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The Use of the I3E Model in Macroeconomic Analysis for the Irish Economy*

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Abstract

The I3E (Ireland Environment, Energy and Economy) model is a single-country, intertemporal computable general equilibrium (CGE) model focusing on environmental policies in Ireland. However, the depth of its modelling, which incorporates the economic interactions between production sectors and other agents, also facilitates its use in wider macroeconomic policy analysis. In the Economic and Social Research Institute (ESRI), there are several macroeconomic models developed and applied to investigate macroeconomic policy issues. These are HERMES (Harmonised Econometric Research for Modelling Economic Systems), COSMO (COre Structural MOdel), and FIR-GEM (Fiscal IRish General Equilibrium Model). As with all economic models, the four models vary in their underlying mechanisms and methodologies, and each model has its associated advantages and disadvantages. The focus of this paper is to show the consistency of the I3E model when compared with these existing models. To do so, we compare the results of four different scenarios, and we find that the results of these shocks when applied to the I3E model are largely in line with the respective results of the other three models. Furthermore, any differences can be explained by the different modelling techniques and/or assumptions. As such, we consider the I3E model to be a reliable tool to be used for both environmental policy analysis, and wider macroeconomic policy analysis on the whole.

Keywords: Model comparison, HERMES, COSMO, FIR-GEM, I3E, CGE modelling

JEL classifications: C61, D15, D25

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1 Introduction

The I3E (Ireland Environment, Energy and Economy) model has recently been developed by de Bruin & Yakut (2020) and is a single-country intertemporal computable general equilibrium (CGE) model. The structure of a CGE model, which models the interactions between production sectors and other agents in detail, makes such a model particularly suitable for analysing policies that impact specific sectors or inputs. Accordingly, the I3E model focuses on the impacts of environmental policies on energy demand and the macroeconomy in Ireland. Though the application of the I3E model has focused on climate policies, it is a macroeconomic model and can just as aptly be applied to macroeconomic policies and shocks. There are several other macroeconomic models developed in the Economic and Social Research Institute (ESRI). Each of these models is unique with regards to its methodology and focus, and consequently, each model has its advantages and disadvantages.

The HERMES (Harmonised Econometric Research for Modelling Economic Systems) model was first developed in 1982 and has been widely applied to investigate economic policy issues in Ireland, including labour market dynamics, unemployment, carbon taxation, energy demand, etc. The technical details of its latest version, HERMES-13, are described in Bergin et al. (2013). In the past, the HERMES model was applied to macroeconomic forecasting. Subsequently, the COSMO (COre Structural MOdel of the Irish economy) model has been developed, which has taken over this role. As explained in Bergin et al. (2017), the COSMO model is a macroeconometric model whose estimation utilises all available annual and quarterly data. It has a detailed description of financial frictions and the banking sector. The FIR-GEM (Fiscal IRish General Equilibrium Model) model has recently been developed by Varthalitis (2019). FIR-GEM is a dynamic stochastic general equilibrium (DSGE) model and has been used for fiscal policy analysis in Ireland.

This document compares these different models and their results concerning several macroeconomic shocks, highlighting the underlying mechanisms and methods that may result in diverse outcomes across models to the same shock. The main aim of this paper is to investigate whether the I3E model is consistent with other macroeconomic models of Ireland and will prove reliable in analysing macroeconomic policy issues for the Irish economy. Furthermore, a comparison of these models will also give insights into the varying methods and assumptions in these models and their impacts on results.

The remainder of the paper is as follows. The next section provides a non-technical description of the I3E model. Section 3 summarises the other models mentioned above in a non-technical manner. Section 4 compares the key modelling differences regarding the labour market, the role of expectations, and the investment behaviour which govern the differences in the results across these models. Section 5 compares the results of five different scenario analyses and finally, Section 6 concludes.

2 Non-technical Description of the I3E Model

The I3E model is the first fully dynamic, i.e. intertemporal, computable general equilibrium (CGE) model for the Irish economy. In the following subsections, the economic agents defined in the model and the interactions across these agents are discussed in a non-technical manner. The technical details of the model economy are provided in de Bruin & Yakut (2020). The model parameters are calibrated by using an energy social accounting matrix (ESAM). The data sources and the details of the construction process of the ESAM are available in de Bruin & Yakut (2019).

2.1 Households

The household sector of the I3E model consists of ten representative household groups (RHGs). The RHGs with the abbreviation of u1 (the poorest) to u5 (the richest) are the urban resident households. Similarly, the RHGs with the abbreviation of r1 (the poorest) to r5 (the richest) are the rural resident households. Households choose the optimal level of composite consumption by maximising their utilities subject to their budget constraint. Disposable income is the sum of wage income, dividend income, welfare transfers and pension income from the government, and net factor income from abroad. The RHGs are constructed by using the Household Budget Survey (HBS) of 2015-2016. Each household in the survey is uniquely assigned to a RHG, and then the household-level values of income items and consumption expenditures by commodities are aggregated to generate the RHG-level figures. The Survey on Income and Living Conditions (SILC) is used to obtain the composition of household wage income by the types of labour (i.e. low-, medium-, and high-skilled).

2.2 Firms and Production

The production sector comprises 32 representative activities/firms which represent the main producers in the Irish economy in terms of total value-added, labour demand and sectoral emissions. 27 out of 32 activities determine the level of physical investment by maximising the value of the firm in an intertemporal manner. The model has an explicit representation of the Emissions Trading System (ETS): each activity takes into account its composition of energy demand, the activity emissions subject to the ETS, and free allowances to reduce its ETS emissions and thus the cost of the ETS. In this respect, each activity pays the same purchaser, i.e. retail, price to buy an energy commodity but the *perceived* cost of unit demand is a function of the activity's ETS coverage, free allowances, and the EU-ETS price which is an exogenous variable. The main data source for inter-sectoral linkages is the Supply and Use Tables (SUTs) provided by the Central Statistics Office (CSO). The original SUTs provide information on which industry produces which products, the monetary value of production of each product, the cost of intermediate inputs, the value of gross value-added (payments to the factors of production), production taxes paid to the government, etc. The Labour Force Survey (LFS) is used to disaggregate the sectoral labour demand into types of labour.

