta \log(w_{it}/p_{it}) \end{aligned} \quad (4)$$

In the long run labour converges to a path where labour productivity equals the real wage, however in the short-run dynamics are influenced by output growth, technological progress, real wage growth and a lagged dependent variable.

The mechanism by which convergence of the actual and long-run factor levels is achieved is termed the wage-price system. This system has an error correction structure and is a complete system that delivers the equilibrium levels of the factor inputs. In the labour factor market the nominal wage will adjust to align the first order condition. This process also occurs for the other factors on the

[10] As discussed further below, it is assumed that there is imperfect competition in factor markets: wages are determined in a bargaining framework while the user cost of capital is mainly determined by the interest rate on corporate lending, which is set as a markup over banks' funding costs.

production side. When a 'production gap' exists between the real price and productivity of an input this will feedback through the nominal price to guide capacity utilisation to that required by the first order condition. Through aligning all factors of production this wage-prices system also guides the overall economy towards its potential level of output. Producer prices are determined as a mark-up over marginal costs.

2.2 The Demand Side

Aggregate demand is determined by the national income identity and is divided into nine categories:

$$YER = PCR + IHR + IPR\_NT + IPR\_TR + IPR\_GV + GCR + SCR + XTR - MTR \qquad (5)$$

Where (YER) is real gross domestic product and (PCR) is personal consumption of goods and services. In this identity each of the components are modelled separately. The modelling of each component necessitates that investment be broken out into a number of subcomponents to reflect the differing determinants of various investment categories. There are equations for real traded and non-traded investment, for real government investment and for real investment in dwellings, $(IPR\_TR, IPR\_TR, IPR\_GV, \text{and } IHR)$. XTR and MTR, are real exports and imports respectively. SCR is the change in stocks and it also includes the national accounts residual term. In order to ensure that the output and the expenditure sides of the model are consistent in volume terms stocks are treated as the balancing item.

Personal consumption is a key equation on the demand side and is given by:

$$\begin{aligned}\Delta \log PCR_t &= \beta_1^c + \beta_2^c(\log PCR_{t-1} - \beta_3^c(\log PDR_{t-1}) - \beta_4^c \log(NFHA_{t-1} / \log PCD_{t-1}) \\ &- \beta_5^c(\log KHN_{t-1} / PCD_{t-1})) + \beta_6^c \Delta \log(PDR_t) + \beta_7^c \Delta \log(NFHA_t / \log PCD_t) \\ &+ \beta_8^c \Delta \log(KHN_t / PCD_t)\end{aligned} \qquad (6)$$

This equation states that in the long-run personal consumption grows in line with personal disposable income (PDR), and household wealth. Wealth in this equation has two components, housing wealth (KHN), and net financial assets $(NFHA)$.[11] For the consumer, the value of each of these components of total wealth are assessed relative to price of personal consumption goods and services (PCD).

For a small open economy the dynamics of exports are an important consideration (Ruane et al., 2013). Exports in the model are a function of traded sector output. In turn, traded sector output depends on a number of national and international variables. In the long-run, output is driven by the level of world demand and is also affected by competitiveness modelled as the average wage in the sector relative to competitor trade prices.

[11] The importance of both real estate and financial wealth in consumption dynamics has been reemphasised in the post financial crisis literature, see for example Iacoviello and Pavan (2013).

2.3 The Public Finances

The key equation describing the public finances is the nominal general government balance, $(GGBN)$:

$$GGBN = DTH + DTE + TSN - GCN - IPN\_GV - THN - INP + OGG \qquad (7)$$

This identity comprises the difference between the components of the governments revenue and expenditure plus a residual term (OGG). Government revenue has three components, taxes on personal income and wealth (DTH), corporation tax (DTE) and taxes on products (TSN). The revenue from each of these taxes is the product of the average effective tax rate and the appropriate tax base in each case. On the expenditure side the government's nominal spending is divided into four components, investment (IPN), consumption (GCN), transfers (*THN*), and interest payments (*INP*). As a behavioural rule, government consumption and investment are modelled as rising in line with the economy's potential output. The transfers component of government expenditure is a function of the the level of unemployment and the dependent population. An option is included in COSMO to index these payments to prices or wages. The final component of expenditure is the interest payments on the national debt which is modelled as a function of interest rates and the national debt. This block of COSMO allows analysis of policy changes and also quantification of the impact of macroeconomic shocks on the government balance.

2.4 The Labour Market

As outlined in the discussion of the supply block, over the long-run the behaviour of real wages is determined by the profit maximization condition. However, as in other models of this type, in the short-run a wage bargaining framework is incorporated into the wage equation to allow a richer and more realistic set of dynamics (Livermore 2004). Employers and employees bargain over the net real consumption wage as this is the wage employees are ultimately interested in. The taxes are netted off the gross real consumption wage as paid by the employer. The relative strength of the two bargaining parties also determines the outcome; this is captured through the inclusion of the unemployment rate.[12] This is a proxy for the strength of employees in a wage negotiation. The labour market also displays rational expectations behaviour as in the wage bargaining process as employees in the model also consider future price of consumption goods. The wage equation is thus given as:

$$\Delta \log w_{it} = \gamma_1 + \alpha_1 \left(\log\left(\frac{\mathrm{w_{it-1}}}{\mathrm{p_{it-1}}}\right) + \left(\frac{1-\sigma_{1i}}{\sigma_{1i}}\right)\lambda_{it-1} - \left(\frac{1}{\sigma_{1i}}\right)\log\left(\frac{y_{it-1}}{L_{it-1}}\right)\right) + \alpha_2\left(\log\left(\frac{\mathrm{w_{it-1}}}{\mathrm{PCD_{t-1}}}\right) - \beta_1 URX_{t-1} - \beta_2 DTHX_{t-1}\right) + \delta_1 \Delta\log(PCD_t^e) \qquad (8)$$

where YPD_{it} is the sectoral output deflator, URX_t is the unemployment rate, $DTHX_t$ is the personal effective tax rate, and PCD_t^e is the expected value of the consumption deflator.[13]

[12] The interaction between the unemployment rate and wage bargaining process is discussed in Christofides and Oswald (1992).

[13] Note that p_{it} is the sectoral output deflator so that w_{it}/p_{it} represents the product wage.

