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A Hybrid Econometric Structural Model with Trade and Internationalisation Adjustments (HESTIA)

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A Hybrid Econometric Structural Model with Trade and Internationalisation Adjustments (HESTIA): Modelling the Irish Economy with Multinational Distortions

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Abstract

Ireland's economy is highly globalised and dominated by a small number of large multinational firms. This creates notable challenges in measuring and modelling economic activity, given the distortions caused to series such as Gross Domestic Product (GDP), trade and gross capital formation. This paper attempts to outline a hybrid small-scale structural econometric model with trade and internationalisation adjustments (HESTIA) which can be used to derive a baseline for short term quarterly forecasts and scenario analysis in the presence of these multinational distortions. The model uses adjusted and modified series by isolating specific investment assets and export products that are impacted by multinationals and allowing these to be treated separately. In particular, we present an adjusted output series that better measures the underlying growth rate. To achieve this, the traded sector of the economy is separated into blocks that capture the heterogeneous dynamics of different export sectors while specific distorted asset types are removed from investment series and the remainder modelled with behavioural drivers. The model is built to be updated with a quarterly frequency, relying on the information available following national account release dates.

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1 Introduction

In 2016, the Irish national statistics office, the Central Statistics Office (CSO), published the 2015 annual national accounts and reported that GDP had grown by over 26 per cent year on year. The cause of this growth rate has been documented in a range of research papers such as Fitzgerald (2020a), Lane (2017), Economides & Nikolaishvili (2023) and Tedeschi (2018) and the Irish data has since been the focus of distortions in Euro area data (Andersson et al., 2024) as well as the domestic series. The causes of these major swings in Irish national accounts relate to the impact of multinational firm activities. More specifically, the national accounts in Ireland have been impacted substantially by a range corporate activities such as aircraft leasing investment, changes in patents from pharmaceuticals companies, redomiciled PLCs, the inclusion of intellectual property assets in the calculation of investment and contract manufacturing (Fitzgerald, 2020b). Indeed, the growth rate in 2015 was in the main related to onshoring of large volumes of intellectual property assets and the booking of their export revenues in Ireland (Economides & Nikolaishvili, 2023; Tedeschi, 2018; Khder et al., 2020). The issue of redomiciled PLCs has been explored in Fitzgerald (2013a) and patent expiration in Fitzgerald (2013b).

Given these issues, there have been a range of papers that attempt to propose and deploy different measures of economic activity in Ireland that remove these distortions. The most prominent of these has been Lane (2017) that proposes a modified gross national income calculation which removes the activity of redomiciled PLCs as well as the depreciation on aircraft leasing assets and on intellectual property held by multinational firms. Additionally, the Central Statistics Office have produced a series of modified indicators for investment and domestic demand which attempt to remove specific assets and provide more stable indicators.

While measuring the size and developments in the economy is challenged by these distortions, they have also added extreme complications when undertaking short-term forecasting and scenario analysis of the Irish economy. Short term forecasting and scenario analysis typically entails a combination of model-based estimation, to account for external or exogenous factors, and expert judgement to incorporate recent trends or developments in factors which are often outside modelling frameworks, such as uncertainty or sentiment (Franses et al., 2011).

To address these issues, this paper presents a small-scale macroeconometric model of the Irish economy (HESTIA) which attempts to deal with these difficulties and ensure that international economic developments such as shocks to world demand still have a meaningful pass-through to the domestic economy in a modelling context. Building on other small-scale models such as those presented by Bårdsen et al. (2012), Carnot (2002), Møller Andersen et al. (2005) or Cicinelli

et al. (2010), our paper outlines a standard structure for the general model with a wage-price bargaining model for wages, prices, productivity and employment as well as the equations for household and public consumption. The model is then augmented with Irish specific adjustments for exports, imports and investment that attempt to address the main multinational distortions.

In making adjustments for trade, and building on the existing data from the Central Statistics Office for the modified series, we also put forward an additional indicator for the domestic economy, adjusted output. This indicator which is described in considerable detail later in the paper adds to the CSOs' modified domestic demand indicator by including underlying services and goods trade. Thus this indicator allows variation from the traded sector of the economy, that is mostly linked to the domestic economy, to be included in measurement and short term forecasting of economic developments. In the simulations presented in the paper from HESTIA, we find that the reaction of adjusted output to world demand shocks is very similar to historical adjustments from models that predate the 2015 change in the national accounting data (this shows a typical 1:1 relationship between world demand and adjusted output).

Where possible the model draws on the structure, and methodology, used in the ESRI's structural econometric model, COSMO (Bergin et al., 2017). These linkages particularly relate to data inputs, equation parameterisation and variable selection. Most specifically, it uses the external variables which come through COSMO from NIGEM, the National Institutes global econometric model. The model is designed to be estimated on the regular CSO Quarterly National Accounts data as it is used for the determination of baseline forecasts in the ESRIs Quarterly Economic Commentary (QEC).[1] Therefore, it uses a number of data transformations to deal with the typical redactions that occur due to data confidentiality concerns on a quarterly basis and other data issues.

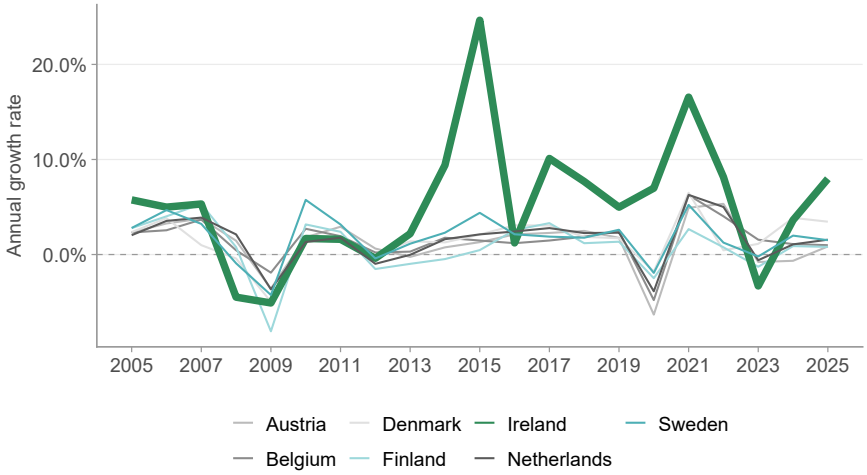
The remainder of the paper is structured as follows. Section 2 documents the statistical challenges posed by multinational enterprise activity for short-term macroeconomic forecasting in Ireland. Section 3 presents the structure and estimated behavioural equations of HESTIA, including the disaggregated treatment of the traded sector, the management of investment distortions, and the derivation of the adjusted output measure. Section 4 examines the dynamic properties of the model through an illustrative simulation of a permanent one per cent increase in world demand, with particular attention to the differential responses of GDP, modified domestic demand and adjusted output. Section 5 concludes.

[1] Past issues of the ESRI's Quarterly Economic Commentary available on the ESRI website.

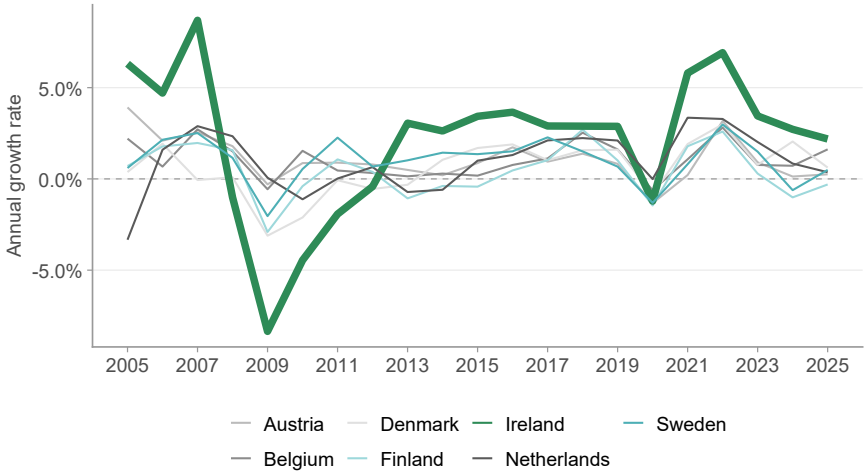
2 Outlining Ireland's Challenges

In recent years, the major swings in Irish economic activity have come increasingly into focus by both domestic (Lane, 2017; Fitzgerald, 2020a, 2013a; Timoney, 2023) and international policymakers and researchers (Accoto et al., 2023; Ahmad et al., 2023; Khder et al., 2020; Tedeschi, 2018). Indeed, the changes to Ireland's national accounting data have been so large that they have impacted headline Euro area statistics such as gross fixed capital formation, which is not typical for a small country like Ireland (Andersson et al., 2024). The overall scale of the distortions can be very easily identified when compared to other countries. Figure 1 presents a comparison of growth rates for Ireland and selected other European economies. While it is clear Ireland's underlying economy is highly volatile in general relative to other economies (as shown by changes in employment), the changes in the GDP growth rate are much more stark, with major swings on a magnitude not seen by other small-open economies in Europe.

Figure 1: Ireland among European peers
GDP growth rate (Y-o-Y, per cent)



Employment growth rate (Y-o-Y, per cent)



Source: Eurostat

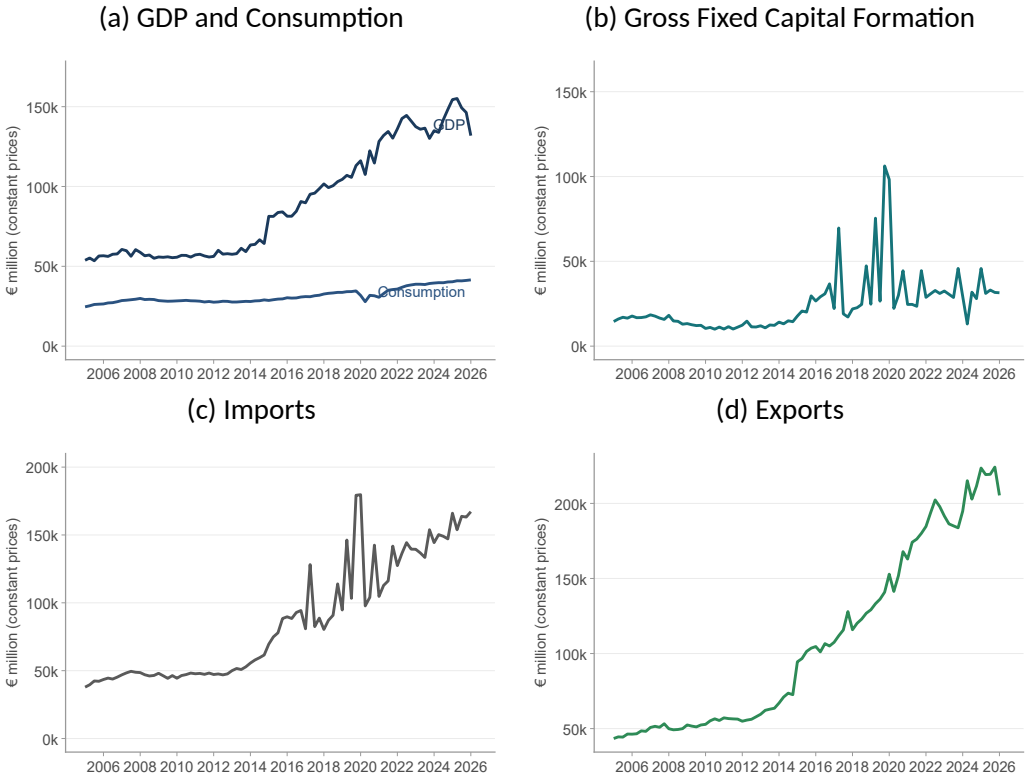
This volatility, as well as the magnitude of the level of key variables such as GDP, is a major issue for measuring the size of economic activity, identifying trends such as in the underlying business and economy cycle, for measuring debt and public finances stability, as well as for modelling purposes. There have been a range of research and policy papers which have explained these changes in Ireland and also proposed alternative indicators such as the ESRG (2016) report and work by Lane (2017) and Fitzgerald (2020a). It is not the aim of this paper to re-open these explanations, however, we do need to expand on some aspects of the debate in order to outline our methodological approach in the proposed model.

Some of the most relevant of these papers are discussed below.

Fitzgerald (2020a) traces the development of distortions to the national accounts over time. Issues began to emerge around factor outflows in the 1970s and 1980s and culminated in the present situation where a large aircraft leasing sector, patents held by pharmaceutical companies, the activity of redomiciled PLCs, and the inclusion of intellectual property in investment combine to render headline measures of economic activity in Ireland highly misleading. For example, panel (a) in Figure 2 traces the development of GDP over time, while including household consumption as a comparison. In addition to one-off annual growth figures that are unrealistic, GDP produces an inaccurate estimate of the size of the economy.

From a modelling perspective, for the Irish economy, these complexities can be split into two separate considerations. First, on the expenditure side of the national accounts, the export, import and investment statistics have been distorted by the activities of these large multinational firms. This includes firm-specific investment dynamics which have seen the movement of large volumes of research and development-related intellectual property assets which were transferred to the Irish balance sheet of multinational firms. The Irish data have also been distorted by investments in aircraft leasing and re-domiciled PLCs as outlined above. These distortions can be clearly seen in the levels of gross fixed capital formation as well as imports (Figure 2 panels (b) and (c) respectively). The capital then typically earns a return for the multinational firms which can be seen in the export statistics (Figure 2 panel (d)) and across various subcategories which will be explored later in the paper. Many of these activities are carried out without interaction with other domestic factors of production such as labour or energy which adds an additional level of complexity from a modelling perspective.