2.3 Commodities

There are 39 commodities in the I3E model. The energy/carbon commodities included in I3E are peat, coal, natural gas, diesel, gasoline, kerosene, LPG, crude oil, fuel oil, other petroleum products, and electricity. The total domestic demand for a commodity is equal to the sum of six items: intermediate input demand, household demand, government demand, investment demand, trade and transportation margin demand, and finally export demand. On the supply side, domestic production and imports are assumed to be an imperfect substitute of each other, i.e. a final consumer cannot substitute their domestic demand for imports in a one-to-one manner. For each commodity, an equilibrium condition is defined and associated with the price of the commodity, i.e. the commodity prices are endogenously solved in the model.

2.4 Labour Market

The I3E model includes three labour types: low-, medium-, and high-skilled labour. The SILC and LFS are utilised to estimate the compositions of wage income of households and labour demand of sectors, respectively. In the surveys, individuals with no formal/primary and lower secondary education are categorised as low-skilled, individuals with upper secondary, post-Leaving Cert, and third-level (non-degree) education as medium-skilled, and finally individuals with third level (with a degree or above) education as high-skilled labour.

In order to reflect the structure of the Irish labour market, the model also incorporates the phenomena of involuntary unemployment and international migration. In the model, total net migration is a function of the per-employee real net-of-tax wage income differential between Ireland and the rest of the world.[1] Total net migration is disaggregated into net migration by skill types using fixed shares which are calibrated using LFS data. The total labour supply of each type of labour is the sum of the native labour supply at the fixed labour force participation rate and the net migration by skill type. The difference between the labour supply and labour demand stemming from the cost-minimisation problem of firms gives the number of unemployed individuals by the type of labour. The equilibrium wage rate for each type of labour is determined by separate wage equations which relate the log of wage rate to the log of the unemployment rate. As the Irish LFS does not include earnings data, the SILC has been utilised to calibrate the parameters of the wage equation.

2.5 Enterprises

A representative enterprise is assumed to be the owner of all firms. This representative enterprise collects all gross sectoral profits and receives transfers from the government, which are fixed in nominal terms,

[1] Since the I3E model is a single country model, there is no distinction between the source country of migrants. In the related literature, the net migration to Ireland is modelled as a function of the relative employment and wages by Kearney (1998); as a function of differences in the unemployment rates and in real after-tax wages rates between Ireland and the UK by Bergin et al. (2013); and as a function of real after-tax wage rates between Ireland and the UK and differences in the unemployment rates between Ireland and Australia by Bergin et al. (2017).

and pays corporate tax to the government. The remaining amount is either saved by the enterprise account (fixed fraction of net-of-tax profit receipts) or paid to households as dividend payments.

2.6 Government

The I3E model has an explicit representation of the government sector. The government collects direct taxes on labour incomes and sectoral profits (corporate tax), indirect taxes on sales of commodities, the carbon tax on energy commodities, the export tax on exported electricity, production tax on production activities, and half of the cost of ETS due to the EU legislation. The carbon tax, which is exogenously determined by the government, is implemented as a fixed price of per-tonne equivalent of carbon and collected on the domestic consumption of energy-commodities. The government allocates its total revenues to the consumption of commodities, welfare transfers and pension payments to households (fixed in real terms - indexed to the average wage), transfers to enterprises (fixed in nominal terms), and interest payments over the outstanding foreign debt stock. The difference between total revenues and expenditures of the government is public saving which drives changes in the foreign debt stock, i.e. as public saving increases (decreases), the government debt stock becomes lower (higher).

2.7 Rest of the World

All monetary flows between the rest of the world and Ireland are traced within the RoW account. The sources of the foreign exchange supply are exports of commodities and the net factor income of households. The sources of foreign exchange demand are imports of commodities, the interest payments of the government over the outstanding foreign debt stock, and half of the cost of ETS due to the EU legislation. The difference between the totals of foreign exchange supply and demand is covered by foreign savings, i.e. the current account balance. The foreign market closure rule implies that for the given level of foreign savings, the equilibrium in the rest of the world account is ensured by the exchange rate adjustment.

3 Comparison of the Models

In this paper, the results of four macroeconomic scenarios will be compared across the I3E, HERMES, COSMO and FIR-GEM models. These models are extensively used to advice Irish policymaking, and therefore it is imperative to investigate the consistency of results across these models. Do these models show similar impacts of macroeconomic shocks? And if not, why is this the case? In order to explain the differences across model results, it is essential to have a deeper understanding of the underlying model structures. To this end, this section provides a comparison of the models in terms of the level of detail concerning economic agents and markets, and the methodologies employed in the estimation/calculation and calibration processes. Then, the key modelling differences regarding the labour market, the role of expectations, and investment behaviour are compared in detail as these differences in modelling are the

main reasons for having the different results, which can emerge across these models in the case of a similar shock. Table 1 summarises the technical details of each model.

3.1 HERMES

The HERMES model is a large supply-side macroeconomic model, originating in the 1980s, which has been used to generate medium-term projections and forecasts of the Irish economy. The model comprises a system of equations whose solution estimates the optimal level (or path) of key macroeconomic variables. The model focuses primarily on output (production) relationships and the subsequent income and expenditure behaviour thereafter. It has an adaptive expectations specification, based on the optimising behaviour of firms and households. That is, firms are profit-maximising, while households are utility-maximising agents. HERMES distinguishes between "tradable" sectors which are exposed to the world economy (primarily manufacturing, agriculture and market services) and "non-tradable" sectors which are not directly involved in international markets (primarily utilities, building and public services).