The supply of labour is determined by demographics, the participation rate and migration. The supply of labour consists of a series of relationships determining population of working age, participation in the labour force and migration. Because of the different pattern of labour market participation for males and females, the supplies of female and male labour are modelled separately. The participation rates are modelled as a function of real after-tax wages and the unemployment rate. A key factor affecting labour supply in Ireland over the last century has been migration. Because of the changing nature of migration over the past decade or so, we model gross flows. In COSMO, emigration is determined by the relative attractiveness of alternative labour markets. For example, if the returns to working in Ireland dis-improve relative to the UK, measured in terms of real after-tax earnings, there will be a tendency for outflows of migrants to start up or accelerate. Immigration is partly exogenous in the model but does react to changes in domestic economic conditions.

3. Real-Financial Linkages

The main channels through which macro-financial linkages and macroprudential policy are embedded in the model are via the supply and demand equations for each type of lending. There are four types of credit in COSMO, reflecting the major components of the lending portfolios of Irish banks. The demand equations for each type of credit are primarily functions of the real cost of credit and activity or income levels. These equations are augmented in some cases where collateral values may play an important role and where macroprudential instruments may constrain the volume of credit. In terms of credit supply, banks are assumed to be monopolistically competitive due to information asymmetries and other frictions (Freixas and Rochet, 1998). From a modelling perspective, this implies that banks set interest rates as a mark-up over funding costs (Davis and Liadze, 2012). The assumption that banks set interest rates independent of loan quantities is crucial to the separate identification of the supply and demand functions for credit (Nobili and Zollino, 2012). The next section discusses these equations in more detail.

3.1 Household Credit

The Central Bank of Ireland recently introduced restrictions on the ratio of loan-to-income (LTI) and loan-to-value (LTV) at which households could borrow (CBI, 2015). As these restrictions target new mortgage lending, mortgage demand is modelled in terms of the volume of new mortgage lending rather than the outstanding stock of mortgage credit. It is assumed to be a function of repayment capacity, given by income levels and the mortgage interest rate, and house prices, which represent the value of household collateral. In addition, the equation is augmented with the exogenous or non-cyclical components of the LTV and LTI ratio, which reflect the change in credit conditions similar to that which can be enacted by the macroprudential authority.[14]

[14] See Duffy et al (2016a) for details.

The equation for new mortgage lending therefore has the following form:

$$\log\left(\frac{MORFL_t}{PCD_t}\right) = \propto_1 + \beta_1 log\left(\frac{MORFL_{t-1}}{PCD_{t-1}}\right) - \beta_2(SVR_t - PCDX_{t-1}) + \beta_3 \Delta logPDR_t$$

$$+\beta_4 \Delta log\left(\frac{HD_t}{PCD_t}\right) + \beta_5 log(LTV_t^a) + \beta_6 log(LTI_t^a) \quad (9)$$

where $MORFL_t$ is the volume of new mortgage lending, SVR_t is the representative variable mortgage interest rate, $PCDX_t$ is the percent change in the personal consumption deflator, HD_t is the housing deflator, and LTV^a and LTI^a are the adjusted LTV and LTI ratios, respectively.

The outstanding mortgage stock then evolves according to a perpetual inventory method which relates the current stock to the stock in the previous and the current level of new mortgage lending.

The supply of mortgage credit is represented by the mortgage interest rate and is modelled as a mark-up over deposit and money market funding costs (Davis and Liadze, 2012). This time-varying spread is a function of cyclical, risk and prudential policy factors. The riskiness of mortgage lending to the household sector should reflect the loss-given-default associated with this type of lending as well as the ability of households to service this debt. The former is captured by the equity households have in their homes while the unemployment rate is used to approximate the latter. As discussed below, both of the variables are important predictors of mortgage arrears in the Irish context.[15]

COSMO also allows macroprudential policy to act directly on the bank and not just indirectly via mortgage demand. These additional instruments affect the cost of credit by targeting the liquidity and capital structure of the bank. Restrictions on the loan-to-deposit ratio were introduced in Ireland as part of the *Financial Measures Programme* (CBI, 2011) in 2011 while requirements for the capital to risk-weighted assets have been introduced through the implementation for the Basel III framework (BCBS, 2010).

The supply of mortgage lending is modelled in an error-correction framework with the following long-run form:

$$\begin{aligned} SVR_t \; = \; & \propto_1 + \beta_1 HHEquity_t + \beta_2 URX_t + \beta_3 LTD_t + \beta_4 CAP_t + \beta_5 IDep_t \\ & + \beta_6 Euribor_t + \varepsilon_{2t} \end{aligned} \quad (10)$$

where SVR_t is the representative mortgage interest rate, $HHEquity_t$ is household equity given by the residual proportion of housing wealth net of the mortgage stock, LTD_t is the loan-to-deposit ratio, CAP_t is the ratio of bank capital to risk-weighted assets, $IDep_t$ is the deposit interest rate, and $Euribor_t$ is the representative interest rate on short-term money market funding.

Consumer loans have historically represented a relatively small share of the loan book of Irish banks.[16] The approach to modelling this type of non-collateralised lending in COSMO is similar to

[15] Unfortunately, the time-series of mortgage arrears is relatively short. For this reason, the main predictors of mortgage arrears rather than the arrears variable itself are included in the mortgage supply equation.
[16] The average share of consumer loans in total lending over the last 3 decades has been approximately 10 percent. For comparison, the share of mortgage credit was 40 percent over the same period.

that for mortgages. The quantity of consumer credit demanded is a function of the cost of consumer credit, personal income and net housing wealth, with the latter capturing the "wealth effect" of higher house prices on the demand for consumer loans.[17] On the supply side, the interest rate on consumer loans is again a variable mark-up over the interest rates on deposit and wholesale funding. The main difference between the mortgage interest rate and consumer interest rate equations is that net financial wealth replaces household equity as a proxy for the risk associated with unsecured lending to households.

3.2 Corporate Credit

The Irish bubble and bust period highlighted the differences in the volatility of commercial real estate and non-real estate corporate lending. COSMO therefore models the demand for each type of corporate credit separately. The demand for bank credit by non-real estate firms is assumed to be a function of the cost of borrowing, corporate profits, the price of commercial property and real GDP. Corporate profits are included to capture the preference of firms who face an external financing premium to use relatively cheaper internal resources to fund investment opportunities.[18] The value of commercial property can influence the cost and availability of credit through the collateral channel (Kiyotaki and Moore, 1997), while real GDP is used to capture the real investment requirements of non-financial firms.[19]

The demand equation for real estate credit is similar to that for non-real estate lending except that the corporate profits variable is excluded due to the lack of data on the profits of real estate firms. The advantage of allowing for different coefficients on the other variables across the real estate and non-real estate equations is that it highlights the particularly strong cyclicality and sensitivity to property prices of the former.