Figure 2: Key Series Impacted by Multinational Distortions on Expenditure Side of National Accounts (€, million quarterly)



Source: CSO

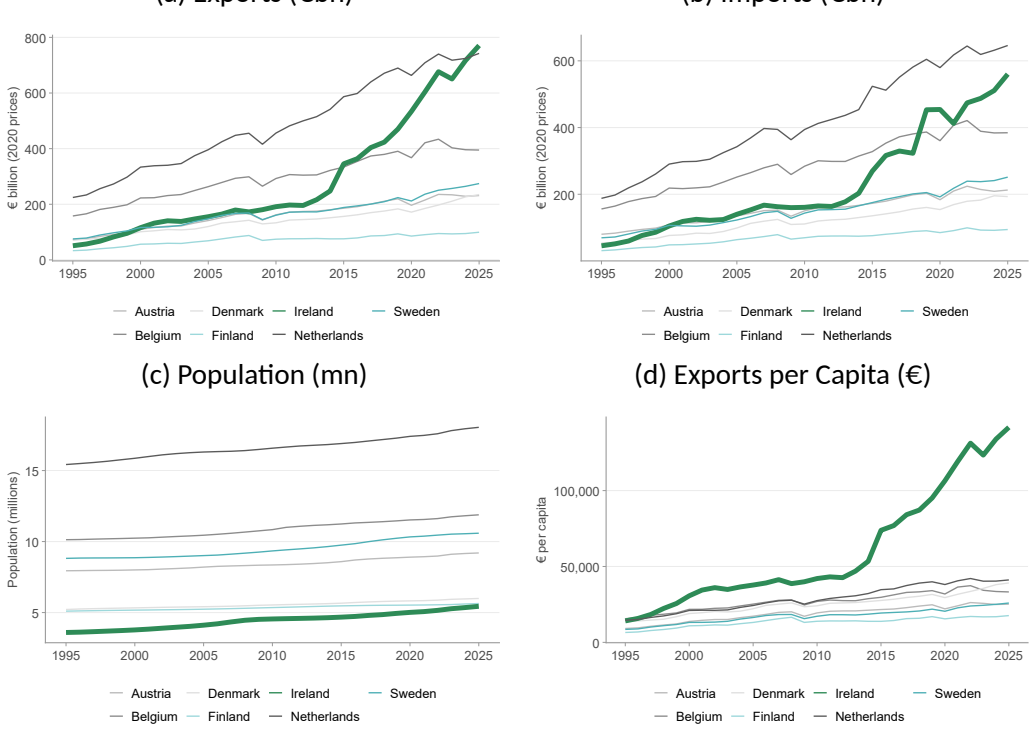
Second, even after accounting for statistical distortions, exports are particularly concentrated and booming in two sectors, namely pharmaceuticals and computer services. These sectors are dominated by a very small number of multinational enterprises and the exports in these areas have grown extremely rapidly in recent years.

These multinational distortions create major challenges in establishing a stable and representative econometric framework of the Irish economy. This is the case for both short term and medium term forecasting as well as policy modelling and scenario building. The challenge comes in attempting to build behavioural models which attempt to link the above distorted series with their underlying theoretical drivers. For example, investment no longer has an economic relationship with its theoretical drivers such as output changes or the cost of credit alone; rather it is also driven by company specific strategies and other idiosyncratic factors. Furthermore, exports and imports cannot be as easily linked to changes in global trading conditions as the dynamics are largely firm or sub-category specific

in nature.

From the traded side, the scale of the changes in the Irish economy are very clearly identified in Figure 3. In this chart, the levels of Irish exports and imports (in billions of euro) are presented alongside those of other small open economies in Europe. What is very clear, in particular for exports, is that the levels have grown in an exceptional fashion. In the early 2000s, the level of exports and imports in Ireland was close to that of Austria and Denmark, both countries with larger populations. In 2025, the level of exports from Ireland surpassed the level of the Netherlands; a country nearly three times the size in population terms. This can be clearly seen in 3 (c) and (d) which present exports per capita and population for the countries presented. Irish exports per capita have long exceeded those of its European peers, but the gap has widened dramatically since 2015, following changes to the national accounts relating to intellectual property assets. The data presented in 3 highlight that the growth in exports has taken off since 2015, with exports per capita begin to decouple from population trends after this point.

Figure 3: Ireland and Selected European Peers



Source: CSO & Eurostat

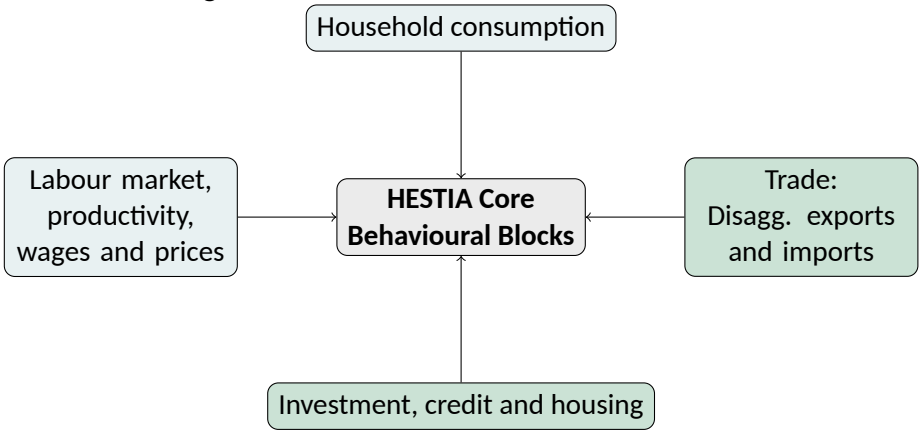
3 Model Structure and Outline

To deal with the aforementioned challenges, in this section, we present a small-scale structural econometric short term forecasting model. The model uses the data released from the quarterly national accounts to provide a hybrid structure (part estimated, part based on technical assumptions) which removes the internationalisation effects from core equations but allows their impacts to continue to be built into aggregates like GDP using technical assumptions. The model's main innovations relative to other models of the Irish economy come from our disaggregation on the expenditure side of the economy using national accounting data from the quarterly accounts. This development is deliberate as transforming the series in the manner we have undertaken to remove the internationalisation and multinational distortions can only be done with data on the expenditure side. Our focus on the quarterly data (rather than the more disaggregated data from the annual accounts) is to ensure that the framework is aimed at producing short term forecasts that can be updated within year as the data becomes available.

As outlined in Figure 4 HESTIA consists of four main behavioural blocks — household income and consumption; labour market, productivity, wages and prices; disaggregated trade (exports and imports); house prices and credit; and investment and housing supply. The structure is broadly consistent in terms of structure and ECM methodology with models such as Ballantyne et al. (2020), Bårdsen et al. (2012) and Bassillière et al. (2013)

Where possible, we model relationships using an error correction framework. Short run factors were included based on a test of significance up to 4 lags with non-significant factors removed.

Figure 4: Main Behavioural Blocks in HESTIA



Source: Authors' work.

The adjustments to the model structure to deal with the multinational side of the economy comes mainly through trade (imports and exports) and investment (both in green boxes above). In the first two sub-sections below, we outline in detail how we derive and undertake those adjustments as well as providing information on the rationale for any transformations undertaken. In the remaining sub-sections, we outline the remaining core blocks, introduce the measure of adjusted output as well as summarising the model structure as a whole. Finally, we present the measure of adjusted output.

3.1 Trade: disaggregated exports and imports

As discussed above, there are major challenges with export volumes from a modelling perspective in Ireland. Two factors must be taken into consideration. First, exports are sectorally concentrated in computer services and in pharmaceuticals. These two sectors are more sensitive to world demand than underlying goods or services exports. Second, there is a need to deal with globalisation factors, namely contract manufacturing (goods for processing) and merchanting. These factors have been a non-trivial share of total exports in recent years though they often have a tenuous connection with activity in the domestic economy. Imports in Ireland must also be carefully modelled because of issues around sectoral concentration and the nature of global supply chains in pharmaceuticals, aircraft leasing, royalties and R&D. We address these issues by decomposing exports and imports into relevant categories and modelling them separately.

3.1.1 Exports

Our first categorisation on the export side is to separately model services and goods exports. We further divide goods exports into pharmaceuticals exports, non-pharmaceuticals exports and a residual category. This residual category is the difference between the headline goods exports figure and the exports figure from merchandise trade data. It captures the portion of goods exports attributable to globalisation activities like contract manufacturing and merchanting.[2][3]

[2]Contract manufacturing is a process where one company hires another to manufacture a good or component. In Ireland, this typically involves a multinational contracting a producer abroad to produce goods that are then sold abroad. Such transactions are recorded as a net export from Ireland despite the economic activity occurring abroad. For more information see here.

[3]Merchanting is a method of intermediate trade where an Irish company purchases a good abroad and re-sells it abroad. The mark-up on this good is recorded as an export despite the goods never entering Ireland. For more information see here.

We divide services exports into computer services exports and non-computer services exports, which we call underlying services exports. Finally, we include a services residual equal to the difference between the headline services exports figure and the two services exports categories described above.[4] The overall export identity in current prices is:

$$\begin{aligned} xtn_t &= xtn\_gsu_t + xtn\_gsp_t + xtn\_gsr_t \\ &+ xtn\_svu_t + xtn\_svc_t + xtn\_svr_t \end{aligned} \tag{1}$$

where the individual series are derived by combining information contained in the Quarterly National Accounts (QNA), monthly cross-border trade data published by the CSO (CBorT), and the Quarterly International Accounts (QIA):[5]

xtn_gsu_t = Total cross-border trade (CBorT) − xtn_gsp_t
xtn_gsp_t = Chemicals and related products, (5 in CBorT)
xtn_gsr_t = Total goods exports (QNA) − Total cross-border trade (CBorT)

xtn_svu_t = Communications + insurance + finance + travel + repairs + other (QIA)
xtn_svc_t = Computer services exports (QIA)
xtn_svr_t = Total services exports (QNA) − xtn_svc_t − xtn_svu_t

Figure 5 highlights the need to model these sectors separately. While underlying goods and services exports have shown modest steady growth in the last twenty years (darkest blue and green bars), pharmaceuticals and computer services exports have shown remarkable levels of growth (blue and green bars). In addition, Ireland's multinational sector and the nature of global economic activity have contributed to increases in the size of the goods and services exports residuals, which capture these internationalisation factors (grey bars).

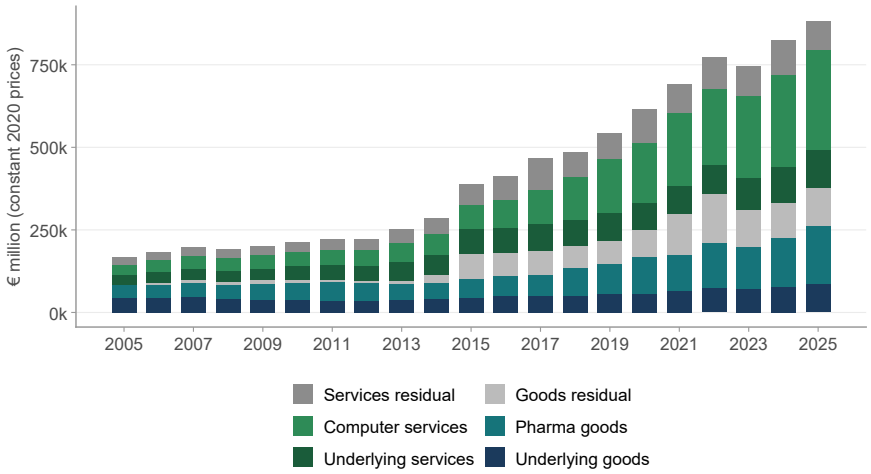
[4] The residual services category captures activities related to Research and Development, royalties, operational leasing and other business services

[5] Using data from three sources requires a number of adjustments related to deflating and seasonally adjusting nominal trade data.

First, services exports are backcast to account for missing data. Detailed sectoral data for services exports is available on a quarterly basis from 2012 onwards. For the period 2003-2012, annual data is available. During this period, we take the annual share for each sector and apply it to the quarterly total. For the period 1995-2002, we hold the share from 2003 constant and backcast the sectoral breakdown.

Second, while the Quarterly National Accounts data are seasonally adjusted by the Central Statistics Office, the monthly trade statistics are not. Where data are not seasonally adjusted we apply the ARIMA X.12 seasonal adjuster in EViews.

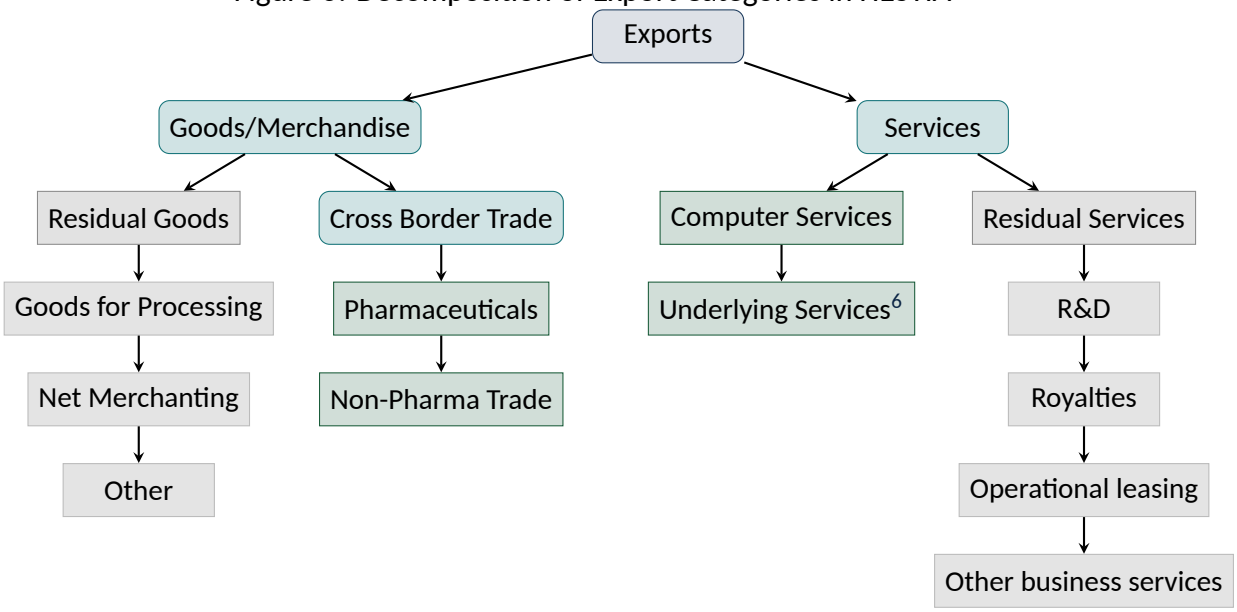
Figure 5: Annual exports by category (€ million, annual)



Source: CSO

In addition, pharmaceuticals and computer services exports are more sensitive to world demand than underlying goods and services exports. The following graphic summarises our treatment of exports in the model. Square green boxes are endogenous and estimated using an error correction framework with world demand as an explanatory variable. The grey residual blocks are addressed with a technical assumption while the pink boxes describe the sub-components of the residual series.