The output side of the model is split into 11 production sectors, each of which produces a single good (4 of which are tradable). The manufacturing sector consists of high-tech, traditional and food processing manufacturing and utilises capital, labour and materials in its production process. The market services sector constitutes distribution services, transport and communication, and other business services (e.g. professional, financial, personal). The last of these sub-sectors of market services is considered tradable, while the first two are largely non-tradable. Demand for housing in the model is taken as a function of price, income, demographics and cost of capital. The traded sector (foreign demand) together with foreign prices and wages (competitiveness) play a key role in determining traded sector output). In addition to the traded sectors, the model incorporates the openness of the Irish economy through a migration channel. The model has quite a detailed fiscal policy block which compares actual budget balance with an indexed budget balance, with the measure of fiscal policy dependent upon the difference between the two balances.

3.2 COSMO

COSMO is a medium-term econometric model of the Irish macroeconomy, designed for economic policy projections, which represents the interactions between households, firms, production, the financial market, the housing market and government. COSMO is used to simulate the response of the Irish economy to a number of economic shocks. The short-run specifications of the model are founded in Keynesian principles, with neoclassical supply theory forming the basis of long-run modelling. COSMO's innovation comes from its detailed focus on financial market frictions, namely its focus on macroprudential policy, its treatment of the housing market, and the inclusion of credit market interactions. This model is exceptionally useful and reliable when investigating macroeconomic shocks on the financial system, the credit market and the housing. This structure distinguishes it from many of the models which were specified and used prior to the 2008/09 financial crisis.

Table 1: Macroeconomic Models Developed in ESRI for the Irish Economy

	HERMES-13	COSMO	FIR-GEM	I3E
Production				
# of sectors	11	3	3	32
# of factors of production	2	2	2	4
# of labour types	1	1	1	3
Commodities				
# of commodities	13	3	3	39
# of tradable	4*	1	1	35
Households				
# of households	1	1	2	10
Sources of heterogeneity	-	-	Saving behaviour	Area of residence & disposable income
Labour Market				
Unemployment	Yes	Yes	No	Yes
Migration	Yes	Yes	No	Yes
Wage determination	Bargaining	Bargaining	Equilibrium/fixed public wage	Wage equation for each labour type
Model includes				
Fiscal policy	Yes	Yes	Yes	Yes
Monetary policy	No	Yes***	Yes***	No
Financial markets	No	Yes	Yes	No
Housing markets	Yes	Yes	No	No
Technical features				
Model horizon		2040		2055
Type of analysis*	Short-to-medium term	Short-to-medium term	Short-to-medium term	Medium-to-long term
Expectations	Adaptive	Adaptive	Rational	Rational
Uncertainty	No	No	Yes	No
Methodology	Econometrics	Econometrics	Non-linear (and linearised) numerical solutions	Mathematical
Calibration method	Econometric estimation with historical data	Econometric estimation with historical data	Calibration with historical data & utilising the literature for some parameter values	Mathematical calculation for a base-year calibration based on SUTs** supported with realisations in several key variables
Data Sources				
National accounts	Yes	Yes	Yes	Yes
Government accounts	Yes	Yes	Yes	Yes
Micro-level data	No	No	No	Yes

* Short-term is defined as a five years period. Medium- and long-term are defined as 10 to 15 and 20 to 25 years, respectively.

**: Supply and Use Tables.

***: As monetary policy is delegated to European Central Bank (ECB), a changes in its policy exogenously affects interest rates and thus firms and household decisions.

The model comprises three sectors: traded, non-traded and government. Output in the traded sector is determined by world demand and Irish competitiveness, while for the non-traded sector, it is influenced only by domestic demand. Within the labour market of the model, the migration channel means that the domestic labour market is influenced by foreign labour market conditions. Consumers are assumed to have rational expectations. Wages in this system are determined in a bargaining framework.

COSMO consists of one household type, which makes consumption decisions based on both current income and the stock of wealth, while both households and firms demand credit from the financial market on the basis of activity levels, the cost of borrowing and collateral value. Interest rates are determined as a mark-up over the costs of funding. The model is estimated using historical data in a system of econometric equations.

3.3 FIR-GEM

FIR-GEM is a small, open economy DSGE model for the Irish economy, which amongst other issues is used as a tool for fiscal policy analysis in Ireland. As such, it incorporates a detailed fiscal system, including debt-elastic interest rates, empirically relevant nominal and real frictions and allows for a variety of fiscal instruments and rules. To encapsulate the openness of the Irish economy, there are three production sectors: tradable goods, non-tradable goods, and public goods.

The model comprises three types of agents with rational expectations: household, firm and government. Households are divided into two subgroups, distinguished by their saving behaviour (i.e. Ricardian or non-Ricardian). Similarly, there are four types of firms in the model. The final good producer uses the intermediate tradable goods for the production of a good to be sold for private consumption. On the other hand, the composite tradable good producer uses imports and home-produced tradable goods to produce an intermediate good. The governmental budget constraint outlines public debt as a function of the shares of total public debt held by foreign and domestic households, government consumption, investment, the public wage bill, public transfers in real and per capita terms, and total tax revenues.

The model is calibrated using Irish data over 2001-2014. A symmetric equilibrium in FIR-GEM is obtained when the set of market-clearing conditions are satisfied, tradable and non-tradable goods markets, as well as the labour, capital and bonds markets.

4 The Implications of Technical Differences

In this section, the implications of having different technical features across models are emphasised in order to compare the dynamics of the models in a proper manner.

4.1 Labour Market Modelling

The modelling of labour markets is an important feature of macroeconomic models. In the case of Ireland, having a detailed labour market, including migration, involuntary unemployment, and the skill composi-

tion of the labour market is crucial in understanding the market dynamics.