In terms of the supply of corporate credit, the interest rate on corporate credit is set as a mark-up over funding costs. As with the mortgage and consumer credit interest rate, the mark-up depends on cyclical, risk and policy factors. The effect of cyclical and risk factors are captured by the insolvency rate and income gearing of Irish firms, respectively, while the impact of prudential policy factors are captured by the loan-to-deposit and capital to risk-weighted assets ratios.[20]

3.3 Arrears, Insolvencies and Bank Capital

Following the financial crises, financial distress in the Irish private sector was most vividly manifested in the spike in household mortgage arrears and corporate insolvencies. Modelling the triggers of this distress and its transmission back to banks' balance sheets is therefore of critical importance if a model is to be useful from a financial stability perspective.

[17] See McCarthy and McQuinn (2014) for evidence on the relationship between consumption and housing wealth in Ireland.
[18] The substantial majority of Irish firms are small and medium sized enterprises.
[19] See McInerney (2016) for a discussion on the role of commercial property prices in bank lending.
[20] A particularly interesting feature of the credit supply equations is the differential magnitude of the coefficients on the capital ratio which indicate how Irish banks adjust to higher capital requirements. See McInerney (2016) for a discussion of this aspect of the model and how these coefficients relate to the international evidence.

Mortgage arrears in COSMO are assumed to be a function of the repayment capacity and equity position of the household. Studies using Irish loan-level data have found that the main factors driving repayment capacity are unemployment and income gearing, where the latter is approximated by the mortgage repayment to income ratio (Lydon and McCarthy, 2013). International studies of mortgage arrears using aggregate data have found that "undrawn equity", or the residual proportion of housing wealth net of mortgage debt, is also a significant predictor of arrears (Whitely et al, 2004). COSMO therefore relates mortgage arrears to variables that affect the ability of the household to service the mortgage such as the mortgage interest rate, the income gearing of the household and the unemployment rate, and to a variable that reflects the equity position of the household, namely "undrawn equity".

The approach to modelling corporate insolvencies is similar to that of mortgage arrears in that firm survival is a function of real and financial variables. International evidence on the aggregate rate of corporate solvency suggests that indebtedness, the cost of credit, and property prices, as a reflection of collateral values, are significant drivers of the aggregate rate of corporate insolvency (Vlieghe, 2001). Irish evidence at the micro-level also suggests that demand factors and indebtedness play an important role in firm survival (Kelly et al, 2014). COSMO therefore relates the aggregate rate of corporate insolvency in Ireland to the cost of corporate credit, the unemployment rate, commercial property prices, and to corporate indebtedness as approximated by the ratio of corporate credit to GDP.[21]

Finally, as mentioned above, COSMO treats banks' holdings of capital endogenously and it is assumed that these holdings are adjusted primarily through retain earnings. Banks tend to maintain often considerable buffers above the minimum capital requirements mandated by the prudential authority. The size of these buffers may relate to differences in how banks assess portfolio risks, in order to ensure prompt access to wholesale funding at relatively low interest rates if growth opportunities arise, or to avoid penalties if capital holdings were to temporarily breach the regulatory minimum (Estrella, 2004).

There is much empirical evidence on the main factors that determine these buffers and thus the capital structure of banks.[22] In COSMO, these buffers are a function of the size of the banking system, bank profitability, the share of deposit funding in liabilities, the share of real estate in total lending and the unemployment rate, which captures repayment risk due to macroeconomic factors.[23]

As mentioned above, the capital ratio (CAP_t) is given by the ratio of bank capital to risk-weighted assets and has the following form:

$$\log\left(\frac{BCap_t}{RWA_t}\right) = \alpha_1 - \beta_1 \log\left(Assets_t/YEN_t\right) + \beta_2 \log\left(URX_t\right) + \beta_3\left(Lrn_t - i3m_t\right)$$

$$+\beta_4 \log\left(Constre_t/Loans_t\right) - \beta_5 \log\left(Deposits_t/Liabs_t\right) \tag{11}$$

[21] See McInerney (2016) for details.
[22] See Gropp and Heider (2010) and the references therein.
[23] See McInerney (2016) for a more detailed discussion of the approach to modelling the capital structure of the Irish banking sector.

where $BCap_t$ is bank capital, RWA_t are risk-weighted assets, $Assets_t$ are the total assets of the banking sector, YEN_t is nominal GDP, Lrn_t and $i3m_t$ are the long- and short-term government bond rates, respectively, $Loans_t$ is the total stock of bank lending, $Deposits_t$ are the deposits of the households and non-financial corporate sectors, and $Liabs_t$ are the total liabilities of the banking sector.

3.4 Real Estate Markets

The real estate sector is an important source and propagator of economic shocks (BCBS, 2011). Indeed, both the housing market and the market for commercial property have generated significant economic turbulence in the case of Ireland (Duffy et al, 2016a; McInerney, 2016). As housing represents the primary asset of Irish households, house price fluctuations have important implications from both a macroeconomic and financial stability perspective (McCarthy and McQuinn, 2014; McInerney, 2016). Similarly, the price of commercial property affects the ability of firms to obtain credit through its role as collateral and therefore has consequences for investment decisions. Moreover, a sharp decline in the value of commercial property affects banks' balance sheets through a higher loss-given-default and a higher probability of default, which impairs banks' capital position. As a result, banks are likely to try to reduce their exposure to the sector which may exacerbate the decline in activity and the price of commercial property in that sector (McInerney, 2016).

House prices are modelled as an inverted demand function for housing, which relates real house prices to income levels, the per capita housing stock, and the user cost of housing. [24] These "traditional" models of house prices performed poorly in the boom and bust period, mainly due to the limitations of the user cost variable as a measure of credit availability (Duffy et al, 2016a). The recent literature on house prices has therefore sought to augment these house price models with variables which serve as proxies for credit conditions such as the LTV ratio (Duca et al, 2011). However, as COSMO models both the mortgage interest rate and the quantity of mortgage credit, it can model the impact of credit conditions on house prices more structurally. The indicators of credit conditions in COSMO are the exogenous components of the LTV and LTI ratios. Therefore, COSMO can precisely quantify how changes in credit conditions affect the availability of credit and, through the inclusion of the actual mortgage stock outstanding, their impact on house prices.[25] Finally, the unemployment rate is also included in the house price model as a proxy for market sentiment (Kelly and McQuinn, 2014). Accordingly, the (long-run) equation for house prices has the following form:

$$log\left(\frac{HD_t}{PCD_t}\right) = \propto_1 + \beta_1 log\left(\frac{HStock_t}{Pop2545_t}\right) + \beta_2 log(PDR_t) - \beta_3 USER_t$$

$$+\beta_4 log(MOR_t/PDR_t) - \beta_5 log(URX_t) \qquad (12)$$

where $HStock_t$ is the housing stock, $Pop2545_t$ is the number of 25 to 45 year olds in the population, $USER_t$ is the user cost of housing capital and MOR_t is the outstanding mortgage stock.