Figure 6: Decomposition of Export Categories in HESTIA



Source: Authors' own & CSO.

3.1.2 Export Equations

The behavioural equations for each export category are outlined below. Each category uses world demand as an explanatory variable and follows an error correction framework. Separating out the export categories is a key feature of the traded sector of this model as it allows for isolation of important trends in each category and evaluation of their macroeconomic impact.[7] The export equations have been estimated primarily during periods of growth in world demand, these coefficients may not be symmetric in the event of a downturn in world demand.

Underlying goods exports capture all cross-border trade excluding pharmaceuticals and chemicals.

$$\Delta \ln(xtr\_gsu_t) = \alpha + \beta_1(\ln(xtr\_gsu_{t-1}) - \beta_2 \ln(wdy_{t-1})) + \beta_3 \Delta \ln(wdy_t) + \beta_4 \Delta \ln(xtr\_gsu_{t-1}) \quad (2)$$

Pharmaceutical goods exports are modelled as follows.

[7] While coefficients in our various export equations for world demand are large, the error correction models remain stable for each sub-sector. (returns to its long-run equilibrium after a shock via the error correction term). This is similar to the results of world trade elasticities found by Martínez-Martin (2016)

$$\Delta \ln(xtr\_gsp_t) = \alpha + \beta_1(\ln(xtr\_gsp_{t-1}) - \beta_2 \ln(wdy_{t-1})) + \beta_3 \Delta \ln(wdy_t) + \beta_4 \Delta \ln(xtr\_gsp_{t-1}) \quad (3)$$

Underlying services exports consists of exports in communications, finance, insurance, travel and repairs.

$$\Delta \ln(xtr\_svu_t) = \alpha + \beta_1(\ln(xtr\_svu_{t-1}) - \beta_2 \ln(wdy_{t-1})) + \beta_3 \Delta \ln(wdy_t) + \beta_4 \Delta \ln(xtr\_svu_{t-1}) \quad (4)$$

Computer services exports are modelled as follows.

$$\Delta \ln(xtr\_svc_t) = \alpha + \beta_1(\ln(xtr\_svc_{t-1}) - \beta_2 \ln(wdy_{t-1})) + \beta_3 \Delta \ln(wdy_t) + \beta_4 \Delta \ln(xtr\_svc_{t-1}) \quad (5)$$

We grow the residuals for both goods and services exports forward based on an exogenous forecast parameter that is set using a combination of judgement[8] and the current evolution of the goods and services residuals:

$$xtr\_gsr_t = xtr\_gsr_{t-4} \times (1 + FORE(xtr\_gsr)) \quad (6)$$
$$xtr\_svr_t = xtr\_svr_{t-4} \times (1 + FORE(xtr\_svr)) \quad (7)$$

The variables are forecast in real terms. The export deflator is also modelled endogenously. Its growth rate is then applied to separate identities for goods and services deflators and the two forecasts can be combined for any export category for goods (i) or services (j) to generate a nominal forecast as follows:

$$xtn\_i_t = xtr\_i_{t+1} \times xtd\_gs_{t+1})$$
$$xtn\_j_t = xtr\_j_{t+1} \times (xtd\_sv_{t+1})$$

3.1.3 Imports

We also divide imports into categories. Again, pharmaceuticals and computer services are isolated because of the sector-specific dynamics associated with these

[8] Where appropriate HESTIA applies judgement parameters, initially set to one, which allow for adjustments in light of real-time data, qualitative information, or exceptional events, with the effects feeding through endogenously to other variables in the model.

highly global sectors. Underlying imports are also divided into goods and services, while we also separately model machinery and equipment imports. Finally, in addition to goods and services residual categories similar to those described for exports, imports in the 'other transport equipment' category are separated out as an additional predetermined category.

$$\begin{aligned} mtn_t &= mtn\_gsr_t + mtn\_gsp_t + mtn\_gsu_t + mtn\_gsm_t \\ &+ mtn\_svu_t + mtn\_svc_t + mtn\_gso_t + mtn\_svr_t \end{aligned} \tag{8}$$

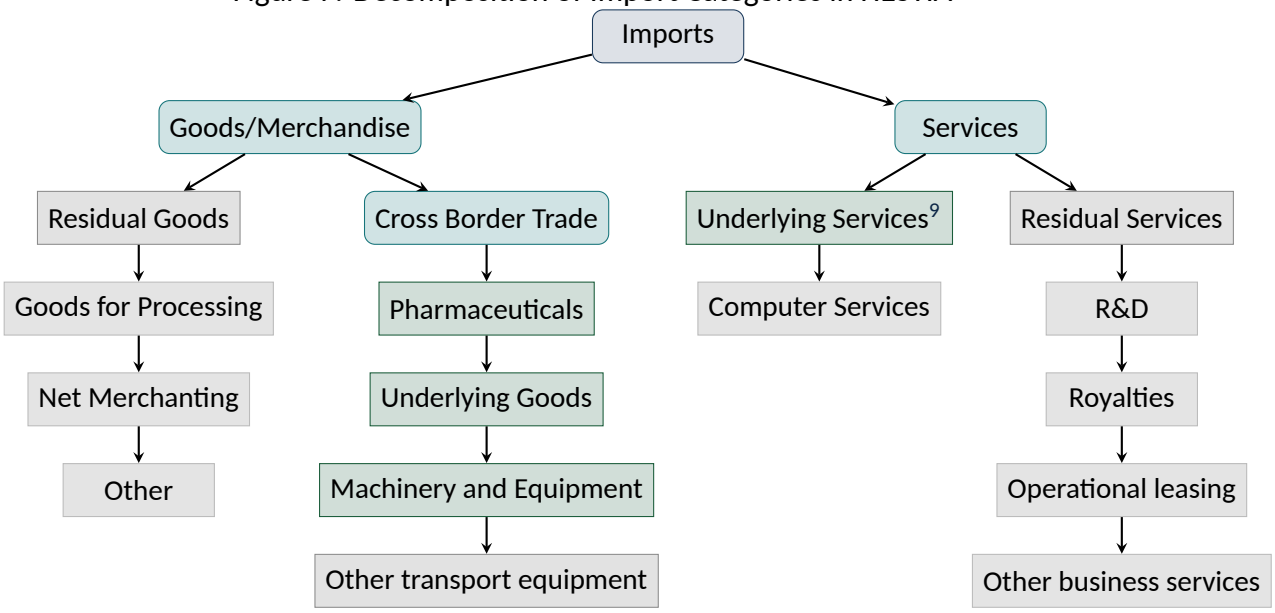
where:

mtn_gsp_t = Chemicals and related products (5 in CBorT)
mtn_gsm_t = Machinery and transport equipment (7 in CBorT) − mtn_gso_t
mtn_gso_t = Other transport equipment (79 in CBorT)
mtn_gsu_t = Total cross-border trade (CBorT) − mtn_gsp_t − mtn_gsm_t − mtn_gso_t
mtn_gsr_t = Total goods imports (QNA) − Total cross-border trade (CBorT)

mtn_svc_t = Computer services imports (QIA)
mtn_svu_t = Communications + insurance + finance + travel + repairs + other (QIA)
mtn_svr_t = Total services imports (QNA) − mtn_svc_t − mtn_svu_t

The following graphic summarises our treatment of imports in the model. Green boxes are endogenous and estimated using an error correction framework with differing divers as described below. The grey residual blocks are addressed with a technical assumption.

Figure 7: Decomposition of Import Categories in HESTIA



Source: Authors' own & CSO

3.1.4 Underlying trade

For the purposes of the adjusted output measure proposed in this paper, we further define underlying exports and imports that captures the portion of traded activity most relevant to the progress of the domestic economy.

$$\begin{aligned} X(Underlying) &= xtr\_gsu + xtr\_svu \\ M(Underlying) &= mtr\_gsu + mtr\_svu + mtr\_gsm \end{aligned}$$

3.1.5 Import equations

Pharmaceuticals imports are modelled using pharmaceutical goods exports as an explanatory variable because of the globalised focus of the industry in Ireland and the nature of supply chains in pharmaceuticals production.

$$\begin{aligned} \Delta \ln(mtr\_gsp_t) &= \alpha + \beta_1(\ln(mtr\_gsp_{t-1}) - \beta_2 \ln(xtr\_gsp_{t-1})) + \beta_3 \Delta \ln(xtr\_gsp_t) \\ &+ \beta_4 \Delta \ln(mtr\_gsp_{t-1}) \end{aligned} \quad (9)$$

The underlying goods imports category contains cross-border trade goods excluding pharmaceuticals and machinery and equipment. It is modelled as a function of modified domestic demand.

$$\begin{aligned}\Delta \ln(mtr\_gsu_t) &= \alpha + \beta_1(\ln(mtr\_gsu_{t-1}) - \beta_2 \ln(mdr_{t-1})) + \beta_3 \Delta \ln(mdr_t) \\ &+ \beta_4 \Delta \ln(mtr\_gsu_{t-1}) \end{aligned} \quad (10)$$

Underlying services imports also use MDD as an explanatory variable, as shown in the following equation.

$$\begin{aligned}\Delta \ln(mtr\_svu_t) &= \alpha + \beta_1(\ln(mtr\_svu_{t-1}) - \beta_2 \ln(mdr_{t-1})) + \beta_3 \Delta \ln(mdr_t) \\ &+ \beta_4 \Delta \ln(mtr\_svu_{t-1}) \end{aligned} \quad (11)$$

Machinery and equipment imports are modelled separate to the underlying goods category because they are best modelled using modified investment as an explanatory variable rather than modified domestic demand.

$$\begin{aligned}\Delta \ln(mtr\_gsm_t) &= \alpha + \beta_1(\ln(mtr\_gsm_{t-1}) - \beta_2 \ln(mitr_{t-1})) + \beta_3 \Delta \ln(mitr_t) \\ &+ \beta_4 \Delta \ln(mtr\_gsm_{t-1}) \end{aligned} \quad (12)$$

Again, we grow the residuals forward based on an technical assumptions and judgement parameters. One final transformation that we make is to account for the link between the non-modified investment activity and imports. This investment (which will be discussed in more detailed below) relates to aircraft leasing and R&D-related intellectual property assets. These investments are offset in a national accounting sense by related imports. These imports would be in categories mtr_gso_t and mtr_svr_t respectively. We therefore use a series of identities to ensure that the level of other investment is assumed into the level of imports in these categories and the remainder in these categories grows with a technical assumption:

$$mtr\_gso_t + mtr\_svr_t = nitr_t + mtr\_resid_t \quad (13)$$

$$with$$

$$mtr\_resid_t = mtr\_resid_{t-4} \times (1 + FORE(mtr\_resid)) \quad (14)$$

where *nitr* is defined in the next section. For the other final import categories, we make technical assumptions and judgement-based growth rates.

$$mtr\_gsr_t = mtr\_gsr_{t-4} \times (1 + FORE(mtr\_gsr)) \quad (15)$$

$$mtr\_svc_t = mtr\_svc_{t-4} \times (1 + FORE(mtr\_svc)) \quad (16)$$

$$(17)$$

As with exports, we forecast imports in real terms. We model the import deflator endogenously and apply its growth rate to separate goods and services deflators. Any import category for goods (i) or services (j) can be transformed to current prices as follows:

$$\begin{aligned} mtn\_i_t &= mtr\_i_{t+1} \times mtd\_gs_{t+1} \\ mtn\_j_t &= mtr\_j_{t+1} \times mtd\_sv_{t+1} \end{aligned}$$

3.1.6 Import and export deflators

We model the import and export deflators separately. The export deflator is modelled as a function of consumer prices in export markets, weighted by Ireland's trading partners.

$$\begin{aligned} \Delta \ln(xtd_t) &= \alpha + \beta_1(\ln(xtd_{t-1}) - \beta_2 \ln(\frac{cpx_{t-1}}{rex_u s_{t-1}})) \\ &+ \beta_3 \Delta \ln(xtd_{t-1}) + \beta_4 \Delta \ln(\frac{cpx_t}{rex_u s_t}) \end{aligned}$$

The import deflator is modelled as a function of energy prices and consumer prices in Irish export markets.[10] The energy prices variable is a weighted average of oil, coal, and gas import prices. The weights M(s) are calculated as a four-quarter moving average of the ratio of each energy source to total imported energy.

$$erw_t = M(s)_{oil} * P(Oil)_t + M(s)_{gas} * P(Gas)_t + M(s)_{coal} * P(Coal)_t$$

$$\begin{aligned} \Delta \ln(mtd_t) &= \alpha + \beta_1(\ln(mtd_{t-1}) - \beta_2 \ln(\frac{erw_{t-1}}{rex_u s_{t-1}})) - \beta_3 \ln(\frac{cpx_{t-1}}{rex_u s_{t-1}})) \\ &+ \beta_4 \Delta \ln(\frac{cpx_t}{rex_u s_t}) + \beta_5 \Delta \ln(\frac{erw_t}{rex_u s_t}) \end{aligned}$$

[10] The consumer prices variable in export markets (cpx) and the energy price variable (erw) are denoted in dollars and must be scaled by the exchange rate.

3.2 Investment, Credit and Housing

Section 2 highlighted the need to strip out the 'other investment' series and model modified investment directly. Headline investment can therefore be written as the sum of modified investment and other investment:

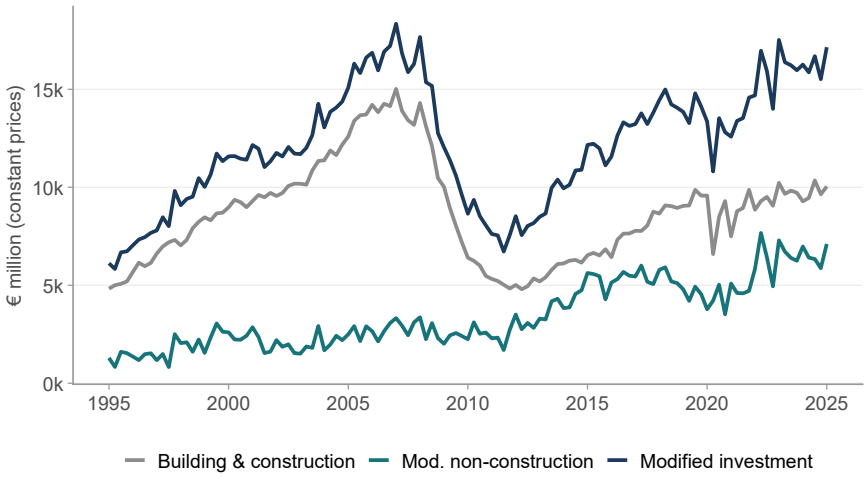
$$itr_t = mitr_t + nitr_t \tag{18}$$

In practice, other investment is backed out by taking modified investment from headline investment so can be thought of as non-modified investment. Within modified investment, we use the breakdown provided in the QNAs of building and construction investment and modified non-construction investment.

$$mitr_t = itr\_bc_t + mitr\_noc_t \tag{19}$$

The evolution of building and construction investment and modified non-construction investment is presented in Figure 8. The steady growth of modified non-construction investment contrasts with the boom and bust behaviour of the building and construction investment series. Both series are modelled separately and the modelling strategy for each is outlined below.