Migration plays an important role in the Irish labour market. I3E, HERMES-13 and COSMO incorporate migration in their modelling of the labour market. The driving force of net migration in the HERMES-13 and COSMO models is the difference between the wage rate and unemployment rate between Ireland and the UK. In the I3E model, however, the driver of net migration is the per-employee real net-of-tax wage income differential between Ireland and the rest of the world. The current version of the FIR-GEM model uses the standard method of labour market modelling. Each type of household chooses the number of hours worked (labour supply), and each firm chooses demand for labour and the labour market equilibrium solves for the equilibrium wage rate.

The HERMES-13 and COSMO models make no differentiation between labour types, whereas I3E distinguishes between low-, medium- and high-skilled labour. The first consequence of having only one type of labour in the HERMES-13 and COSMO models is that net migration directly impacts the total labour supply. In the I3E model, the total net migration figure is distributed across the labour types based on fixed shares of total migration.[2] Therefore, although the net migration figures are consistent across these models due to a similar shock, the I3E model will be able to provide differentiated effects across the labour types, of such a shock.

Concerning labour force participation (LFP), the HERMES-13 model endogenises the LFP of the Irish population by assuming that the rate of LFP is a function of real wage, total employment and a time trend. In COSMO, the rate of LFP is a function of real after-tax wages and the unemployment rate. In the case of an increase in the wage rate, for instance, total labour supply increases because of both an increase in the LFP of the Irish population and the invoked net migration. These two models also incorporate the differences in the pattern of labour market participation for males and females and models the supplies of female and male labour separately by assuming that female participation is more responsive to changes in economic conditions. In the I3E model, however, the LFP of the Irish population is assumed to be fixed. Therefore, an increase in the wage rate will result in less upward pressure on wages in the HERMES-13 and COSMO models as compared to I3E as the LPF rate of Irish population will increase in the case of the former models. Moreover, gender differences are ignored in the I3E model.

In the HERMES and I3E models, the labour input is defined as the number of employed individuals, whereas it is defined as total hours worked in the COSMO and FIR-GEM models. The differences in the definitions affect the interpretation of the results on employment and unemployment.

4.2 The Role of Expectations

In the HERMES-13 and COSMO models, the behaviour of economic agents is driven by parameters which are estimated using historical data. The estimated functional forms include the variables' values in the current period and the previous period (one lagged value of the variable) with an Error Correction

[2] These share parameters are calibrated as 0.1108, 0.3808, and 0.5084 for the low-, medium-, and high-skilled labour, respectively, by using the LFSs. In other words, half of the total net migration is constituted by high-skilled individuals.

Model (ECM). Therefore, the optimal value of private consumption stemming from the utility maximisation problem of households and the optimal combination of inputs stemming from the cost minimisation problem of firms are determined in a backward-looking manner. For instance, Bergin et al. (2013, 55) states that *"HERMES does not explicitly handle how households' expectations are formed and how they affect consumption and household investment. This means that the model may not fully capture the short-term*[3] *response of households to fiscal policy. For example, if households expect the government to tighten fiscal policy in the future, they may react by increasing savings in the expectation of future tax increases."*.

In the FIR-GEM and I3E models, on the other hand, economic agents explicitly take into account the future values of some key variables such as prices, including the factor prices, tax rates, government indebtedness, etc. in their maximisation/minimisation problems. The I3E model assumes perfect foresight: all agents have perfect knowledge about the future sequences of all variables. In the FIR-GEM model, however, agents have to take into account the uncertainty in the economy through the stochastic discount factor, which is a function of the current and the future prices. These differences in the way behaviour are modelled have significant implications for how agents react to shocks.

4.3 Investment Decision of Firms

In the HERMES-13 model, the investment decision of firms concerning physical capital stock is governed by the difference between the actual and the "optimal" capital stock. The latter variable is estimated as a function of world output and the factor prices in Ireland by using an ECM). If the actual capital stock is lower than the optimal stock, firms increase their investment expenditures and vice versa. The model also defines public investment expenditure, which is assumed to be a policy variable, i.e. its value is exogenous to the model. The COSMO model solves the investment demand of firms as a function of the user cost of capital and the level of output such that for a positive output shock, firms increase their physical capital stock to facilitate the increased level of production. In the FIR-GEM model, Ricardian households allocate the entire capital stock in the economy between the tradable and non-tradable sectors. The net-of-depreciation change in the sectoral capital stock is equal to the sectoral investment.

In the I3E model, firms are distinguished by their investment decisions: dividend maximisers and non-dividend maximisers. The firms in the first group, which comprises 27 out of 32 sectors, decide how much to invest in physical capital stock by maximising the present discounted value of their dividend streams. Each of the remaining five sectors' (water and sewerage, telecommunication services, real estate services, public services and other services) investment expenditure in period t, on the other hand, is assumed to be a positive function of its profit in period t.[4] Therefore, it should be noted that the results of these models regarding investment expenditures and the physical capital stock are not comparable. The differences in the results of physical capital stock lead to quite distinct impacts on the level of sectoral output and thus, real gross domestic product.

[3] The authors define the short-term as the first couple of years after the introduction of the shock

[4] See Table A.2 for the list of activities and their corresponding NACE codes.

4.4 Calibration Process

The calibration process applied in the HERMES and COSMO models is based on econometric methods, whereas the FIR-GEM model calibrates the structural parameters of the model economy by applying historical data on macroeconomic variables. Using historical time-series data to calibrate models is advantageous in the sense that it utilises real changes in macroeconomic variables over time to estimate their sensitivity to changes in each other. This has the advantage that historical patterns can be used to forecast into the near future. There are, however, three main limitations of utilising historical data: a limited amount of observations of certain variables, inconsistencies in the number of observations, and changing definitions of some variables over time.

The structure of the model is based on theory, and the behavioural equations are econometrically estimated parameters. Estimation also identifies the dynamics of behavioural relationships. Importantly COSMO utilises a mixed frequency approach whereby both an annual and a quarterly version of the model are constructed. This involves the estimation of the long-run relationships using both the annual and quarterly dataset. 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 best model is then selected, and the long-run relationship and dynamics from this are then imposed with the final model being calibrated so that the annual and quarterly equations match.