[24] See Murphy (2004) for an overview of this literature.

[25] The mortgage stock in the house price equation is normalised by income so that significant deviations of mortgage credit from income will indicate a relaxation of credit conditions. See McInerney (2016) for further discussion of the role of this variable in a model of the Irish banking and property sectors.

On the supply side, housing investment is modelled as a function of Tobin's Q, cyclical factors, and the cost and availability of credit. Tobin's Q reflects the profitability of residential investment and is approximated by the ratio of house prices to construction costs.[26] Similar to the model for housing demand, there are two credit channels in the model of housing supply. The first channel is the cost of credit to construction firms given by the interest rate on corporate credit while the second channel reflects the availability of credit as approximated by the growth rate of construction credit.[27] Finally, the unemployment rate and corporate insolvency rate are included in the model as indicators of sentiment that may proxy for uncertainty about the future path of house prices (Duffy et al, 2016a; McInerney, 2016).

This gives the following equation for residential investment:

$$log(IHR_t) = \alpha_1 + \beta_1 \log(IHR_{t-1}) + \beta_2 log\left(\frac{HD}{BCosts}\right) - \beta_3 \Delta(INFC_t - PCDX_{t-1})$$

$$+\beta_4 \Delta\left(\frac{ConstRE_t}{PCD_t}\right) - \beta_5 \log(URX_t) - \beta_6 \log(Insolr_t) \quad (13)$$

where $BCosts_t$ are building costs, $INFC_t$ is the corporate credit interest rate and $Insolr_t$ is the corporate insolvency rate.

The total stock of dwellings then evolves according to the perpetual inventory method where current residential investment accumulates on to the depreciated stock from the previous period (Duffy et al, 2016a).

Unfortunately, time series data on the stock of commercial property are not available for Ireland. Instead, and following Whitely and Windram (2003), COSMO assumes that the supply of commercial property can be approximated by the private sector capital stock. The price, or capital value, of commercial property is then modelled as an inverted demand function that is similar to the house price model. Capital values are assumed to be a function to real GDP, the private sector capital stock and the cost and availability of credit.[28] Importantly, COSMO allows house prices to affect commercial property capital values in the short run as construction firms compete for the same resources to complete both residential and commercial property investment.

4. Estimation Methodology

One of the innovative features of the COSMO model is that it uses both annual and quarterly data. In order to have data available at both frequencies annual series are converted to quarterly and vice versa. In constructing the quarterly series it is necessary to interpolate several variables. For this purpose the Chow-Lin interpolation method which smoothes the error term across years is extensively used (Chow and Lin 1971). [29] With both a quarterly and an annual dataset available the equations that make up the model are estimated at both quarterly and annual frequencies. This

[26] See Poterba (1984) for a Tobin's Q model of housing investment.
[27] Unfortunately, the interest rate on corporate credit is not available by sector and so the weighted-average across all sectors is used.
[28] See McInerney (2016) for details.
[29] For a discussion on the applications of the Chow-Lin method in the context of National Accounts see Marini (2016).

approach has the advantage that it allows for the estimation of the quarterly dynamics of an equation even where only annual data is available or the use of the annual estimates where quarterly data is excessively noisy.

As previously outlined, COSMO is built with an error correction structure. This is a key feature of this class of models as it provides a well defined long-run equilibrium and quasi steady-state path for the variables (Carnot 2002). This structure is thus reliant on the estimation of the error correction coefficient. By using two frequencies long-term relationships between variables can be established even where quarterly time series would have been too short for these to be estimated. This is an important consideration in the case of the Irish economy as quarterly national accounts for Ireland are only available from the first quarter of 1997 and many financial series are also only available over a short time horizon.

As regards constructing a single model with data at two frequencies, in order to achieve a consistent quarterly and annual model, versions of the long-run relationship of each equation are estimated using both the annual and quarterly datasets. The dynamic responses to shocks in both models are then tested. Of the two estimated long-run relationships, that which most closely coincides with prevailing national and international estimates, or with theoretical priors, is selected and along with the estimated dynamics is imposed on the annual and quarterly datasets. The matching of the annual/quarterly relationship is therefore achieved through calibration. As a final step the dynamic response to shocks in both models is tested again and from this the final model is selected and the matching quarterly/annual equation is calibrated.

More formally if the 'true' or preferred model is that estimated using the annual data:

$$\Delta \ln(y_{At}) = \alpha_{A0} + \lambda_{A1}\left[\ln(y_{At-1}) - \sum_{j=1}^{J} \beta_j \ln(x_{Aj,t-1})\right] + \gamma_A \Delta \ln(y_{At-1}) + \sum_{j=1}^{J} \delta_{Aj} \Delta \ln(x_{Ajt}) \tag{14}$$

A quarterly model can be (approximately) calibrated to exhibit the same dynamic behaviour

Quarterly version:

$$\Delta \ln(y_{Qt}) = \alpha_{Q0} + \mu\lambda_{A1}\left[\ln(y_{Qt-1}) - \sum_{j=1}^{J} \beta_j \ln(x_{Qj,t-1})\right] + \gamma_A \Delta \ln(y_{Qt-1}) + \sum_{j=0}^{J} \delta_{Qj} \Delta \ln(x_{Qjt}) \tag{15}$$

where

$$\delta_{Qj} = \frac{4\delta_{Aj} + \mu\lambda_A \beta_j \begin{Bmatrix} 3 + 2(1 + \mu\lambda_A + \gamma_A) \\ + (1 + \mu\lambda_A + \gamma_A)^2 - \gamma_A \end{Bmatrix}}{\begin{Bmatrix} 1 + (1 + \mu\lambda_A + \gamma_A) + (1 + \mu\lambda_A + \gamma_A)^2 \\ + (1 + \mu\lambda_A + \gamma_A)^3 - \gamma_A - 2\gamma_A(1 + \mu\lambda_A + \gamma_A) \end{Bmatrix}} \tag{16}$$

with μ calibrated by grid search.