Figure 8: Components of modified investment (EUR bn, quarterly, constant prices)



Source: Authors' calculations.

Within building and construction investment, we separately model dwellings and non-dwellings investment. Non-dwellings investment consists of improve-

ments, transfer costs and other building and construction investment.[11] Through dwellings investment, the investment block of the model interacts with the house price and credit block.

$$itr\_bc_t = itr\_dw_t + itr\_bc\_ndw_t \quad (20)$$

Data redactions complicate the modelling of modified non-construction investment. In particular, redactions are a feature of the quarterly series for intangible assets and for machinery and equipment. We leverage data published by Eurostat on the components of modified non-construction investment to model three sub-categories; machinery, ICT equipment, and a residual category.

The residual category is the portion of modified non-construction investment that remains after investment in machinery and in ICT equipment have been removed. Given that aircraft leasing investment and some IP investment is already excluded from modified investment, this residual consists of non-aircraft transport equipment and some non-IP software investments.

$$mitr\_noc_t = mitr\_noc\_m_t + mitr\_noc\_ict_t + mitr\_noc\_r_t \quad (21)$$

where the sub-categories are constructed from Eurostat's table on Gross fixed capital formation by main asset type - published quarterly:[12]

$$\begin{aligned} mitr\_noc\_m_t &= \text{Other machinery and equipment (Eurostat)} \\ mitr\_noc\_ict_t &= \text{ICT equipment (Eurostat)} \\ mitr\_noc\_r_t &= mitr\_noc_t - mitr\_noc\_m_t - mitr\_noc\_ict_t \end{aligned}$$

In the short term forecasts, we grow Other GFCF forward based on an exogenous forecast parameter that is set using a combination of judgement and its current evolution:

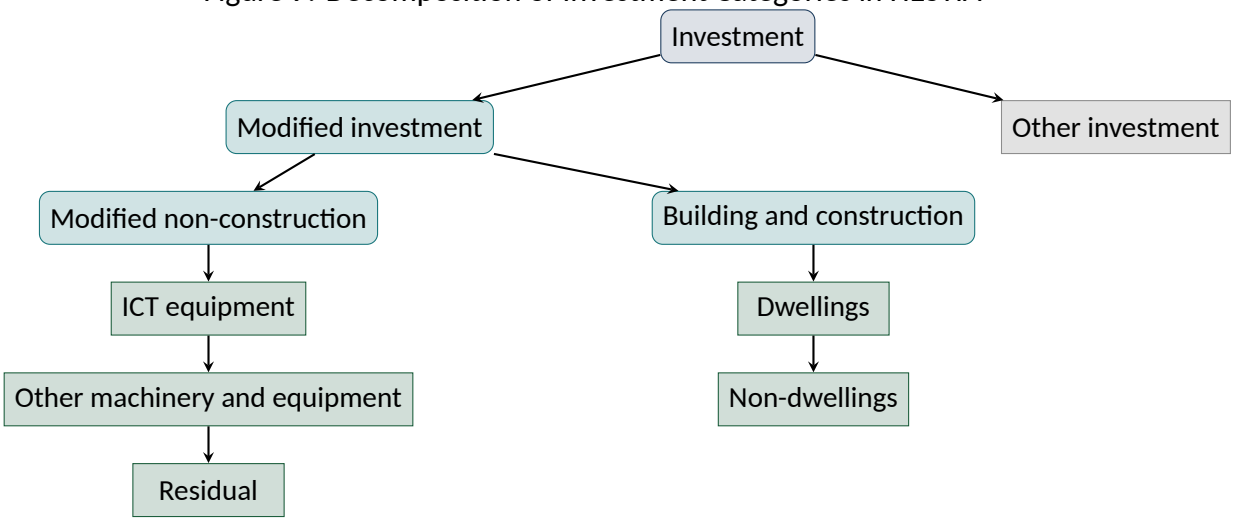
$$nitr_t = nitr_{t-4} \times (1 + FORE(nitr)) \quad (22)$$

The following graphic summarises how investment is forecasted in this model. The green sub-components of investment are modelled endogenously while other investment is treated as predetermined by judgement:

[11] Transfer costs refer to the costs associated with moving assets such as land registry or other financial fees.

[12] Table code namq_10_an6, while the required asset class codes are N11G, N11OG, and N1132G.

Figure 9: Decomposition of Investment Categories in HESTIA



Source: Authors' own & CSO.

3.2.1 Cost of capital

The real cost of capital in this model (r) is proxied using the interest rate on loans to non-financial corporations (r(nfc)) minus the consumer price index:

$$r_t = r(nfc)_t - pcdx_t$$

The forecast for the NFC interest rate is based on an error-correction framework using the European interbank overnight rate (ecb_t) as an explanatory variable. The interbank overnight rate is modelled as exogenous and a path is assumed over the forecast horizon based on expectations of ECB policy.

$$\Delta r(nfc) = \alpha + \beta_1(r(nfc)_{t-1} - \beta_2 ecb_{t-1}) + \beta_3 \Delta ecb_t \tag{23}$$

3.2.2 Modelling modified non-construction investment

Modified non-construction investment is further segregated into three sub-categories; machinery, ICT equipment, and a residual category. Each of these categories is modelled as an accelerator model, where real adjusted output and the real cost of capital are the explanatory variables. The three estimated equations for these categories are as follows:

$$\begin{aligned}\Delta \ln(mitr\_noc\_ict_t) &= \alpha_1 + \beta_1(\ln(mitr\_noc\_ict_t) - \beta_2 \ln(yer\_adj_t) - \beta_3 r_t) \\ &+ \beta_4 \Delta \ln(yer\_adj_t) + \beta_5 \Delta r_t + \epsilon_t \end{aligned} \quad (24)$$

$$\begin{aligned}\Delta \ln(mitr\_noc\_m_t) &= \alpha_1 + \beta_1(\ln(mitr\_noc\_m_t) - \beta_2 \ln(yer\_adj_t) - \beta_3 r_t) \\ &+ \beta_4 \Delta \ln(yer\_adj_t) + \beta_5 \Delta r_t + \epsilon_t \end{aligned} \quad (25)$$

$$\begin{aligned}\Delta \ln(mitr\_noc\_r_t) &= \alpha_1 + \beta_1(\ln(mitr\_noc\_r_t) - \beta_2 \ln(yer\_adj_t) - \beta_3 r_t) \\ &+ \beta_4 \Delta \ln(yer\_adj_t) + \beta_5 \Delta r_t + \epsilon_t \end{aligned} \quad (26)$$

3.2.3 Modelling building and construction investment

Building and construction investment can be divided into dwellings investment and non-dwellings investment. Non-dwelling investment is modelled on a seasonally adjusted basis as a function of real adjusted output and the cost of finance:

$$\begin{aligned}\Delta \ln(itr\_bc\_ndw_t) &= \alpha + \beta_1(\ln(itr\_bc\_ndw_{t-1}) - \beta_2 \ln(yer\_adj_{t-1})) \\ &+ \beta_3 \Delta \ln(itr\_bc\_ndw_{t-1}) + \beta_4 \Delta \ln(yer\_adj_t) \end{aligned} \quad (27)$$

Dwellings investment is modelled in a series of equations that explicitly treats the following stages of the production system: planning permissions, housing commencements (starts) and housing completions. Beginning with housing completions, we model this variable in an error correction framework using housing commencements as an explanatory variable. The growth rate for housing completions is applied to the value of dwellings investment from the previous quarter to generate the forecasted value for dwellings investment.[13] While the relationship between commencements and completions has been distorted in 2024 and 2025 by a policy intervention, it is expected that the relationship will return in the medium term.[14]

[13] Implicit in this calculation is the assumption that the makeup of dwelling investment does not change substantially over the forecast horizon, ie the real value of the average dwelling is comparable year-on-year.

[14] A waiver of the development levy paid by developers and water connection charges was introduced to stimulate housing supply. This led to increased commencement activity throughout 2024, concentrated in the months before the waivers were due to expire. These commencements are not expected to follow the typical time-to-completion of 9-18 months.

$$\begin{aligned}\Delta \ln(hs\_cpl_t) = \quad & \alpha + \beta_1 \left(\ln(hs\_cpl_{t-1}) - \beta_2 \ln(hs\_com_{t-1})\right) \\ + \quad & \beta_3 \Delta \ln(hs\_cpl_{t-1}) + \beta_4 \Delta \ln(hs\_com_t)\end{aligned} \tag{28}$$

The planning permissions equation, which is where we input behavioural factors, is set as an error correction model being determined by the unemployment rate (to capture two influences: macroeconomic developments as well as capacity constraints), house prices to capture price dynamics and interest rates on non-financial corporates to capture financial factors. The specification is as follows:

$$\begin{aligned}\Delta \ln(hs\_pln_t) = \alpha + \beta_1 (\ln(hs\_pln_{t-1}) - \beta_2 \ln(urx_{t-1}) - \beta_3 \ln(hp\_d_{t-1}) - \beta_4 \ln(nfcn_{t-1})) \\ + \beta_5 \Delta \ln(hs\_pln_{t-3}) + \beta_6 \Delta \ln(urx_{t-2}) + \beta_7 \Delta \ln(hp\_d_{t-4})\end{aligned} \tag{29}$$

where the short term factors have been selected using the general to specific method as discussed in the econometric sections below. The commencements equation is as follows:

$$\begin{aligned}\Delta \ln(hs\_com_t) \quad = \quad & \alpha + \beta_1 \left(\ln(hs\_com_{t-1}) - \beta_2 \ln(hs\_pln_{t-1})\right) + \beta_3 \Delta \ln(hs\_com_{t-1}) \\ + \quad & \beta_4 \Delta \ln(hs\_pln_t)\end{aligned} \tag{30}$$

Which is set as an error correction model linking commencements to planning permissions.

3.2.4 House Prices and Mortgage Credit

The house price model follows the broad approach outlined in Egan et al. (2024), whereby residential property prices are determined by affordability conditions[15] and housing supply within an error-correction framework. Higher levels of affordability increase households' purchasing power and place upward pressure on prices, while increases in the housing stock act to ease supply constraints and reduce price pressures. The estimated specification is given by:

[15]The affordability measure $0.3(pdr_{t-1}/12)(ccn_{t-1}/1200) \cdot \frac{1-(1+ccn_{t-1}/1200)^{-300}}{pcd_{t-1}}$ is derived from the present value of a mortgage annuity and approximates the maximum loan available to a representative household. It assumes that 30 per cent of disposable income can be allocated to mortgage repayments and that the mortgage is repaid over a 25-year (300 month) horizon. Affordability therefore increases with disposable income and declines as mortgage interest rates rise, providing a direct link between household borrowing capacity and house prices.

$$
\begin{aligned}
\Delta \ln\left(\frac{hd_t}{pcd_t}\right) &= \alpha \\
&+ \beta_1\left[\ln\left(\frac{hd_{t-1}}{pcd_{t-1}}\right) - \beta_2 \ln\left(\frac{0.3(pdr_{t-1}/12)}{(ccn_{t-1}/1200)} \cdot \frac{1-(1+ccn_{t-1}/1200)^{-300}}{pcd_{t-1}}\right) - \beta_3 \ln(cap_{t-1})\right] \\
&+ \beta_4 \Delta \ln\left(\frac{hd_{t-4}}{pcd_{t-4}}\right) + \beta_5 \Delta \ln\left(\frac{0.3(pdr_t/12)}{(ccn_t/1200)} \cdot \frac{1-(1+ccn_t/1200)^{-300}}{pcd_t}\right) \\
&+ \beta_6 \Delta \ln\left(\frac{0.3(pdr_{t-1}/12)}{(ccn_{t-1}/1200)} \cdot \frac{1-(1+ccn_{t-1}/1200)^{-300}}{pcd_{t-1}}\right) \qquad (31)
\end{aligned}
$$

where hd denotes the house price index, pcd is the personal consumption deflator, pdr is household disposable income, ccn is the residential mortgage interest rate and cap represents the housing stock.

The residential mortgage rate equation represents the pass-through from ECB policy rates to mortgage lending rates. Unlike the mortgage supply equation presented in Egan et al. (2024), which explicitly included banking sector capital ratios, the present specification adopts a parsimonious representation of mortgage rate determination. Mortgage rates are modelled as adjusting towards a long-run equilibrium relationship with the ECB policy rate while allowing for short-run changes in policy rates to pass through to lending rates. The estimated equation is specified as:

$$\Delta ccn_t = \alpha + \beta_1 (ccn_{t-1} - \beta_2 ecb_{t-1}) + \beta_3 \Delta ecb_t \qquad (32)$$

where ccn denotes the residential mortgage interest rate and ecb is the ECB policy rate. The specification implies that increases in ECB policy rates are transmitted to Irish mortgage borrowers through higher lending rates, reducing mortgage affordability and ultimately exerting downward pressure on housing demand and property prices. Consequently, the mortgage rate equation serves as an important transmission mechanism linking monetary policy developments to the wider housing market.