The FIR-GEM model follows a calibration strategy which is commonly used in the DSGE setting. Accordingly, the values of parameters are set to match the first (mean) and the second (standard deviation) moments of historical data.

The I3E model, on the other hand, is an applied model, which combines both theory and data in the calibration process. Static relationships are calibrated based on data, and behavioural elements apply theory and estimations. To illustrate this, we give two examples. The shares of the various inputs in the production of a sector are calibrated based on data, where from the SUTs we know exactly how much of each input is used in production. How these inputs can be substituted with each other in the production process is modelled based on the theory by assuming that inputs are imperfect substitutes of each other. Again from the HBS data and SUTs, we know how much of each good is consumed by each household. How households change their consumption patterns across goods as relative prices changes are modelled based on dynamic consumption theory. The main parameter in modelling these relations is the elasticity of substitution, and their values are chosen in line with the literature. In the future, the calibration of these parameters can be done by using Irish historical data.

More specifically, I3E follows the traditional calibration method of CGE modelling. The problem of each agent is solved based on economic theory by using well-behaved mathematical formulations, and then the data is used to calibrate the parameter values. In this way, the calibration process ensures the consistency between the economic theory and the data pertaining to the economy. The parameter values show the structure of the economy and any change in their values govern the changes in the respective

agent's behaviour.

The calibration process starts with collecting data regarding the sources of supply (domestic production and imports) and demand (intermediate input demand, private consumption demand, public demand, and exports) of commodities. In the I3E model, the Supply and Use Tables (SUTs) for the year of 2014 are used. The cost structure of each sector regarding the payments to the factors of production (labour and capital) and net taxes (taxes minus subsidies) on production are also obtained from the SUTs. The information provided by the SUTs is extended by using national accounts and government accounts in order to form a social accounting matrix (SAM) which depicts the economic relations between the agents in an economy in an accounting equilibrium manner.[5] Since the system of national accounts provides the households sector in an aggregate manner, the disaggregation of the sector into several household groups requires the use of micro-level data sets. To this end, the HBS, LFS, and SILC surveys are extensively used in retrieving data to disaggregate the households sector (10 groups in urban and rural areas) and the labour market (three types of labour).

Although calibrating parameters by using a single year of data may seem restrictive in reflecting the structure of an economy, the I3E model extends the strategy commonly used in the literature. In this respect, the following realisations in the Irish economy between 2014 and 2019 have been introduced to each scenario path, including the path of business-as-usual (*BaU*).

- Declining peat production based on the Energy Balances (EB) published by the Sustainable Energy Authority of Ireland (SEAI).
- Changes in the composition of electricity production based on the EB of the SEAI.[6]
- Changing international energy prices.
- Declining trend of the ETS allowances of the sectors until 2030 as planned by the EU legislation.
- Increasing trend of the EU-ETS price.
- The increase in the level of the carbon tax in 2020.

Therefore, even along the path of *BaU*, the I3E model does not follow a static path described by the constructed SAM. The values of parameters and policy variables including tax rates, as in all other models mentioned in this paper, are assumed to be constant at their base-year, which is 2014 in I3E, levels along all scenarios unless otherwise stated.

5 Scenario Analyses

In this paper, four different scenarios are analysed in order to show the capabilities of the I3E model and to test its performance with respect to other ESRI modelling exercises. Five scenarios were chosen

[5] See de Bruin & Yakut (2019) for further details on SAMs and the formation of the SAM for the Irish economy.

[6] As the current version of the I3E model does not include renewable energy commodities, the decline in peat and coal demand of the sector is assumed to be compensated by increasing use of natural gas.

from shocks run and documented in the COSMO, HERMES-13 and the FIR-GEM models. These are an increase in foreign prices, an increase in interest rate, a decrease in the corporate/capital tax rate, an increase in government consumption and an income tax rate shock.

5.1 Increasing Foreign Prices

In this simulation, a foreign price shock as introduced in the HERMES-13 model in Bergin et al. (2013, 41-42) is replicated as far as possible for the I3E model. The results across models are then compared. As the nature of the shocks is substantially different, the results are also reasonably different.

In the HERMES-13 model, this shock is introduced by increasing wage rates and prices in the US, the UK and the EU (which form the main trade partners of Ireland), by 1 percentage point compared to the baseline. This increases commodity prices (substitution effect) and the wage rate (income effect) for Ireland's trade partners inducing greater demand for Irish products. Furthermore, the higher wage rate decreases net migration to Ireland.

In the I3E model, the shock is introduced by increasing the export prices of selected commodities by 5%. These commodities and their share in total exports (in 2014) are as follows: food, beverage and tobacco sector (9%), chemical products (6.8%), basic pharmaceuticals (16.4%), high technology production (6.2%), trade services (6.8%), financial services (16.3%), and other services (28.5%). Although the values are the same for each commodity, there are two different international prices for exported and imported commodities, which are exogenous to the model. This distinction in international prices allows the I3E model to run differentiated scenario analysis with respect to changes in the rest of the world. The price receipt by the seller, $PE_{c,t}$, is a function of the international price, $PWE_{c,t}$, the rate of export tax, $exptax\_c,t$, and the level of exchange rate, ER_t.[7]

$$PE_{c,t} \;=\; PWE_{c,t}\,(1-exptax_{c,t})\,ER_t$$

In this respect, an increase in the export price of commodity c leads to an increase in the price receipt by the seller and induces it to sell more abroad. There are two counterbalancing effects in the I3E model. Firstly, as the export of the commodity increases, the supply to the domestic market decreases, which puts upward pressure on the domestic prices and makes increased selling in the domestic market more profitable. Secondly, higher foreign exchange income due to higher exports leads to an appreciation in the domestic currency (lower ER_t) which lowers the price received by the seller in the domestic currency and hence lowers the profit levels. The equilibrium is reached when all prices are adjusted in a consistent manner until all excess demand (or supply) in all markets is eliminated.