This conversion procedure can best be illustrated through an example. Annual data for the import price deflator is available since 1970 while data at the quarterly frequency is only available since the first quarter of 1997. Estimating separate models at each frequency may therefore produce different dynamics and long-run behaviours, particularly as the relation between the import price deflator (mtd) and its determinants may be subject to structural breaks over the longer time period. Prior to consistency being imposed, separate models are estimated using the quarterly and annual data to determine which model is most plausible in terms of statistical properties and theoretical priors.

In COSMO, the import price deflator is a function of global non-commodity prices (*cpx)* and oil prices (*poe)* converted into euro using the euro-dollar exchange rate (*rex_us).* First, the long-run relationship between the variables is determined. Separate long-run models are estimated using the annual and quarterly data over the full sample for which each frequency is available. These models yield the following coefficients, where "_a" and "_q" represent the annual and quarterly values of the variables, respectively.

$$\log(mtd\_a_t) = -0.26+0.98*\log(cpx\_a_t/rex\_us\_a_t)+0.13*\log(poe\_a_t/rex\_us\_a_t) \quad (17a)$$

$$\log(mtd\_q_t) = 1.39+0.64*\log(cpx\_q_t/rex\_us\_a_t)+0.09*\log(poe\_q_t/rex\_us\_q_t) \quad (17b)$$

It is clear that although the long-run response of import price is similar using the annual and quarterly data, the response with respect to competitor prices is quite different. From an empirical perspective, an elasticity of over 0.9 on the response of import prices to global prices would be expected *a priori*, given the share of non-commodity imports in total Irish imports.

Prior to imposing a structure on the long-run relationship, the dynamics of the annual and quarterly models are estimated in an error-correction model, yielding the following coefficients:

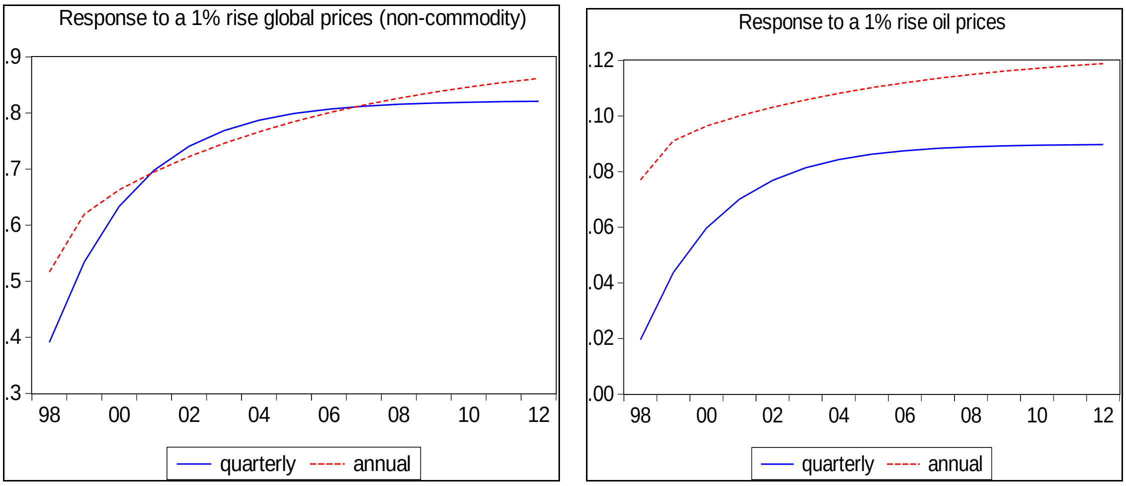
$$\begin{aligned}\Delta\log(mtd\_a_t) = {} & 0.01-0.11*(\log(mtd\_a_{t-1})-0.91*\log(cpx\_a_{t-1}/rex\_us\_a_{t-1}) \\ & -0.12*\log(poe\_a_{t-1}/rex\_us\_a_{t-1}))+0.52*\Delta\log(cpx\_a_t/rex\_us\_a_t) \\ & +0.07*\Delta\log(poe\_a_t/rex\_us\_a_t)+0.11*\Delta\log(mtd\_a_{t-1}) \quad (18a)\end{aligned}$$

$$\begin{aligned}\Delta\log(mtd\_q_t) = {} & 0.08-0.12*(\log(mtd\_q_{t-1})-0.82*\log(cpx\_q_{t-1}/rex\_us\_q_{t-1}) \\ & -0.09*\log(poe\_q_{t-1}/rex\_us\_q_{t-1}))+0.35*\Delta\log(cpx\_q_t/rex\_us\_q_t) \\ & +0.01*\Delta\log(poe\_q_t/rex\_us\_q_t)-0.13*\Delta\log(mtd\_q_{t-1}) \quad (18b)\end{aligned}$$

These models exhibit slightly different dynamics[30] in the short and long run as is indicated in Figure 3, which plots the response of import prices to a 1 percent increase in competitor prices (left panel) and a 1 percent increase in oil prices (right panel).

[30] in some cases the annual data gives an estimation of the error correction coefficient where the quarterly would have estimated a weak or insignificant parameter due to the short time horizon.