3.3 Household Income, Consumption, and Government Consumption

Real private consumption (*pcr*) is one of the largest components of modified domestic demand and adjusted output in HESTIA, and is central to the domestic transmission of external and policy shocks. We model real private consumption as a function of real household disposable income (*pdr*) within an error correction

framework consistent with the broader macroeconometric literature, where consumption equations are typically specified with disposable income as the primary long-run driver (Davidson et al., 1978; Muellbauer & Lattimore, 1995; Campbell & Mankiw, 1991).

$$\Delta \ln(pcr_t) = \alpha + \beta_1(\ln(pcr_{t-1}) - \beta_2 \ln(pdr_{t-1})) + \beta_3 \Delta \ln(pdr_t) + \epsilon_t \quad (33)$$

Real disposable income, pdr, is determined in the long run by real wages, defined as the ratio of nominal weekly earnings (*wen*) to the personal consumption deflator (*pcd*). This specification reflects the dominant role of labour income in the Irish household income distribution, where movements in gross wages are the primary driver of changes in household purchasing power over the medium term. In this way, the household block is directly linked to the labour market block described in the following section, through which nominal wages are jointly determined with consumer prices and productivity. Any deviation of real disposable income from its real wage-determined equilibrium is gradually corrected over time, establishing a channel through which labour market developments feed through into private consumption and, ultimately, into modified domestic demand and adjusted output.

$$\Delta \ln(pdr_t) = \alpha - \beta_1 (\ln(pdr_{t-1}) - \beta_2 \ln(\tfrac{wen_{t-1}}{pcd_{t-1}})) + \beta_3 \Delta \ln(\tfrac{wen_{t-1}}{pcd_{t-1}}) + \epsilon_t \quad (34)$$

The two-equation system linking wages to disposable income and disposable income to consumption establishes a critical domestic transmission channel within HESTIA. Increases in nominal wages, filtered through the consumption deflator, pass through to real disposable income and subsequently to private consumption. This domestic demand channel is central to the second-round effects of external shocks in HESTIA, as will be illustrated in the world demand simulation presented in Section 4, where the transmission through wages and income produces a relatively muted and lagged consumption response relative to the more immediate reaction in the traded sector.

Government consumption is modelled as a technical assumption in the short run taking information from the government budgetary documents to parameterise its growth rate. This allows the variable to be predetermined as a policy choice.

3.4 Labour Market , Productivity, Wages and Prices

The labour market, productivity, wages and prices follows the broad approach of Bårdsen et al. (2012) in specifying a simultaneous wage-price system grounded in

the theory of collective wage bargaining and monopolistic price setting (Layard et al., 2005; Bårdsen et al., 2005). The block consists of four jointly determined variables, namely labour productivity (*prd*), consumer prices (*pcd*), nominal wages (*wen*), and the unemployment rate (*urx*).

Labour productivity is specified as a function of real wages and the unemployment rate in the long run, capturing both the efficiency wage channel, whereby higher real wages incentivise greater effort and productivity, and a capacity utilisation effect via the unemployment rate, consistent with Okun's law interpretations at the firm level (Bårdsen et al., 2005).

$$\begin{aligned} \Delta \ln(prd_t) &= \alpha + \beta_1(\ln(prd_{t-1}) - \beta_2 \ln(\tfrac{wen_{t-1}}{pcd_{t-1}}) - \beta_3 \ln(urx_{t-1})) \\ &+ \beta_4 \Delta \ln(prd_{t-1}) + \beta_5 \Delta \ln(\tfrac{wen_{t-1}}{pcd_{t-1}}) + \beta_6 \Delta \ln(urx_t) \end{aligned} \tag{35}$$

Consumer prices are modelled as a mark-up on unit labour costs, the difference between nominal wages (*wen*) and productivity (*prd*), with the import price deflator (*mtd*) entering both the long-run cointegrating relationship and the short-run dynamics. This specification reflects the openness of the Irish economy, where import price pass-through is an important determinant of domestic inflation alongside domestic cost pressures (Bergin et al., 2017). The import deflator is itself modelled endogenously as a function of competitor prices and energy prices (see section 3.1.6 for this).

$$\begin{aligned} \Delta \ln(pcd_t) &= \alpha + \beta_1(\ln(pcd_{t-1}) - \beta_2(\ln(wen_{t-1}) - \ln(prd_{t-1})) - \beta_3 \ln(mtd_{t-1})) \\ &+ \beta_4(\Delta \ln(wen_t) - \Delta \ln(prd_t)) + \beta_5 \Delta \ln(mtd_t) \end{aligned} \tag{36}$$

Nominal wages are determined within a wage bargaining framework in which real wages in the long run are a function of labour productivity and the unemployment rate, consistent with the wage curve literature (Blanchflower & Oswald, 1994). The unemployment rate enters negatively, capturing the degree of labour market slack and its disciplining effect on wage demands. The wage and price equations together form a simultaneous system in which wages respond to prices and prices respond to wages, with the unemployment rate and productivity providing the real-side anchors for the long-run equilibrium, a standard feature of the wage-price spiral in semi-structural models (Bårdsen et al., 2012, 2005).

$$\begin{aligned} \Delta[\ln(wen_t) - \ln(pcd_t)] &= \alpha + \beta_1(\ln(wen_{t-1}) - \ln(pcd_{t-1})) - \beta_2 \ln(prd_{t-1}) \\ &- \beta_3 \ln(urx_{t-1}) - \beta_4 \Delta \ln(urx_t) \end{aligned} \tag{37}$$

Finally, the unemployment rate is modelled using an Okun's law relationship in equilibrium correction form (Okun, 1962). Rather than using headline GDP, we specify unemployment as a function of adjusted output (*yer_adj*), reflecting the argument developed in Section 3.5 that adjusted output is the more appropriate measure of domestic economic activity for labour market modelling purposes.

$$\Delta \ln(urx_t) = \alpha + \beta_1(\ln(urx_{t-1}) + \beta_2 \ln(yer\_adj_{t-1})) + \beta_3 \Delta \ln(yer\_adj_{t-1}) \tag{38}$$

The labour market block interacts with the rest of the model through several channels. Wages feed into the household income and consumption block through their effect on real disposable income, as described in the preceding subsection. Consumer prices feed into real wages, the import deflator and the real cost of capital. Unemployment feeds back into the adjusted output identity through its effect on wages and thereby consumption, establishing a self-correcting mechanism whereby deviations of output from trend are gradually absorbed through labour market adjustment. This ensures that the domestic side of HESTIA is coherently tied to adjusted output rather than to the distorted headline GDP measure.

3.5 Measuring Economic Output - An Adjusted Measure

This paper also introduces the concept of adjusted output. This consists of consumption, government expenditure, modified investment, and the underlying elements of the traded sector when sectoral concentrations and multinational distortions have been removed.

3.5.1 Measuring Adjusted Output in Ireland

The novel measure proposed in this paper, adjusted output, can be thought of in one of two ways. First, it takes the existing concept of MDD which consists of consumption, government consumption and modified investment. We then augment this with the portions of international trade that are the most consistent and most connected to the domestic economy.

$$
\begin{aligned}
mdr_t &= pcr_t + gcr_t + mitr_t \\
yer\_adj_t &= mdr_t + X(Underlying) - M(Underlying), \\
where &: \\
X(Underlying) &= xtr\_gsu_t + xtr\_svu_t \\
M(Underlying) &= mtr\_gsu_t + mtr\_svu_t + mtr\_gsm_t
\end{aligned}
$$

Alternatively, it can be thought of as a series of top-down adjustments to GDP. GDP as conceptualised using the expenditure approach is subjected to a series of adjustments that remove distortions associated with multinational activity and sector-specific effects in international trade.

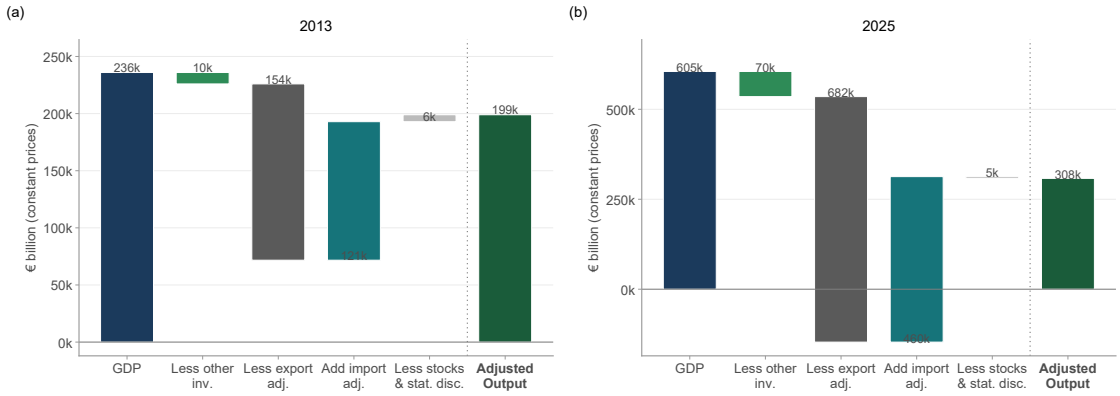
$$
\begin{aligned}
yer\_adj_t = \; & GDP \\
& - nitr_t \\
& - xtr\_gsp_t + mtr\_gsp_t \\
& - xtr\_svc_t + mtr\_svc_t \\
& - xtr\_gsr_t + mtr\_gsr_t \\
& - xtr\_svr_t + mtr\_svr_t \\
& + mtr\_gso_t \\
& - stk_t \\
& - \text{Statistical discrepancy}
\end{aligned}
$$

In this way, adjusted output can be constructed intuitively as either a top-down or a bottom-up measure. In addition, adjusted output has the advantage that it can be constructed consistently on a quarterly basis. The constituent parts in the bottom-up representation are unlikely to see the kind of fluctuations associated with the activity of multinationals that cause difficulty in interpreting the quarterly performance of the economy. There are clear advantages to a consistent, interpretable, timely measure of output that is domestically oriented but not restricted solely to domestic activity. From a short-term forecasting perspective, this measure is more appropriate for use in modelling the labour market than MDD because economic activity in the traded sector (captured by underlying exports) also demands labour.

The importance of incorporating some of the traded sector's activity in a measure of domestic performance or overheating is also emphasised by DoF (2022). They point out that MDD growth, particularly on a quarterly basis, is impacted by multinational investment, which often has a high import content. The inclusion of machinery and equipment imports in the adjusted output measure controls for this factor. Conversely, it is important that sector-specific developments in pharmaceuticals are not included in adjusted output. Recent experience of tariff-related inventory management saw large quarterly swings in pharmaceuticals exports in 2025.

The walk from GDP to adjusted output in 2013 and 2025 is presented in Figure 10.[16] The sharp growth in GDP over this period emphasises the need for an adjusted measure. In addition, the chart shows that the adjustments to exports in 2025 were larger than GDP.

Figure 10: GDP to adjusted output walk, 2013 and 2025, € million, constant prices

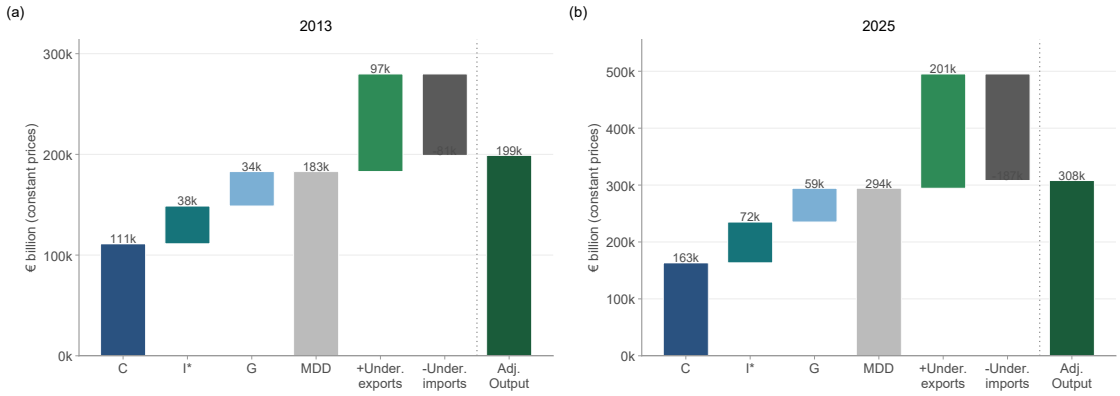


Source: CSO and authors' calculations.

Figure 11 shows the walk from MDD to adjusted output in 2013 and 2025. Figures 10 and 11 both show that there has been a sizeable increase in international trade, but Figure 11 highlights that this growth is still observable even excluding exports driven by globalisation factors and the two booming sectors of pharmaceuticals and computer services. Second, in 2025, we observe that Modified Domestic Demand and adjusted output provided a similar estimate of the size of the Irish economy.

[16] 2013 is chosen as it is the first year where the breakdown of the services exports and imports categories are available. As discussed in the appendix, we apply a backcasting for years before 2013. However, the backcasting process increases the size of the statistical discrepancy in the walk provided.

Figure 11: MDD to adjusted output walk, 2013 and 2025, € million, constant prices

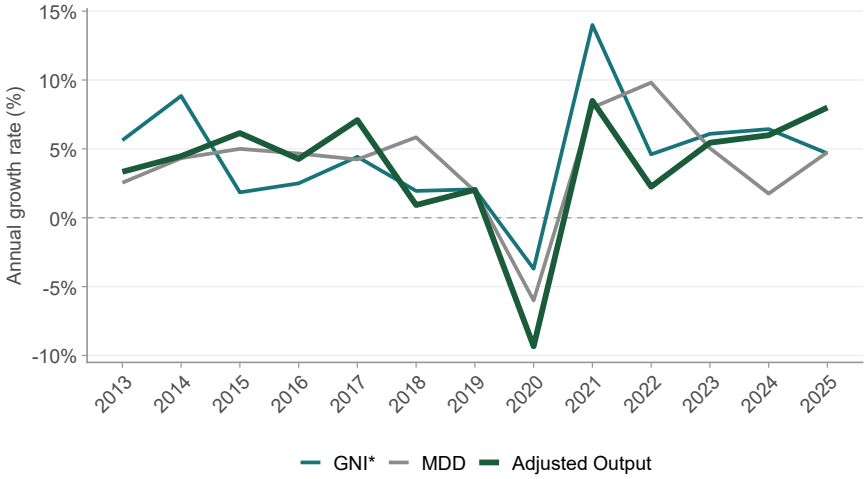


Source: CSO and authors' calculations.

This similarity between the estimate of the size of the economy provided by MDD and adjusted output belies the differences in how the two measures assess performance year-on-year. Figure 12 shows the evolution of the annual growth rates in the two measures as well as in the modified GNI measure. It shows that adjusted output tracks modified GNI growth more closely than MDD does. The estimate of growth in individual years can differ substantially. For example, MDD growth in 2018 was close to 6 per cent while modified GNI and adjusted output estimated growth of around 2 per cent.

