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AN APPLICATION OF THE I3E MODEL

KELLY DE BRUIN, EOIN MONAGHAN AND AYKUT MERT YAKUT

ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

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Aykut Mert Yakut

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THE AUTHORS

Kelly de Bruin and Aykut Mert Yakut are Research Officers and Eoin Monaghan is a Research Assistant at the Economic and Social Research Institute (ESRI).

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EXECUTIVE SUMMARY

Introduction

The outbreak of the COVID-19 virus has triggered a global public health crisis. Although restricting the movement of people is a crucial step to contain the spread of the virus, it has resulted in a substantial contraction in economic activity. The health crisis and the concomitant shutdown of a significant proportion of the economy are expected to result in a prolonged global recession, with severe and unprecedented impacts on the global economy.

This report aims to assess the economic and environmental impacts of the COVID-19 crisis on the Irish economy, by applying the Ireland Environment, Energy and Economy (I3E) model. As a dynamic general equilibrium model, I3E allows us to quantify the consequences of the restrictions on various economic agents in a consistent and comprehensive manner. In this report, we apply an Irish CGE model (I3E) and analyse the impacts of the COVID-19 crisis. The main scenario of the report, namely *COVID*, takes into account several changes in the structure of the Irish economy, including the decline in energy prices, alterations in the structure of production, changes in the composition of consumption, the decline in the labour force participation rate, the government stimulus package, and, finally, changes in the composition of trade. In order to better understand the contributions of each of these structural changes, the results of each of these components are discussed separately. In addition, a set of sensitivity scenarios are run by considering the possible impacts of both lower energy prices for an extended period and a prolonged recovery in the economic structure.

Main Findings

The results summarised below are provided as percentage deviations from the business-as-usual (*BaU*) scenario, along which it is assumed that there is no pandemic (and no decline in energy prices).

- The results show that the overall economic activity measured by real gross domestic product (GDP) will decline by 13%, depending on the duration of the restrictions. The private consumption in real terms shrinks by 15.5%.
- The substantial decline in investment expenditures will have long-lasting repercussions for the sectoral capital stock which will prevent the Irish economy from returning back to its *BaU* pattern.
- The decreased energy prices will help Ireland in reducing both the cost of production and the import bill which, in turn, positively affects trade balance.
- Decreasing tax revenues due to the economic slowdown and increasing government expenditures in the form of transfers will substantially deteriorate public balances, where the debt stock will increase by 14.2%.
- The total disposable income of all households will decrease due to the declines in both wage and capital income. The government stimulus package will play a substantially corrective role to reduce

the adverse economic impacts of the crisis on disposable income of the most vulnerable household groups in urban and rural areas.

- The initial impacts of the COVID crisis will increase inequality across household types, however with the government stimulus package inequality decreases.
- From an environmental perspective, the results imply that although lower energy prices will boost energy demand, the impacts of decreased energy demand due to decreased consumption and production will be larger. As a result, the economy-wide CO_2 emissions decline by 9.5% in 2020.
- From 2021, even when assuming a gradual economic recovery, the low energy prices will result in increased emissions compared to *BaU*. Resulting in Ireland missing its 2020 and 2030 non-ETS emissions targets (by far).

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1 Introduction

The outbreak of the novel coronavirus, namely COVID-19, in China in early January 2020 has started an unprecedented health-care system crisis across the globe. The total number of infected people currently exceeds 8 million (as of 15th June 2020), 5.4% of whom have lost their lives. At the time of writing this report, several economic and social measures have been in place for the last two-to-three months in the majority of countries. In this respect, schools and all non-essential business activities are closed, there are restrictions on the working hours of retail food sellers and strict rules in market places to keep "physical distance" between customers[1].

The outbreak of the pandemic has prompted a quickly expanding array of research on its possible economic implications. Given the uncertainty surrounding the length of the lockdown procedures and the overall development of the virus, most research on the economic impacts of COVID-19 thus far make projections based on a variety of "low", "medium" and "high" level restriction scenarios. These provide an estimated range of possible impacts on the macroeconomy, while also reflecting the dynamic nature of response efforts to tackling the virus. The majority of research to date, however, has made a clear projection that the virus will result in large negative economic impacts, owing to the nature of the pandemic as a simultaneous (negative) supply and demand shock. Indeed, the Irish Department of Finance acknowledged that it was "beyond doubt" that we are in the midst of a recession (DoF, 2020b).