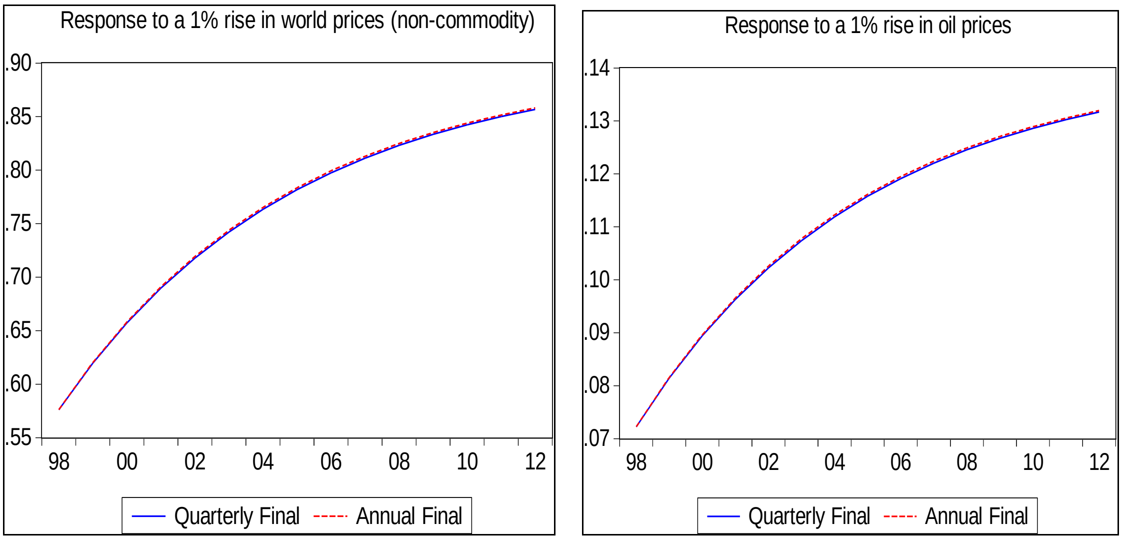
Figure 3: Response of Import prices to Non-Commodity and Oil Price Shocks



As mentioned, to ensure similar responses to shocks in both the quarterly and annual models, consistency needs to be imposed on both the long-run and dynamic behaviour. As the long-run coefficients from the annual model most closely correspond to prevailing national and international estimates, these can be imposed directly on the quarterly model.

However, matching the dynamic properties of the models requires using the conversion equation in (16) for the short-run parameters.[31] In addition, the scaling of the annual error-correction parameter can be found by performing a Wald test on the equality of the calibrated quarterly parameter and the scaled annual parameter. In this case, the scaling parameter is found to be 0.26. Figure 4 illustrates the results of the conversion procedure for the non-commodity and oil price shocks.

Figure 4: Imposing consistency between annual and quarterly models of Import prices



[31] We do not include the final version of the quarterly model for expository reasons. As an example of the conversion of the short-run parameters, the coefficient on the change in oil prices in the quarterly model has the following form: 4*dpoe_a+0.26*ecm_a*lrop_a*(3+2*(1+0.26* ecm_a +dy_a)+(1+0.26* ecm_a + dy_a)^2- dy_a))/(1+(1+0.26* ecm_a + dy_a)+(1+0.26* ecm_a +DY_A)^2+(1+0.26* ecm_a + dy_a)^3- dy_a - 2*DY_A*(1+0.26* ecm_a + dy_a))*dlog(poe_q/rex_us_q), where dpoe_a, ecm_a, lrop_a, and dy_a are the coefficients of the change in oil prices, error-correction, long-run oil price impact and the lagged change in the dependent variable from the annual model.

5. Simulations

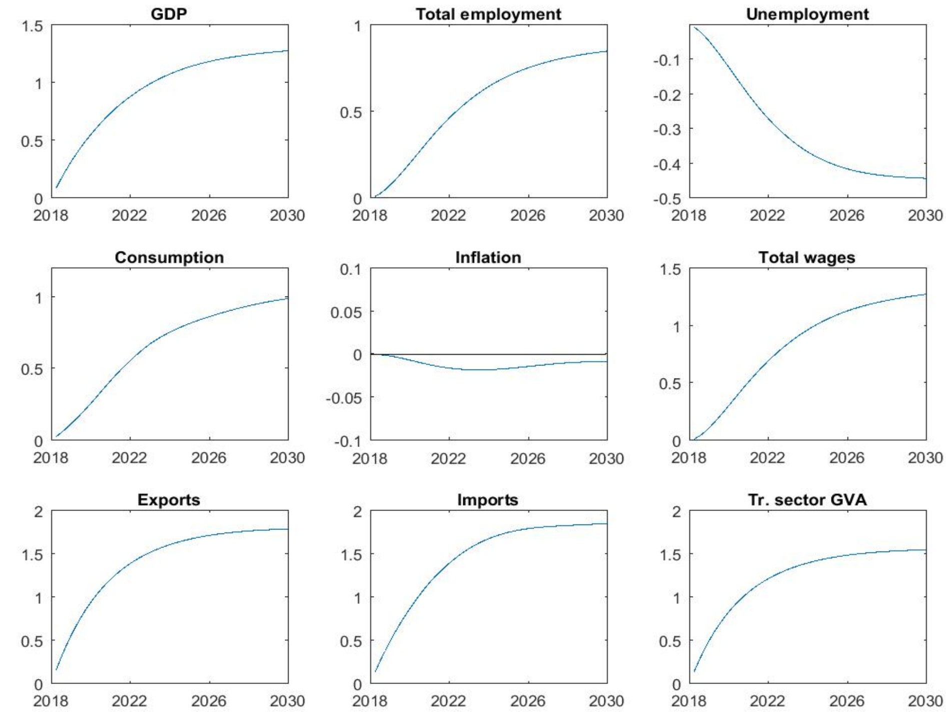
This section presents the results of a range of out-of-sample simulations using COSMO. These simulations are useful in assessing the performance of the model, for example, in terms of its stability or convergence; establishing the usefulness of COSMO in providing simulations, scenarios and forecasts of the Irish economy; and allowing comparisons to be made with results from comparable models or predictions of economic theory. The deterministic solution of the model is obtained dynamically, assuming a constant growth rate as terminal condition for the forward solution.

The baseline scenario, running up to 2040, is built upon exogenous projection assumptions from three main sources: first, all exogenous global variables (such as exchange rates, foreign bond prices, interest rates and the oil price) are taken from the 1.16-b version of the National Institute of Economic and Social Research's Global Econometric model (NIGEM); second, the demographic projections are taken from the ESRI demographic model; and third, the short-term evolution of the model is set to match the forecasts of the Quarterly Economic Commentary of the ESRI (see Duffy et al, 2016b). The baseline scenario also assumes a passive stance from the government, meaning that the fiscal instruments that are set exogenously, such as the tax rates, remain unchanged and both spending and investment grow at a level enough to keep their share of output constant.

Figures 5-8 show the responses of selected series of the model in reaction to permanent shocks to different variables. The figures show the evolution over 48 quarters after the shocks, which are assumed to start in 2018. The y-axis reflects percent deviation (or percent points deviation for the variables already expressed in percentages) from the baseline scenario. We introduce four different shocks: a 1% increase in world demand, a 1pp. reduction of the income tax rate, a 1% increase in wages for all sectors and a 10% decrease of house prices. For comparability, the responses of 6 variables are shown for all shocks: GDP, employment, the unemployment rate, private consumption, inflation (measured by the private consumption deflator) and total wages. Three additional variables are included with each shock, these change in each case in accordance with what variable is most relevant to the shock.