The key question in short-term forecasting is to assess and predict the performance of the economy, not to measure its size. There are clear differences in the picture painted by the two different measures of performance.

Figure 12: MDD, GNI* and adjusted output growth rates at constant prices, 2013–2025



Source: Authors' calculations & CSO

3.6 Overview of Model Structure

The full model structure is illustrated in Figure 13. On the external side, world demand (*wdy*), competitor prices (*cpx*), the ECB policy rate (*ecb*), energy prices (*erw*) and the exchange rate (*rex_us*) are sourced from NiGEM and treated as exogenous. World demand enters the model through the four estimated export equations. Competitor prices and energy prices drive the export and import deflators (*xtd*, *mtd*), which feed into domestic consumer price formation. The ECB rate drives the NFC lending rate (*nfcn*) and the mortgage rate (*ccn*), which feed into the investment and housing blocks respectively.

Within the trade block, the four estimated export categories, pharmaceutical goods (*xtr_gsp*), underlying goods (*xtr_gsu*), computer services (*xtr_svc*) and underlying services (*xtr_svu*), each follow an error correction model with world demand as the long-run driver. On the import side, pharmaceutical imports (*mtr_gsp*) are driven by pharmaceutical exports; underlying goods (*mtr_gsu*) and services (*mtr_svu*) imports are driven by modified domestic demand; and machinery and equipment imports (*mtr_gsm*) are driven by modified investment. Residual export and import categories are grown at trend rates.

Within the investment block, total investment is split into modified investment (*mitr*), covering building and construction (*itr_ndw*) and modified non-construction investment (*mitr_noc*) disaggregated into ICT, machinery and a residual component, and other investment (*nitr*), which captures MNE-related assets and is treated as exogenous. Modified investment is driven by adjusted output and the real cost

of capital. Housing completions (hs_cpl) feed into the housing stock (cap), which alongside the mortgage rate and real disposable income determines housing demand (hd).

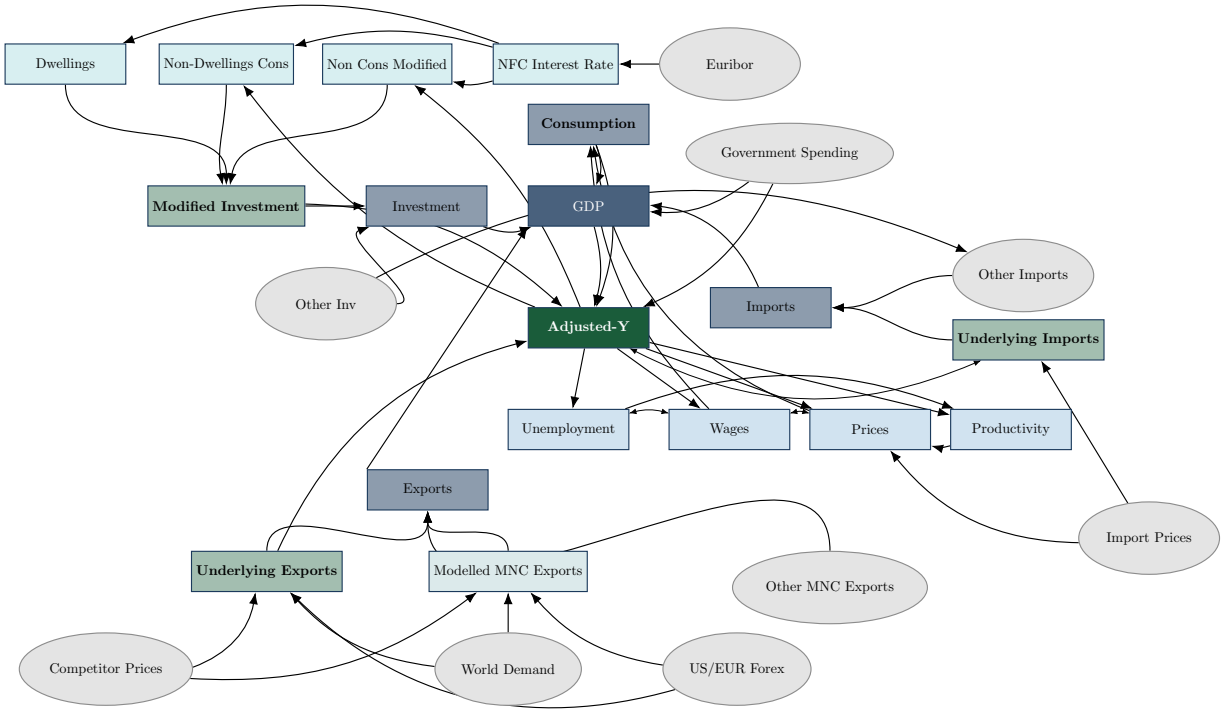
In the labour market, productivity (prd), consumer prices (pcd), nominal wages (wen) and unemployment (urx) are jointly determined. Wages respond to prices, productivity and unemployment; prices respond to unit labour costs and import prices; and unemployment follows an Okun's law relationship with adjusted output. Wages feed into real disposable income (pdr), which in turn drives private consumption (pcr).

The behavioural components aggregate into three output measures through accounting identities. Headline GDP (yer) includes all expenditure components, consumption, total investment, government consumption, total exports and imports, and stocks, and is therefore subject to the full range of MNE distortions. Modified domestic demand (mdr) is confined to consumption, modified investment and government consumption, containing no traded sector component. Adjusted output (yer_adj) adds underlying goods and services net trade to modified domestic demand and deducts machinery and equipment imports, capturing domestic economic activity while excluding the MNE-dominated export and investment components that distort headline GDP.

4 Dynamic Properties of HESTIA

This section presents the properties of HESTIA by presenting a dynamic simulation through a positive world demand shock. Given that HESTIA represents a small open economy, fluctuations in external demand are among the most important sources of economic disturbance. The simulation therefore provides the most appropriate illustration of the model's transmission mechanisms, showing how an external shock propagates through the traded sector into domestic income, consumption and investment, and how the adjustment of key macroeconomic variables differs markedly depending on which output measure is used to assess the response. Our analysis proceeds in two parts. The first examines the responses of a broad set of macroeconomic variables spanning both the traded and domestic sides of the model. The second decomposes the shock across these three measures of economic output, namely headline GDP, modified domestic demand (MDD) and adjusted output, to illustrate how the treatment of multinational distortions shapes the measured impact of the same underlying shock.

Figure 13: Overview of HESTIA Model



Source: Authors' calculations.

4.1 Dynamic Simulation - 1% Shock to World Demand

This section examines the reaction of key macro variables to a persistent one per cent increase in world demand (*wdy*). The purpose of this scenario analysis is to illustrate the differential sensitivities of the three output measures outlined in Section 3, namely actual GDP (*yer*), adjusted output (*yer_adj*), and modified domestic demand (*mdr*), and to demonstrate the value of the disaggregated treatment of the traded sector that is central to HESTIA's design. We present results for a selection of variables that together span both the traded and domestic sides of the model. As outlined in Section 4, a world demand shock enters HESTIA exclusively through the export equations, as documented in Appendix 7. A sustained rise in world demand raises the volume of goods and services exports in each of the four estimated export categories, with the magnitude of the response governed by the sector-specific long-run world demand elasticities. These can be seen in the estimated export equations in Appendix 7. The initial export expansion feeds into domestic income, which in turn raises private consumption and modified in-

vestment through the standard demand-side channels of the model. It should be noted that for this simulation government expenditure is held at its baseline path and so any fiscal multiplier channel is deliberately closed.

Figure 14 presents the responses of the four estimated export categories. The heterogeneity of their responses underlines the importance of sector-level disaggregation within the traded block. Pharma goods exports (*xtr_gsp*) and computer services exports (*xtr_svc*) respond most strongly, rising by 0.7 and 1.1 per cent respectively after one year and reaching 2.2 and 3.5 per cent at the five-year horizon. Non-pharma goods exports (*xtr_gsu*) follows a similar path after one year, rising by 1.0 per cent after one year but its response is more muted by the end of the five-year horizon reaching 1.9 per cent above the baseline. Underlying services exports (*xtr_svu*) respond significantly less, reaching 0.4 per cent after one year and 1.1 per cent at year five. Total exports (*xtr*) stand approximately 0.7 per cent above baseline after one year and 2.3 per cent after five years. These results confirm that the sensitivity of exports to world demand varies across sectors, and that a single-equation treatment of the traded sector may distort both the aggregate export response and the downstream domestic transmission to the level of output.

A parallel distortion is visible in the investment block. Total investment (*itr*) rises by 0.3 per cent after one year and 0.7 per cent after five years, while modified investment (*mitr*), which as described in Section 3 strips out the non-modified component linked to headline GDP, rises by 0.5 per cent after one year and 1.3 per cent after five years. Modified investment responds more strongly than total investment throughout the horizon. This reflects the new disaggregated treatment of non-construction investment, whereby the ICT, machinery and equipment, and residential sub-components each respond to adjusted output and the real cost of capital through their own estimated equations. By separating modified from non-modified investment, HESTIA avoids the amplification embedded in total investment and produces a domestic investment response that is more credibly linked to adjusted output and the real cost of capital.

Figure 14 also shows the responses of some key labour market and household variables. Private consumption (*pcr*) and wages (*wen*) respond more gradually, as the initial shock feeds through the income channel with a lag. Private consumption rises by 0.04 per cent after one year, 0.4 per cent after three years, and 0.5 per cent at the end of the horizon. Nominal wages rise by 0.3 per cent after one year and 0.6 per cent after five years, reflecting the gradual tightening of labour market conditions. These responses are modest relative to the headline export and investment movements described above, which is as expected. Overall, they reflect the gradual transmission of the initial traded-sector shock through income and spending channels into the broader economy.

Finally, Figure 14 also presents the responses of the three output measures

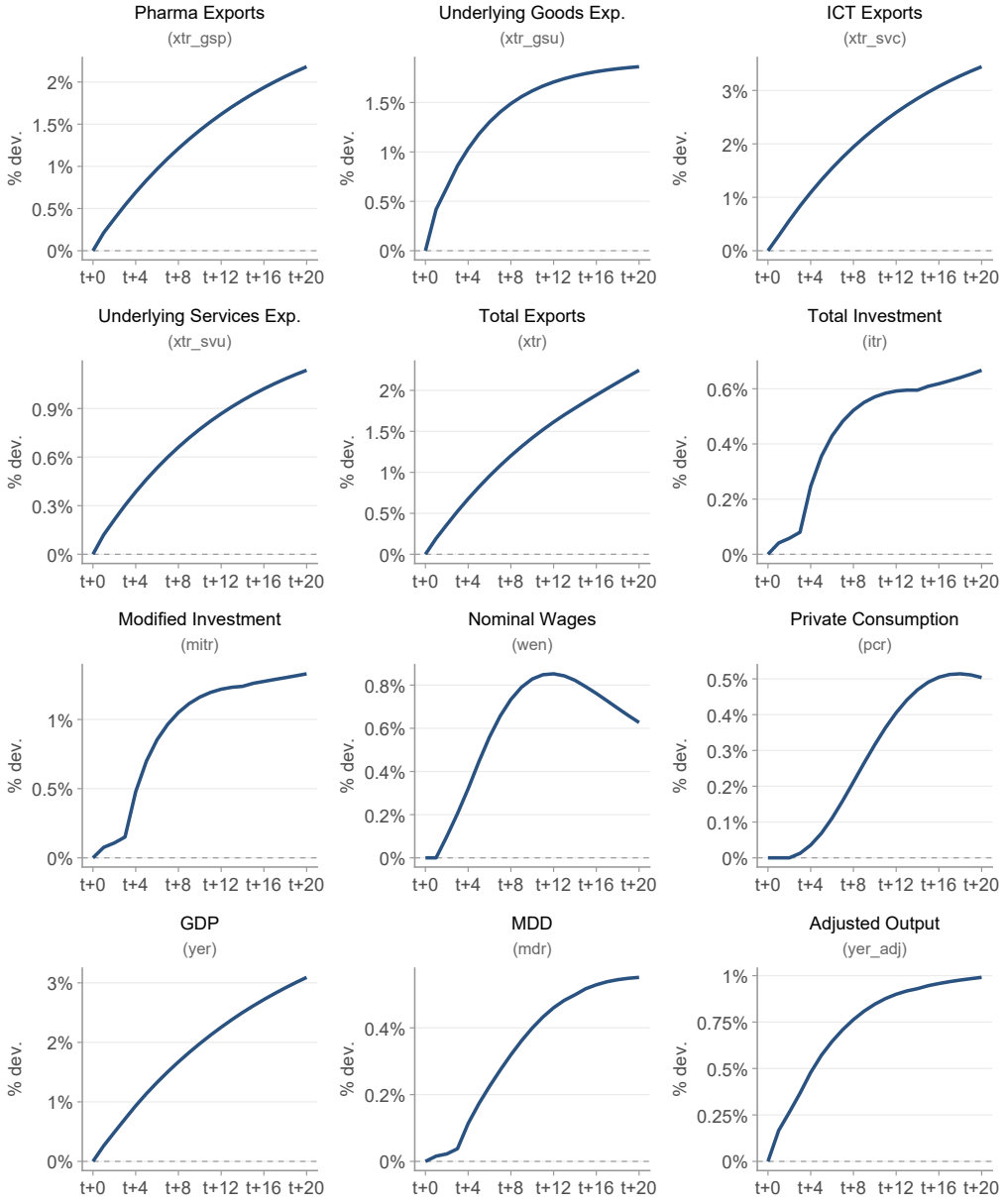
produced by HESTIA. The first and most striking result is the gap between them. After one year, actual GDP rises by 0.9 per cent above the baseline. This is compared to just a 0.5 and 0.1 per cent increase for adjusted output and MDD respectively. After three years, these figures diverge even further with actual GDP now 2.3 per cent above the baseline compared to 0.9 and 0.5 per cent for adjusted output and MDD respectively. By the end of the five-year horizon, actual GDP stands at 3.1 per cent above baseline, adjusted output at 1.0 per cent, and modified domestic demand at 0.6 per cent. This ordering is stable throughout the simulation horizon. Interestingly, the long run response of our adjusted output variable is close to unity. This is consistent with other structural models of the Irish economy, such as COSMO (Bergin et al., 2017), where NiGEM's global demand for Irish exports is also the principal exogenous driver of export demand. It is also broadly consistent with the export-demand literature, which typically finds long-run income elasticities around unity for advanced economies. Cross-country evidence suggests long-run export income elasticities that are typically at or above unity, with Montenegro and Senhadji & Montenegro (1999) reporting average estimates of around 1.5 and Devarajan et al. (2023) finding average export elasticities of approximately 1.4 for high-income economies.