The results of several key variables are presented in Table 2 as a difference from BaU. Higher export prices induce greater production by the Irish firms which, in turn, increases the demand for the factors of production. Increasing capital demand leads to an increase in the investment expenditures by 1.6%,

[7] In the Irish context, only the export of electricity is subject to export taxation as its domestic production is exempted from the carbon tax.

Table 2: The Results of Increasing Foreign Prices

		I3E*	HERMES**
%Δ from BaU	Real GDP	0.51	0.8
	Real Total Investment	1.57	0.7
	Real Private Consumption	0.61	0.6
	Real Mean Wage	0.21	0.6
	Total Employment	0.36	0.2
	Per Capita Real GDP	0.49	0.8
	Per Capita Consumption	0.60	0.5
Δ from BaU	Debt-to-GDP Ratio	-0.01	-2.6
	Unemployment Rate	-0.29	-0.1
	Net Migration (in thousand)	0.54	-0.5

*: 7^{th} year results after the introduction of the shock.
**: 6^{th} year results after the introduction of the shock.

compared to *BaU*, whereas increasing labour demand leads to an increase in total employment by 0.4%. Increasing employment shifts wage rates and thus the net-of-tax wage income up which, in turn, leads to greater net migration into Ireland. As a result of the combined effects in the labour market, real mean wage rate increases by 0.2%, and the unemployment rate decreases by 0.3 percentage points, compared to *BaU*. The increased level of GDP induces government consumption, whereas lower mean wage decreases the transfers (welfare and pension) to households as their nominal values are indexed to the mean wage. In addition, the appreciation in the domestic currency also increases the interest payments of the government over its outstanding foreign debt stock. As a result, the public finances as measured by the debt-to-GDP ratio negligibly worsens.

In the HERMES model, the main driver of economic growth is the increased outputs in manufacturing and market services activities. The impact of the shock on the latter sector is less than that of the former sector, as the manufacturing sector produces a tradable commodity. Increased production in both sectors invokes labour demand which pushes the wage rate up. An increase in the economic activity increases total government revenue which, in turn, helps the government to reduce its indebtedness as a share of GDP.

The results of the I3E model concerning macroeconomic aggregates are in line with those of the HERMES model. The investment figure is higher in the I3E model, compared to HERMES, as activities make their investment decisions by maximising the present discounted value of their dividend stream. The difference in the change in net migration comes from the differences in the definition of net migration. HERMES defines net migration as net emigration (i.e. emigration less immigration), whereas the definition in I3E is net migration (i.e. immigration less emigration). Therefore, these two models produce consistent results regarding net migration.

5.2 Increasing Interest Rate

In this scenario, the interest rate is increased by 1pp in the I3E model, and the results are compared with those of Bergin et al. (2013, 44-45). The results are provided in Table 3.

Table 3: The Results of Increasing Interest Rate

		I3E*	HERMES**
%Δ from BaU	Real GDP	-0.66	-0.50
	Real Total Investment	-3.41	-0.90
	Real Private Consumption	0.48	0.20
	Real Mean Wage	-0.20	-0.40
	Total Employment	-0.28	-0.30
	Per Capita Real GDP	-0.64	-0.50
	Per Capita Consumption	0.51	0.30
Δ from BaU	Debt-to-GDP Ratio	1.38	2.40
	Unemployment Rate	0.20	0.20
	Net Migration (in thousand)	-1.18	0.60

*: 7^{th} year results after the introduction of the shock.
**: 6^{th} year results after the introduction of the shock.

In the I3E model, the interest rate directly affects the sequence of the optimal level of composite consumption decision of households. The interest rate determines the opportunity cost of saving and thus determines the optimal level of consumption in two consecutive periods of time as dictated by the well-known consumption Euler equation. From a firm's point of view, the interest rate increases the cost of investment and thus affects the sequence of optimal investment decisions and, in turn, the sectoral capital stock of firms. In the HERMES model, the interest rate affects the cost of capital in the manufacturing sector, whereas the services sector is not affected. Also. The interest rate affects the cost of borrowing for dwelling investments.

The results of both models are in line with each other regarding the direction of the changes in the key macroeconomic variables; real GDP and investment expenditure decrease and lead to a decline in the demand for labour. The lower level of employment increases the rate of unemployment and reduces the real mean wage which, in turn, leads to a decline in the net migration to Ireland. The slowdown in economic activity lowers government revenues and leads to an increase in the debt-stock-to-GDP ratio.

The magnitudes of the same shock, while similar for most key variables, are somewhat different in the case of real investment expenditure. In addition to the differences in the determination of investment, as mentioned in Section 4.3, the investment decision of the services sector is not responsive to changes in the interest rate in the HERMES model. This feature of the HERMES model substantially affects the impacts of aggregate investment since the services sector, including the sectors of telecommunication, residential services, other services, and accommodation & hotels, is one of the biggest investor sectors in Ireland. For instance, the I3E results indicate that the decline in the investment expenditure of the services sector is 1.83%, compared to *BaU*, in the case of a 1pp increase in interest rate.

5.3 Decreasing Corporate/Capital Tax Rate

In this scenario, the corporate tax rate is decreased by 1% in the I3E model. These results are compared with those of the FIR-GEM model's for a decrease in the capital tax rate as described in Varthalitis (2019).[8] In the I3E model, the corporate tax rate plays an important role in the investment decision process of firms. Lower corporate taxes increase the stream of dividends and lead to an increase in investment. The corporate tax rate, therefore, has indirect impacts on the capital income and thus on household disposable income. In the FIR-GEM model, on the other hand, the capital tax is paid by Ricardian households who decide how much to invest in the tradable and non-tradable sectors. Therefore, its impacts on household disposable income are more direct. Another important difference in the scenario across models is that the shock in the FIR-GEM model is temporary, i.e. the tax rate decreases only for a period after which it goes back to its initial level, whereas the shock is permanent in the I3E model, i.e. the tax rate remains lower until the end of the model horizon.