Figure 5 shows the response of the model to a 1% increase in world demand. A world demand shock provides an appropriate starting point to test the behaviour of the model, as Ireland is a small open economy heavily influenced by external conditions and world demand is taken as a purely exogenous variable. When this type of shock is introduced in the model, its effects are noticed first on the traded sector. The increased external demand pushes up Irish exports and the production in the sector relative to the baseline. To facilitate increased production in the traded sector investment also rises above its baseline values.

Figure 5: responses to a 1% increase in world demand

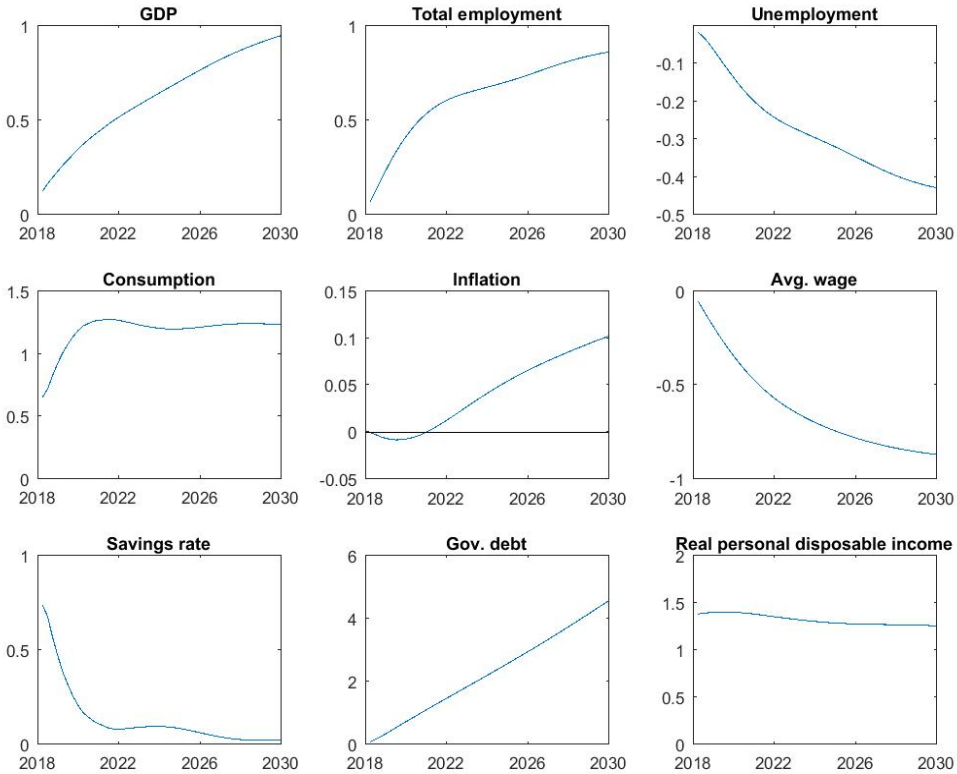


At the same time, both employment and wages go up in the sector, so that the firms can meet the new demand. The positive effect on employment and wages are also felt on the other sectors, as increased demand for inputs in the traded sector pushes up internal demand and imports. The higher wages overall help attract more workers to the labour market, but the increase in labour demand is enough to absorb the new workers and the unemployment rate falls relative to the baseline.

More employment and higher wages mean an increase in personal incomes and consumption. This has a positive effect on the fiscal position of the government. On the other hand, higher wages negatively impact the competitiveness of Irish exporting firms, although the net effect on exports is still positive. Overall, the world demand increase produces a positive effect in the Irish economy, with the traded sector leading an expansion that pulls the rest of the economy up.

Figure 6 shows the response of a 1 percent point decrease in the income tax rate. The most immediate effect of the decrease is to positively impact disposable personal income. Consumption and savings both respond positively to the increase in income. It takes some time for consumption to adjust so the impact on the savings rate is higher in the short-run. The increase in consumption pushes up internal demand, leading to an increase in employment and total wages, although average wages go down as employment grows faster than total wages. Increasing incomes and production naturally lead to an increase in the Irish GDP.

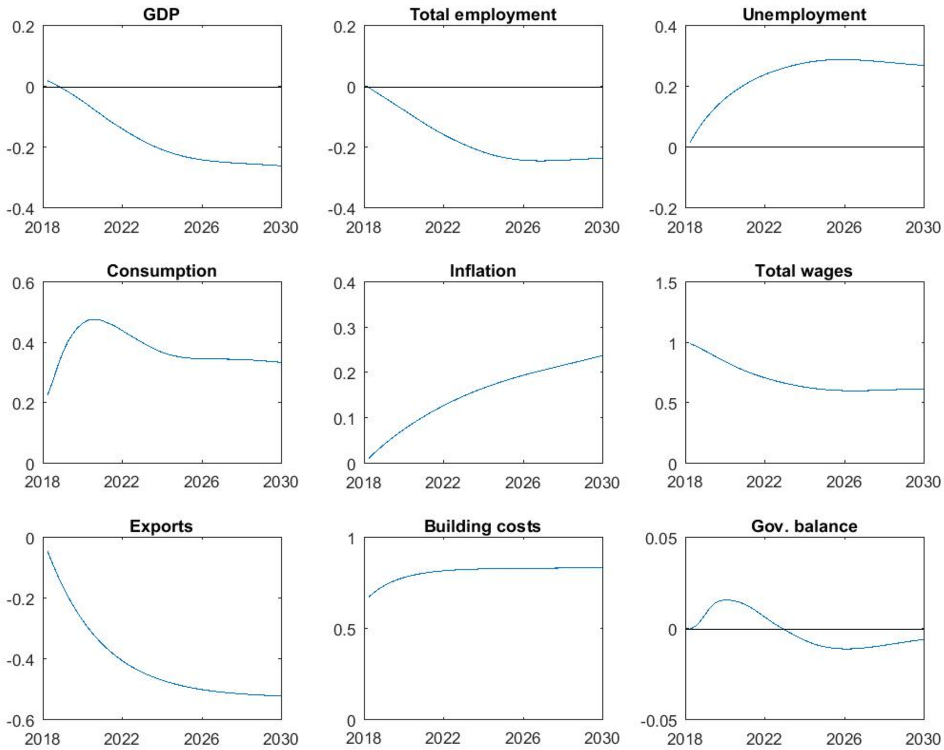
Figure 6: responses to a 1pp reduction on the income tax rate



Higher savings on impact increase investment, helping to sustain the increase in GDP in the long run. Furthermore, the financial sector is also influenced by the increase in activity. Increased personal incomes and production will increase the demand for household and commercial credit, respectively, and the stronger labour market will increase the demand for mortgages.