The divergence between the three measures reflects the structural design of HESTIA and illustrates the problem that motivates the model. Actual GDP would appear to overstate the domestic impact of external demand shocks because it aggregates all export categories, including pharmaceuticals and computer services, whose large long-run elasticities (3.02 for pharma goods and 4.49 for computer services, respectively) generate an outsized export response that has limited connection with the domestic economy. Modified domestic demand, on the other hand, understates the impact because it excludes all trade channels, confining transmission to the second-round effects on consumption and investment alone. Adjusted output (yer_adj), by including underlying goods and services trade while excluding the MNE-dominated sectors, would therefore seem to provide an economically appropriate middle ground. The impulse response of adjusted output to a world demand shock is consistent with the response of GDP in the ESRI's COSMO model estimated on pre-2015 data (Bergin et al., 2017), suggesting that adjusted output captures a degree of domestic economic activity that is broadly comparable to pre-distortion headline GDP.

4.2 Decomposing the Sources of Output Divergence

Figure 15 decomposes the deviation from baseline of the three output measures into the contributions of their components. These decompositions sharpen the interpretation of the aggregate results and provide the clearest illustration of the

Figure 14: Response of Selected HESTIA Variables to a Permanent 1% Shock to World Demand



Source: Authors' calculations.

case for adjusted output.[17]

[17]Note that government consumption is held constant throughout and therefore contributes zero to all three decompositions by construction.

Panel (a) of Figure 15 decomposes headline GDP (*yer*). The figure shows that aggregate exports (*xtr*) contribute by far the largest share of the total response throughout the horizon, rising from 0.94 percentage points after one year to 3.2 percentage points after five years and accounting for the vast majority of the total GDP response to the world demand shock. This reflects the high world demand elasticities of the pharma and computer services export sectors, which dominate the aggregate export response. Total investment (*itr*) contributes a further 0.04 percentage points after one year, growing to 0.08 percentage points after five years, while private consumption (*pcr*) contributes 0.01 percentage points after one year and 0.08 percentage points after five years. Imports provide a small but growing negative offset, reaching -0.3 percentage points by year five as rising domestic demand draws in additional imports. The GDP decomposition suggests that the response is largely driven by MNE-dominated export sectors rather than any broad-based expansion of the domestic economy, a finding that directly motivates the modelling approach taken in this paper.

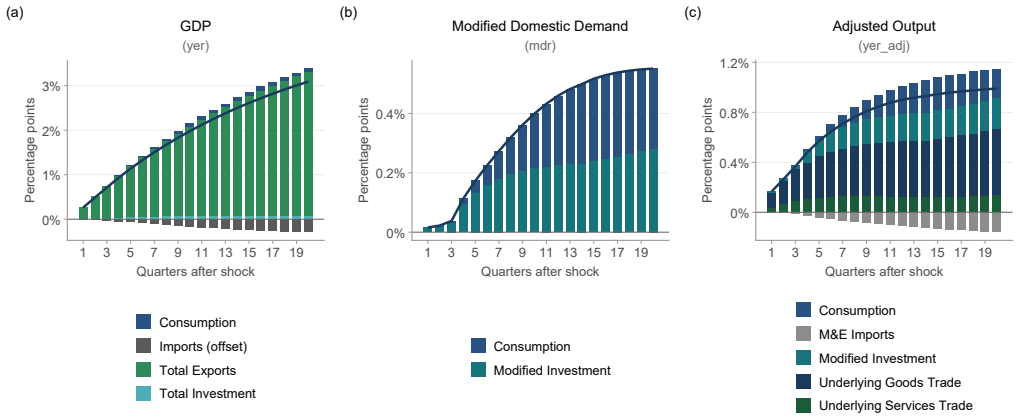
Panel (b) of Figure 15 decomposes modified domestic demand (*mdr*). The figure shows that the response is driven entirely by private consumption (*pcr*) and modified investment (*mitr*), as MDD contains no traded component by construction. After one year, consumption contributes 0.02 percentage points and modified investment 0.09 percentage points. These contributions grow slowly over the horizon, reaching 0.27 and 0.28 percentage points respectively by year five, for a total MDD response of 0.55 per cent. This reflects the fundamental limitation of MDD as a measure of the economy's response to external shocks: by excluding all of the traded sector, it captures only the second-round domestic effects of the shock and misses the contribution of the underlying traded sector.

Finally, Figure 15 decomposes adjusted output (*yer_adj*) and best illustrates the value of the measure proposed in this paper. The decomposition includes the same consumption and modified investment contributions as MDD, supplemented by the net contribution of underlying goods trade (exports *xtr_gsu* less imports *mtr_gsu*) and underlying services trade (exports *xtr_svu* less imports *mtr_svu*), together with a deduction for machinery and equipment imports (*mtr_gsm*). After one year, underlying goods trade contributes 0.29 percentage points, underlying services trade 0.10 percentage points, modified investment 0.09 percentage points, and consumption 0.02 percentage points, with machinery and equipment imports deducting −0.03 percentage points. By year five, the underlying goods trade contribution has grown to 0.53 percentage points and underlying services to 0.14 percentage points, while the machinery and equipment import deduction widens to −0.16 percentage points as rising modified investment generates additional import demand. Consumption and modified investment contribute 0.24 and 0.25 percentage points respectively at the five-year horizon. The adjusted output decomposition offers a more nuanced picture than either MDD or

GDP. Relative to MDD, two features stand out. First, by deducting machinery and equipment imports (*mtr_gsm*), adjusted output properly accounts for the import content of investment; MDD implicitly assumes that all investment creates domestic value added, whereas in practice a substantial share leaks abroad through capital goods imports. Second, the growing negative contribution from underlying services net trade reflects the fact that rising domestic incomes generate additional services import demand. MDD misses this channel entirely by excluding all trade. Relative to GDP, the key distinction is in what is excluded rather than what is included. By stripping out the MNE-dominated pharma and computer services export sectors, adjusted output removes the components whose dynamics are driven by firm-specific decisions rather than Irish domestic economic conditions. The result is a decomposition in which the contributions have a plausible domestic economic interpretation, something that cannot be said of either GDP, which is distorted by MNE accounting flows, or MDD, which is too narrow a measure to capture the economy's full external exposure.

The three decompositions presented in this section show clearly the importance of disaggregating components of the traded sector which is at the centre of HESTIA. The differential responses of GDP, MDD, and adjusted output to an identical world demand shock, 3.09 per cent, 0.55 per cent, and 0.99 per cent respectively after five years, encapsulate the core challenge of modelling the Irish economy in the presence of MNE distortions, and demonstrate that adjusted output may provide a more informative and tractable measure of the domestic economic cycle for short-term forecasting and scenario purposes.

Figure 15: Decomposition of GDP, MDD and Adjusted Output's Deviation from Baseline Following a Permanent 1% Shock to World Demand



Source: Authors' calculations.

5 Adjustment parameters and short term forecasting

The model presented in this paper has multiple uses but one particular aim is to help produce baseline forecasts which can inform the ESRI's Quarterly Economic Commentary. These baseline forecasts can provide an initial run for forecasters to assess economic developments, allowing in particular the external assumptions around world demand, competitors prices, energy prices, policy interest rates etc to feed through to the domestic economy.

However, short term forecasts are typically driven by many factors which are outside the scope of a macroeconometric model of this nature. This includes factors such as uncertainty, momentum, short term fluctuations, policy changes and other real time developments. For example, Brosnan & Redmond (2025) outlined how real-time hiring data from LinkedIn can offer insights on sectoral trends in hiring. In addition, the ESRI's Nowcast model provides a forecast in real time for MDD (Egan, 2023). Often idiosyncratic factors related to multinationals can also be impactful for Ireland in terms of the short term data.

Incorporating these factors can be difficult, and this is especially the case where such impacts ought to feed back into the wider model endogenously. To take this into consideration, we have adapted the framework to work on a series of judgement parameters where the outcome of the baseline model is multiplied by a scaling factor. These scaling factors then feed back through the model as the independent variables in the model equations. The initial value for each judgement parameter is 1, resulting in no change from the model forecast. If the forecasters believe that judgement is required these parameters can be set to incorporate any magnitude needed. These factors, through the judgement parameters, allow for adjustments to the model forecast to feed back into other variables endogenously.

6 Concluding Remarks

The Irish national accounts are a source of considerable challenge for policymakers and researchers in terms of measuring the size of the economy, extrapolating underlying performance and trends as well as modelling economic relationships. These distortions are caused by the extremely dominant multinational sector in Ireland. In this paper, we present a small-scale macroeconometric model of the Irish economy which adjusts for the large multinational distortions that are present in exports, imports and investment series. Our aims are to: a) remove series from the core model which have volatile pathways driven by individual corporate mechanics but maintain these in the overall forecasts; b) appropriately model the external side of the economy which is dominated by a small number of very large export sectors; and b) maintain a core model and measure for the Irish economy which captures domestic developments.

By decomposing investment, exports and imports in the manner presented, we can develop a framework which can be used to undertake short term baseline forecasts in the presence of the multinational distortions and also for scenario analysis. Our model is built on quarterly data to allow for the update and re-estimation immediately after the release of the Irish Quarterly National Accounts and to be sufficiently flexible to work on within-year forecasts. In addition to treating multinational distortions, we present an indicator of adjusted output which complements the CSO measure of modified domestic demand but adjusts for trade in underlying exports and imports (which by definition are not subject to the major swings in other export or import categories).

There are a number of avenues of further research which are suggested from our paper. If sufficient quarterly data become available, an indicator of modified gross national income (GNI*) could be appended to the structure and therefore produce a link to this broadly used indicator produced by the CSO. Second, if more detail on the export and import deflators were available at a quarterly level, a better tailoring of the analysis for different sectors could be completed. Furthermore, a more expanded government sector could be incorporated both in terms of government consumption as well as fiscal forecasting models. These would be worthy extensions.

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Appendix A: Variable names and description

Given the degree of disaggregation in the trade and investment blocks of HESTIA, the model employs a systematic naming convention to identify variables and their sub-categories. Table 1 sets out the key components of this convention.

Code component	**Description**
Suffixes	
__d	Deflator
__n	Current prices
__r	Constant prices
Trade prefixes and infixes	
mt_	Imports
xt_	Exports
_gs_	Goods
gsp	Goods: Pharmaceutical
gsm	Goods: Machinery
gsu	Goods: Underlying
gsr	Goods: Residual
_sv_	Services
svc	Services: Computer
svu	Services: Underlying
svr	Services: Residual
Investment prefixes and infixes	
it_	Total investment
_dw_	Dwelling construction
ndw	Non-dwelling construction
mit_	Modified investment
noc	Non-construction
_noc_m_	Non-construction: Machinery
_noc_ict_	Non-construction: ICT equipment
_noc_r_	Non-construction: Residual

Table 1: Variable naming convention

Source: Authors' own.

For example, the code xtn_svc describes exports (xt) at current prices (n) for computer services (svc). The following table specifies all of the variable codes and their description.

Model code	Description
cpx_t	Trade prices in basket of competitors, USD
ecb_t	ECB policy rate: Key ECB policy rate, per cent
erw_t	Weighted average of oil, coal and gas import prices
gcd_t	Deflator for net government expenditure on goods and services
gcn_t	Net government expenditure on goods and services at current prices
gcr_t	Net government expenditure on goods and services at constant prices
hs_com_t	Housing commencements, units
hs_cpl_t	New dwelling completions, units
$hs\_p\ln_t$	Planning permissions for new dwellings, units
itn_t	Investment: Gross fixed capital formation at current prices
itr_t	Investment: Gross fixed capital formation at constant prices
itr_dw_t	Dwellings construction investment at constant prices
$itr\_bc\_ndw_t$	Non-dwelling construction investment at constant prices
mdn_t	MDD: Modified domestic demand at current prices
mdr_t	MDD: Modified domestic demand at constant prices
$mitr_t$	Modified investment at constant prices
$mitr\_noc_t$	Modified non-construction investment at constant prices
$mitr\_noc\_m_t$	Modified non-construction investment in machinery at constant prices
$mitr\_noc\_ict_t$	Modified non-construction investment in ICT equipment at constant prices
$mitr\_noc\_r_t$	Modified non-construction investment (residual) at constant prices
mtd_t	Import deflator
mtd_gs_t	Goods imports deflator
mtd_sv	Services imports deflator
mtn_t	Imports at current prices
mtn_gsp_t	Pharmaceutical goods imports at current prices
mtn_gsm_t	Machinery goods imports at current prices
mtn_gsr_t	Residual goods imports at current prices
mtn_gsu_t	Underlying goods imports at current prices
mtn_svc_t	Computer services imports at current prices
mtn_svr_t	Residual services imports at current prices
mtn_svu_t	Underlying services imports at current prices
mtn_gso_t	Other transport equipment imports at current prices
mtr_t	Imports at constant prices
mtr_gsp	Pharmaceutical goods imports at constant prices
mtr_gsm	Machinery goods imports at constant prices
mtr_gsr	Residual goods imports at constant prices

Table 2: List of variables (A)

Source: Authors' calculations.

Model code	Description
mtr_gsu	Underlying goods imports at constant prices
mtr_svc	Computer services imports at constant prices
mtr_svr	Residual services imports at constant prices
mtr_svu	Underlying services imports at constant prices
mtr_gso_t	Other transport equipment imports at constant prices
$nitr_t$	Other investment at constant prices
$nfcn_t$	Interest rate on loans to non-financial corporations
pcd_t	Personal consumption deflator
$pcdx_t$	Inflation rate
pcn_t	Personal consumption expenditure at current prices
pcr_t	Personal consumption expenditure at constant prices
pdr_t	Household personal disposable income
prd_t	Labour productivity
rex_us_t	Exchange rate, GBP/USD
stk_t	Change in stocks
urx_t	Unemployment rate
wdy_t	World demand
wen_t	Nominal weekly earnings
xtd_t	Export deflator
xtd_gs_t	Goods export deflator
xtd_sv_t	Services exports deflator
xtn_t	Exports at current prices
xtn_gsp_t	Pharmaceutical goods exports at current prices
xtn_gsr_t	Residual goods exports at current prices
xtn_gsu_t	Underlying goods exports at current prices
xtn_svc_t	Computer services exports at current prices
xtn_svr_t	Residual services exports at current prices
xtn_svu_t	Underlying services exports at current prices
xtr_t	Exports at constant prices
xtr_gsp_t	Pharmaceutical goods exports at constant prices
xtr_gsr_t	Residual goods exports at constant prices
xtr_gsu_t	Underlying goods exports at constant prices
xtr_svc_t	Computer services exports at constant prices
xtr_svr_t	Residual services exports at constant prices
xtr_svu_t	Underlying services exports at constant prices
yer_adj_t	Adjusted output at constant prices
yer_t	GDP, real

Table 3: List of variables (B)

Source: Authors' calculations.