Table 4: The Results of Decreasing Corporate/Capital Tax Rate

		I3E*	FIR-GEM
%Δ from BaU	Real GDP	0.05	0.44
	Real Total Investment	0.24	0.94
	Real Private Consumption	-0.02	0.19
	Real Mean Wage	0.01	-
	Total Employment	0.03	-
	Per Capita Real GDP	0.05	0.44
	Per Capita Consumption	-0.02	0.19
Δ from BaU	Debt-to-GDP Ratio	0.12	0.05
	Unemployment Rate	-0.02	n/a
	Net Migration (in thousand)	-0.01	n/a

*: 7^{th} year results after the introduction of the shock.
"-": the variable is available but not reported in Varthalitis (2019).
"n/a": the variable is not available in the model.

The I3E results imply that the lower level of corporate tax induces investment expenditures and thus boosts overall economic activity measured by real GDP by around 0.1%, compared to *BaU*. Increasing investment leads to greater capital accumulation and increased labour demand which, in turn, increases real mean wage. The changes in the rate of unemployment and net migration are negligible. Although household disposable income increases due to higher capital income in the form of dividends, real consumption decreases at a negligible level due to higher commodity prices. In addition, the closure rule regarding the saving-investment equilibrium also forces households to increase their savings as public savings decrease. The government tax revenue from labour income (due to higher wage rate and employment) and sales taxes (due to higher prices), whereas its corporate tax revenue decreases and the transfers to households (both welfare and pension) increase as mean wage increases. As a result, there is a deterioration in the debt stock-to-GDP ratio.

[8] The magnitude of the shock is not mentioned by the author.

The results are in line with those of Varthalitis (2019) in terms of the direction of the change in key macroeconomic variables except for private consumption. As explained above, the shock in the FIR-GEM model directly affects household disposable income, whereas the impact is indirect in the I3E model.

5.4 Increasing Government Consumption

In the I3E model, the total government consumption has two components. Its autonomous part is constant under any given scenario, whereas its induced part is a positive function of nominal GDP. In this scenario, the impacts of a 1% increase in the autonomous part of the government demand for goods and services is analysed. The total consumption is distributed across commodities based on fixed shares calibrated from the 2014 Supply and Use Tables (SUTs).

Table 5: The Results of Increasing Government Consumption

		I3E*	FIR-GEM
%Δ from BaU	Real GDP	0.03	0.59
	Real Total Investment	0.13	0.22
	Real Private Consumption	-0.16	0.03
	Real Mean Wage	0.03	-
	Total Employment	0.02	-
	Per Capita Real GDP	0.03	0.59
	Per Capita Consumption	-0.16	0.03
Δ from BaU	Debt-to-GDP Ratio	0.22	0.03
	Unemployment Rate	-0.02	n/a
	Net Migration (in thousand)	-0.07	n/a

*: 7^{th} year results after the introduction of the shock.

"-": the variable is available but not reported in Varthalitis (2019).

"n/a": the variable is not available in the model.

An increased level of government consumption of commodities boosts the overall economic activity and leads to an increase in real GDP, although the magnitude of the change is negligible. Higher demand leads to an increase in demand for factors of production. The impacts on the unemployment rate and migration are negligible. Due to higher commodity prices, private consumption expenditure declines, whereas government transfers to households increase due to higher mean wage rate. The indicator of public indebtedness slightly increases, compared to *BaU*. The results of this scenario are in line with those of the FIR-GEM model in terms of the direction of the change in key macroeconomic variables.

5.5 Income Tax Rate Shock

In the HERMES and COSMO models, households pay an income tax at a fixed rate over their entire income. In the I3E and FIR-GEM models, however, households pay a wage income tax at a fixed rate

over their total wage income.[9] The value of asset/capital income (in the form of dividends) of households in I3E is in the net-of-tax term. In this scenario, the wage income tax rate is increased by 0.5 percentage points (pp) in the I3E model. The income tax rate in the HERMES and COSMO models is increased by a sufficient amount to raise the tax collection by €1 billion which corresponds to a 0.54pp permanent change in the income tax rate in COSMO. In this respect, the impacts of the change in the tax rate are expected to be higher in the HERMES and COSMO models as the tax rate only affects the wage income of households in the I3E and FIR-GEM models.

Table 6: The Results of Income Tax Rate Shock

		I3E*	HERMES**	COSMO	FIR-GEM
%Δ from BaU	Real GDP	-0.08	-0.30	-0.30	-0.09
	Real Total Investment	-0.51	-0.70	-0.70	-0.09
	Real Private Consumption	0.12	-0.70	-0.60	-0.17
	Real Mean Wage	-0.01	0.80	0.50	-
	Total Employment	-0.04	-0.50	-0.40	-
	Per Capita Real GDP	-0.08	-0.20	-0.30	-0.09
	Per Capita Consumption	0.12	-0.60	-0.60	-0.17
Δ from BaU	Debt-to-GDP Ratio	-0.81	-2.10	-1.40	0.03
	Unemployment Rate	0.02	0.20	0.20	n/a
	Net Migration (in thousand)	-0.19	0.10	-0.40	n/a

*: 7^{th} year results after the introduction of a positive shock.

**: 6^{th} year results after the introduction of a positive shock.

In the case of an increase in the wage income tax rate in I3E, household disposable income decreases by 0.44%, compared to *BaU*. Declining disposable income hinders the demand for commodities, reducing overall economic activity. Firms decrease their investment expenditure which, in turn, reduces the demand for labour. This results in reductions in the real wage rate lowering the cost of production, and thus commodity prices go down. As a combined effect, private consumption increases, i.e. the substitution effect suppresses the income effect. Government wage income tax revenue increases by 1%, whereas total government tax revenue increases by around 0.6% due to the declines in other tax collections, especially sales tax (taxes on domestic consumption) and corporate tax. However, total government expenditure decreases as the transfers to households decrease due to the declining mean wage rate. Decreased expenditures and increased revenues lead to a decrease in government indebtedness as a ratio of GDP. Lower employment and real mean wage rate decrease net migration and there is a negligible increase in the unemployment rate, compared to *BaU*.