Figure 7 presents the reaction of COSMO to a 1% increase in wages on all sectors. The reaction of the model to changes in wages has already been discussed on the previous simulations, but the fact that the changes were consequence of other movements in the economy obscured their net effect. Therefore, figure 7 allows us to observe the effect of wage movements in the model without other mitigating factors.

Figure 7: responses to a 1% wage increase



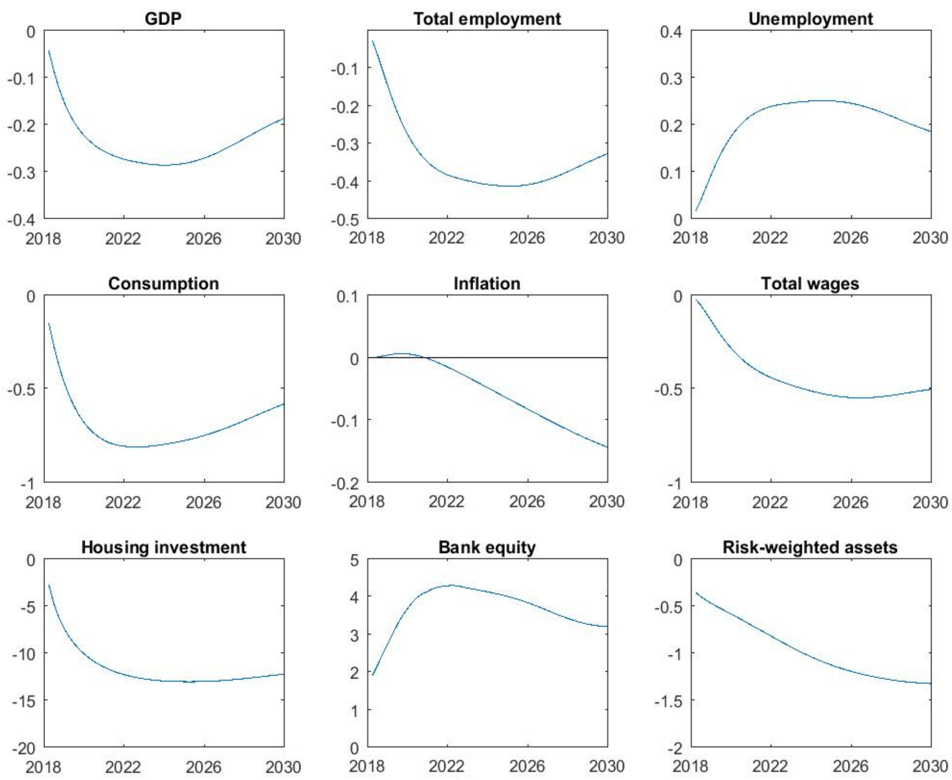
On impact, employment increases and the unemployment rate goes down, as higher wages attract more workers to the job market and participation rises. This effect, however, is small and short-lived, and once the firms are able to adjust their labour force, the higher labour costs leads to lower employment in the long run, with a consequential knock-on impact on the unemployment rate.

The increase in wages affects GDP through two main channels: first, higher wages imply a decrease in competitiveness of the Irish economy, hurting exports and producing a drag in the traded sector. Second, the non-traded sector experiences a fall in production lead by the housing sector, affected by higher construction costs (tightly connected to labour costs). This fall occurs even as the rise on consumption, consequence of the increased disposable income, helps mitigate the fall on internal demand.

For the government, increased wages translate into a modest improvement on their position on the short run, with a positive movement on its balance and a reduction on debt. Both movements are more intense on impact, when both wages and employment are relatively higher, but the fiscal position deteriorates in the long run, as a consequence of the contraction in activity.

Finally, figure 8 shows the responses a 10% reduction on house prices. Although not specifically mentioned, all the shocks analyzed previously produced movements of some measure on house prices. In COSMO, the housing market is fully integrated on the economy and reacts to movements on wages, prices, and demographic or financial conditions, which are transmitted to the sector. In this case, we focus on the opposite effect, on how movements on the housing sector are transmitted to the rest of the economy.

Figure 8: responses to 10% decrease on house prices



In the first instance, lower house prices reduce investment on new construction. Consequently, the labour market deteriorates due to the downward pull from the non-traded sector, in turn hurting consumption and, finally, GDP. In the external sector, imports fall as the demand for inputs for construction falls. However, exports increase over time as the fall in wages improves the competitiveness of the traded sector. Therefore, the situation of the economy improves over time, in comparison with the fall in the short run, but the net effect remains negative with respect to the baseline.

In the financial sector, the combination of the decreased value of the main asset used as collateral by households, housing, and the slowdown on the labour market push up mortgage arrears. Consequently, the deterioration of the position of the banks force them to raise additional capital, in a way that bank equity expands, particularly in the years just after the shock. The consequence is a progressive reduction of the bank's assets, due to a contraction on lending, particularly to construction.

6. Summary and Conclusions

This paper has outlined the features of a new macro-econometric model of the Irish economy. While the model shares some features with other small open economy models, COSMO has a number of novel features, including the use of both annual and quarterly data and the detailed inclusion of financial frictions in a small open economy model. In particular COSMO is the first macroeconometric model that is capable of exploring macroprudential policy through restrictions on credit demand and the composition of liabilities, which constitutes a key channel through which the financial sector can impact on the real economy. As such the model can identify the impact of financial distortions such as those experienced during the Irish property bubble and their effect on the real economy. Moreover, COSMO facilitates an analysis of how macroprudential policy can influence the interaction between real and financial shocks in a structural macroeconomic model.

One of the innovative features of the COSMO model is that it uses both annual and quarterly data. In order to have data available at both frequencies annual series are converted to quarterly and vice versa. With both a quarterly and an annual dataset available the equations that make up the model are estimated at both quarterly and annual frequencies. This approach has the advantage that it allows for the estimation of the quarterly dynamics of an equation even where only annual data is available or the use of the annual estimates where quarterly data is excessively noisy.

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