7 Appendix C: Estimated Equations and Identities

Tables 5 and 7 present the full set of estimated behavioural equations and accounting identities that constitute HESTIA. The equations follow the general equilibrium correction form described in Section 7. For each equation, the equilibrium correction coefficient multiplies the lagged deviation from the estimated long-run relationship, shown in parentheses. Short-run factors were selected by general-to-specific reduction over lags up to four quarters, with insignificant terms removed. Estimations window vary across variables. Where possible, we estimate a full sample which corresponds to 1997Q1 to 2025Q2. Many estimated equations are over a shorter time period either due to data avaiablity or the presence of structural break as tested for by Chow and/or Bai-Perron tests.

Table 4: Estimated equations in HESTIA (a)

Household income and consumption
Real disposable income (*pdr_q*) $\Delta \ln(pdr_t) = 0.52 - 0.15\,[\ln(pdr_{t-1}) - 1.01\,\ln(\frac{wen_{t-1}}{pcd_{t-1}})] + 0.60\,\Delta \ln(\frac{wen_{t-1}}{pcd_{t-1}})$
Private consumption (*pcr_q*) $\Delta \ln(pcr_t) = 0.27 - 0.18\,[\ln(pcr_{t-1}) - 0.85\,\ln(pdr_{t-1})] + 0.19\,\Delta \ln(pdr_t)$
Labour market, productivity, wages and prices
Labour productivity (*prd_q*) $\Delta \ln(prd_t) = -0.17 - 0.07\,[\ln(prd_{t-1}) - 0.50\,\ln(\frac{wen_{t-1}}{pcd_{t-1}}) - 0.06\,\ln(urx_{t-1})] - 0.24\,\Delta \ln(prd_{t-1}) + 0.09\,\Delta \ln(\frac{wen_{t-1}}{pcd_{t-1}}) + 0.01\,\Delta \ln(urx_t)$
Consumer prices (*pcd_q*) $\Delta \ln(pcd_t) = -0.20 - 0.07\,[\ln(pcd_{t-1}) - 0.50\,(\ln(wen_{t-1}) - \ln(prd_{t-1})) - 0.50\,\ln(mtd_{t-1})] + 0.10\,\Delta \ln(wen_t) - \Delta \ln(prd_t) + 0.03\,\Delta \ln(mtd_t)$
Nominal wages (*wen_q*) $\Delta[\ln(wen_t) - \ln(pcd_t)] = 2.50 - 0.17\,[\ln(wen_{t-1}) - \ln(pcd_{t-1})] - 0.60\,[\ln(prd_{t-1}) + 0.60\,\ln(urx_{t-1})] - 0.50\,\Delta \ln(urx_t)$
Unemployment rate (*urx_q*) $\Delta \ln(urx_t) = 0.86 - 0.15\,[\ln(urx_{t-1}) + 0.36\,\ln(yer\_adj_{t-1})] - 1.14\,\Delta \ln(yer\_adj_{t-1})$

Source: Authors' calculations.

Table 5: Estimated equations in HESTIA (b)

Investment, credit and housing
NFC lending rate (*nfcn_q*) $\Delta nfcn_t = 0.93 - 0.31\,[nfcn_{t-1} - 0.69\,ecb_{t-1}] + 0.72\,\Delta ecb_t$
Modified non-construction investment machinery (*mitr_noc_m_q*) $\Delta \ln(mitr\_noc\_m_t) = -0.44 - 0.26\,[\ln(mitr\_noc\_m_{t-1}) - 0.80\ln(yer\_adj_{t-1}) - 0.10\,r_{t-1}] + 1.14\,\Delta \ln(yer\_adj_{t-1})$
Modified non-construction investment ICT equipment (*mitr_noc_ict_q*) $\Delta \ln(mitr\_noc\_ict_t) = -10.42 - 0.46\,[\ln(mitr\_noc\_ict_{t-1}) + 2.64\ln(yer\_adj_{t-1}) - 0.03\,r_{t-1}] + 2.41\,\Delta \ln(yer\_adj_{t-1})$
Modified non-construction investment residual (*mitr_noc_r_q*) $\Delta \ln(mitr\_noc\_r_t) = -4.71 - 0.42\,[\ln(mitr\_noc\_r_{t-1}) + 1.75\ln(yer\_adj_{t-1}) - 0.02\,r_{t-1}] + 3.27\,\Delta \ln(yer\_adj_{t-1})$
Non-dwelling construction investment (*itr_bc_ndw_q*) $\Delta \ln(itr\_bc\_ndw_t) = 0.17 - 0.10\,[\ln(itr\_bc\_ndw_{t-1}) - 0.64\ln(yer\_adj_{t-1})] - 0.14\,\Delta \ln(itr\_bc\_ndw_{t-1}) + 0.98\,\Delta \ln(yer\_adj_t)$
Mortgage credit rate (*ccn_q*) $\Delta ccn_t = 0.22 - 0.09\,[ccn_{t-1} - 0.32\,ecb_{t-1}] + 0.43\,\Delta ecb_t$
Housing completions (*hs_cpl_q*) $\Delta \ln(hs\_cpl_t) = 0.43 - 0.29\,[\ln(hs\_cpl_{t-1}) - 0.82\ln(hs\_com_{t-1})] - 0.35\,\Delta \ln(hs\_cpl_{t-1}) + 0.15\,\Delta \ln(hs\_com_t)$
Housing commencements (*hs_com_q*) $\Delta \ln(hs\_com_t) = -0.09 - 0.15\,[\ln(hs\_com_{t-1}) - 1.17 \cdot \ln(hs\_pln_{t-1})] - 0.30\,\Delta \ln(hs\_com_{t-1}) + 0.91\,\Delta \ln(hs\_pln_t)$
Housing planning permissions $\Delta \ln(hs\_pln_t) = 0.14 - 0.10\,[\ln(hs\_pln_{t-1}) - 0.09\ln(urx_{t-1}) - 1.22\ln(hp\_d_{t-1}) + 0.50\ln(nfcn_{t-1})] - 0.22\,\Delta \ln(hs\_pln_{t-3}) - 0.10\,\Delta \ln(urx_{t-2}) + 1.22\,\Delta \ln(hp\_d_{t-4})$
Real housing demand (*hd_q*) $\Delta \ln(\frac{hd_t}{pcd_t}) = -2.16 - 0.11\,[\ln(\frac{hd_{t-1}}{pcd_{t-1}}) - 1.05\ln(\frac{0.3(pdr_{t-1}/12)}{(ccn_{t-1}/1200)} \cdot \frac{1-(1+ccn_{t-1}/1200)^{-300}}{pcd_{t-1}}) - 1.47\ln(cap_{t-1})] + 0.34\,\Delta \ln(\frac{hd_{t-4}}{pcd_{t-4}}) + 0.38\,\Delta \ln(\frac{0.3(pdr_t/12)}{(ccn_t/1200)} \cdot \frac{1-(1+ccn_t/1200)^{-300}}{pcd_t}) - 0.20\,\Delta \ln(\frac{0.3(pdr_{t-1}/12)}{(ccn_{t-1}/1200)} \cdot \frac{1-(1+ccn_{t-1}/1200)^{-300}}{pcd_{t-1}})$

Source: Authors' calculations.

Table 6: Estimated equations in HESTIA (c)

Trade
Pharma goods exports (*xtr_gsp_q*) $\Delta \ln(xtr\_gsp_t)$ = −0.18 + −0.07 $[\ln(xtr\_gsp_{t-1}) - 3.01 \cdot \ln(wdy_{t-1})] + -0.14\,\Delta \ln(xtr\_gsp_{t-1}) + 0.21\,\Delta \ln(wdy_t)$
Non-pharma goods exports (*xtr_gsu_q*) $\Delta \ln(xtr\_gsu_t)$ = 0.29 − 0.22 $[\ln(xtr\_gsu_{t-1}) - 1.90 \ln(wdy_{t-1})] - 0.26\,\Delta \ln(xtr\_gsu_{t-1}) + 1.06\,\Delta \ln(wdy_t)$
Computer services exports (*xtr_svc_q*) $\Delta \ln(xtr\_svc_t)$ = −0.53 − 0.06 $[\ln(xtr\_svc_{t-1}) - 4.48 \cdot \ln(wdy_{t-1})] + 0.08\,\Delta \ln(xtr\_svc_{t-1}) + 0.47\,\Delta \ln(wdy_t)$
Underlying services exports (*xtr_svu_q*) $\Delta \ln(xtr\_svu_t)$ = 0.28 − 0.08 $[\ln(xtr\_svu_{t-1}) - 1.42 \ln(wdy_{t-1})] - 0.14\,\Delta \ln(xtr\_svu_{t-1}) + 0.55\,\Delta \ln(wdy_t)$
Pharma goods imports (*mtr_gsp_q*) $\Delta \ln(mtr\_gsp_t)$ = −0.24 − 0.01 $[\ln(mtr\_gsp_{t-1}) - 3.00 \ln(xtr\_gsp_{t-1})] - 0.35\,\Delta \ln(mtr\_gsp_{t-1}) + 0.50\,\Delta \ln(xtr\_gsp_t)$
Underlying goods imports (*mtr_gsu_q*) $\Delta \ln(mtr\_gsu_t)$ = −1.08 − 0.26 $[\ln(mtr\_gsu_{t-1}) - 1.22 \ln(mdr_{t-1})] - 0.21\,\Delta \ln(mtr\_gsu_{t-1}) + 0.88\,\Delta \ln(mdr_t)$
Underlying services imports (*mtr_svu_q*) $\Delta \ln(mtr\_svu_t)$ = −1.92 − 0.18 $[\ln(mtr\_svu_{t-1}) - 1.89 \ln(mdr_{t-1})] - 0.26\,\Delta \ln(mtr\_svu_{t-1}) + 0.52\,\Delta \ln(mdr_t)$
Machinery & equipment imports (*mtr_gsm_q*) $\Delta \ln(mtr\_gsm_t)$ = −0.37 − 0.05 $[\ln(mtr\_gsm_{t-1}) - 1.80 \ln(mitr_{t-1})] - 0.05\,\Delta \ln(mtr\_gsm_{t-1}) + 0.45\,\Delta \ln(mitr_t)$
Export price deflator (*xtd_q*) $\Delta \ln(xtd_t)$ = −0.44 − 0.12 $[\ln(xtd_{t-1}) - 0.79 \ln(\frac{cpx_{t-1}}{rex\_us_{t-1}})] + 0.10\,\Delta \ln(xtd_{t-1}) + 0.10\,\Delta \ln(\frac{cpx_t}{rex\_us_t})$
Import price deflator (*mtd_q*) $\Delta \ln(mtd_t)$ = −0.31 − 0.08 $[\ln(mtd_{t-1}) - 0.80 \ln(\frac{cpx_{t-1}}{rex\_us_{t-1}}) - 0.09 \ln(\frac{erw_{t-1}}{rex\_us_{t-1}})] + 0.35\,\Delta \ln(\frac{cpx_t}{rex\_us_t}) + 0.03\,\Delta \ln(\frac{erw_t}{rex\_us_t})$

Source: Authors' calculations.

Table 7: Hestia's identities, definitions and exogenous assumptions (d)

Model identities and definitions

Headline GDP: $yer_t = pcr_t + itr_t + gcr_t + xtr_t + mtr_t + stk_t$

Modified domestic demand: $mdr_t = pcr_t + mitr_t + gcr_t$

Adjusted output: $yer\_adj_t = pcr_t + mitr_t + gcr_t + (xtr\_gsu_t - mtr\_gsu_t) + (xtr\_svu_t - mtr\_svu_t) - mtr\_gsm_t$

Total investment: $itr_t = nitr_t + itr\_ndw_t + mitr\_noc_t$

Modified investment: $mitr_t = itr\_ndw_t + mitr\_noc_t$

Modified non-construction investment: $mitr\_noc_t = mitr\_noc\_m_t + mitr\_noc\_ict_t + mitr\_noc\_r_t$

Total exports: $xtr_t = xtr\_gsp_t + xtr\_gsu_t + xtr\_svc_t + xtr\_svu_t + xtr\_gsr_t + xtr\_svr_t$

Total imports: $mtr_t = -(mtr\_gsp_t + mtr\_gsu_t + mtr\_gsm_t + mtr\_gso_t + mtr\_svc_t + mtr\_gsr_t + mtr\_svu_t + mtr\_svr_t)$

Nominal exports: $xtn_t = xtr_t \times xtd_t/100$

Nominal imports: $mtn_t = mtr_t \times mtd_t/100$

Inflation rate: $pcdx_t = 100\,(pcd_t/pcd_{t-4} - 1)$

Housing stock: $cap_t = cap_{t-1}\,(1 - 0.00) + hs\_cpl_{t-1}$

Exogenous assumptions

The following variables are assumed to evolve along fixed baseline paths. Global variables are held constant or at trend; domestic fiscal and residual components grow at calibrated rates g.

Variable	Description	Source / assumption
wdy_t	World demand	NiGEM baseline path
cpx_t	Competitor prices	NiGEM baseline path
ecb_t	ECB policy rate	NiGEM baseline path
rex_us_t	Exchange rate	NiGEM baseline path
erw_t	Energy prices	NiGEM baseline path
gcr_t	Government consumption	Department of Finance fiscal forecasts
$nitr_t$	Other (non-modified) investment	Trend growth
stk_t	Change in inventories	Trend growth
xtr_gsr_t	Residual goods exports	Trend growth
xtr_svr_t	Residual services exports	Trend growth
mtr_gsr_t	Residual goods imports	Trend growth
mtr_svr_t	Residual services imports	Trend growth
mtr_gso_t	Other transport goods imports	Trend growth
mtr_svc_t	Computer services imports	Trend growth

Source: Authors' calculations.