The results of the I3E model are in the same direction but substantially lower than those of the HERMES and COSMO models due to the different natures of the introduced shocks in addition to the technical differences summarised in the previous section. For instance, in HERMES, the majority of any

[9] The wage income tax rate in the I3E model is inclusive of social security contributions.

increase in labour taxes is passed on to employers through a demand for higher wages by workers as they bargain for after-tax wages and the elasticity of labour supply is high. This is similar in COSMO, although COSMO also includes the unemployment rate in the wage bargaining process as a proxy for the relative strength of workers/firms in wage negotiations. The direction of the change in net migration is positive in HERMES, whereas it is negative in I3E and COSMO due to the differences in the definitions.

6 Conclusion

The ESRI plays an important role in advising policy setting, as well as evaluating the impacts of policy changes, in Ireland. In order to provide scientific evidence for policymakers, the Institute has always had an infrastructure of various macroeconomic models tailored for specific purposes. The legacy of HERMES, which is one of the oldest macroeconomic models for Ireland, is maintained by the COSMO model with an enriched structure, including a detailed description of financial markets. The FIR-GEM model allows us to better understand the interaction between fiscal and monetary policy in Ireland (which is a member country of a currency union). A recent model developed in the Institute is the I3E model, which mainly aims to analyse the impacts of policy changes on the interaction between energy, economy, and environment.

Although the I3E model is developed to focus on environmental policies, its rich macroeconomic structure and micro-foundations allow us to use it in analysing the impacts of changes in other macroeconomic policy variables. All models have their advantages. The advantage of the COSMO model lies in its detailed data-based description of the interaction between the macroeconomy, the financial market, credit market and housing market. The advantage of FIR-GEM is its detailed description of fiscal policy as well as its ability to deal with uncertainty. The main advantages of the I3E model's abilities compared to other macroeconomic models of Ireland are in the sectoral details of the model, including 32 production sectors, 39 commodities, and multiple households. The focus of this paper is to illustrate how the I3E model can be used to analyse several economic shocks sourced from changes in internal and external conditions. Five policy scenarios presented in this paper show both that the results of the I3E model are in line with those of the other models in general, and also that the differences in the results can be explained when the methodological and modelling distinctions are taken into account. The I3E model is a useful tool for policy analysis, which can provide reliable results which are consistent with the current structure of the Irish economy. No single model can capture all of the details and intricacies of the Irish economy, and all macroeconomic models developed in the Institute have their strengths and weaknesses. The suite of macroeconomic models in the Institute complements each other in terms of focus and estimation technique.

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Appendix A Lists of Activities and Commodities

Table A.1: Commodities

AGR	Agriculture	BFM	Basic metal manufacturing
PEA	Peat	HTP	High-technology products
COA	Coal	TRE	Transportation equipment
CRO*	Crude oil	ELC	Electricity
OMN*	Other mining products	NGS	Natural gas supply
FBT	Food, beverage and tobacco	WAT	Water and sewerage
TEX	Textile	CON	Construction
WWP	Wood and wood products	TRD	Trade
OIN	Other industrial products	LTS	Land transportation
GAL	Gasoline	WTS	Water transportation
KRS	Kerosene	ATS	Air transportation
FUO*	Fuel oil	ACC	Accommodation and hotel services
LPG	Liquid petroleum gas	TEL	Telecommunication services
DIE	Diesel	FSR	Financial services
OPP	Other petroleum products	RES	Real estate services
OTM	Other manufacturing	PUB	Public services
CHE	Chemicals and chemical products	EDU	Education sector
BPP	Basic pharmaceutical products	HHS	Health sector
RUP	Rubber and plastic products	SER	Other services
ONM	Other non-metallic products		

*: Not subject to private consumption.

Table A.2: Activities

Activity		NACE Codes	Aggregate Sector	
ACC	Accommodation & hotel services	55–56,79	ACC	
AGR	Agriculture	1-3	AGR	
CON	Construction	41–43	CON	
ELC	Electricity		ELC	
FSR	Financial services	64–66,77	FSR	
PUB	Public sector	84	PUB	
TRD	Trade	45–47	TRD	
BFM	Basic metal manufacturing	24–25	MAN	
BPP	Basic pharmaceutical products	21	MAN	
CHE	Chemicals and chemical products	20	MAN	
FBT	Food, beverage and tobacco	10–12	MAN	
HTP	High-technology products	26–28	MAN	
NGS	Natural gas supply		MAN	
OIN	Other industrial products	17,18,33	MAN	
ONM	Other non-metallic products	23	MAN	Manufacturing
OTM	Other manufacturing	31–32	MAN	
PET	Petroleum		MAN	
RUP	Rubber and plastic products	22	MAN	
TEX	Textile	13–15	MAN	
TRE	Transportation equipment	29–30	MAN	
WAT	Water and sewerage	36,37–39	MAN	
WWP	Wood and wood products	16	MAN	
OMN	Other mining products		MIN	Mining
PEA	Peat		MIN	
ATS	Air transportation	51	TRP	
LTS	Land transportation	49	TRP	Transportation
WTS	Water transportation	50	TRP	
EDU	Education sector	85	SER	
HHS	Health sector	86–88	SER	
RES	Real estate services	68	SER	Services
SER	Other services	remaining*	SER	
TEL	Telecommunication services	61	SER	

*: It excludes NACE codes 5-9 (Mining, Quarrying and Extraction), 19 (Petroleum Products), and 35 (Electricity and Gas Supply).

Note: The activities without NACE codes are further disaggregated sectors.