OECD (2020a) estimates that the immediate impact of the shutdown could be a reduction in the level of output of between one-fifth to one-quarter in most economies. Under this projection, consumers' expenditure potentially drops by around one-third. These sorts of negative impacts would be much greater than those of the global financial crisis in 2008-09. For the majority of economies, this sizeable impact is largely explained by the negative effects on output in the retail, wholesale trade, professional and real estate services. Moreover, in its most recent World Economic Outlook, OECD (2020b) estimates the economic impacts of two different COVID-related scenarios. First is the case in which there is a second wave of the virus, and lockdown is resumed. In the second case, there is no such second wave. Under both scenarios, the impacts on GDP are negative for the UK and the Euro area. In the latter scenario, the Euro area and UK are expected to see GDP decreases of 9.1% and 11.5%, respectively. In a case where there is a second outbreak, the magnitude of the economic contraction becomes 11.5% and 14%, respectively. It should be noted, however, that the OECD emphasises the large uncertainty regarding these forecasts.

In the latest World Economic Outlook (WEO) report, the IMF expects that the growth rate of global GDP will be -3% in 2020, and it corresponds to a 6.4 percentage points decline compared to the Fund's expectations in January 2020. The advanced economies will be contracted by 6.1%, whereas the developing countries will experience a 1% reduction in their aggregate GDP (IMF, 2020). The Fund expects a 1.2% economic growth in China in 2020, but the country's GDP contracted by 6.8% in the first quarter of 2020 on a year-on-year basis.

[1] In order to contain the spread of the virus, people need to keep "physical distance" rather than "social distance", and societies need to extend "social solidarity" to overcome the virus's unprecedented social outcomes.

In the case of Ireland, the decline in employment figures reached approximately 320,000 as of the 27^{th} of March, and it is expected to exceed 650,000 which corresponds to 28% of the total employment (CBoI, 2020). In order to alleviate the negative consequences of the economic slowdown triggered by the virus crisis, the Irish government announced an economic package consisting of weekly payments of €410 (€350) to those employees (self-employed) who lost their jobs (closed down their businesses). The cost of the crisis on the Irish exchequer, including the loss in wage income tax revenue, is expected to vary between €4 and €4.9 billion based on the level of the decline in employment (Beirne et al., 2020, Table 1). The authors also find that for every 100,000 jobs lost in Ireland, the government will face an increase in welfare spending by around €800 million per quarter.

The Central Bank of Ireland projects that the general government balance-to-GDP ratio will be -6%, which was expected to be 0.4% for the year 2020. Similarly, the debt stock-to-GDP ratio will increase from its expected level of 58% to 66% (a 13.8% increase). The Bank expects that the impact of the business interruption on real GDP will be an 8.3% decline, which is mainly sourced from declining private consumption expenditures (9%) and investment expenditures (24.3%). The latter is partially offset by an increase in government expenditures (7.5%) (CBoI, 2020). Fernandes (2020) derives similarly negative figures for Ireland. In the mildest scenario – comprising a return to normality around the end of May – the percentage change of GDP in Ireland is estimated at -4.8%, while in the most stringent scenario, whereby total lockdown remains in place until the end of July, the corresponding value is -10.8% for Ireland.

McQuinn et al. (2020), the latest Quarterly Economic Commentary of ESRI, has projections for three different possible outcomes in terms of the reopening of the economy. The first, "baseline" scenario assumes continued social distancing until the end of 2020. The second, "severe" scenario assumes that strict lockdown measures are reinforced in the fourth quarter (Q4) of 2020, and the third "benign" scenario forecasts normality resuming to the economy in Q4. Each scenario yields different forecasts for the key macroeconomic variables, though in all cases (except public net current expenditure), the values are negative. GDP is expected to decrease by 12%, 17% and 9% in the baseline, severe and benign scenarios, respectively. This large contraction will be sourced from reductions in investment expenditures (-28%, -39% and -18%), a decline in private consumption (-13%, -20% and -12%), and a deterioration in net exports, although government expenditure is predicted to increase by either 11%, 15% or 11%, depending on the scenario (baseline, severe or benign, respectively). Worsening public balances will result in a -9% government balance-to-GDP ratio, an associated loss of €28 billion.

On the subject of the distributional impacts of the COVID-19 crisis, O'Donoghue et al. (2020) uses a "nowcasting" method to determine how policy responses impact the income distribution. The paper finds that inequality in terms of market income increased during the crisis, but that inequality with regards to gross and disposable income (once work and housing expenditures are accounted for), actually decreases. These findings are comparable to those of Beirne et al. (2020), who find that higher income households will be affected more in terms of decreases in disposable income.

Computable general equilibrium (CGE) modelling is one of the most appropriate tools to analyse the economic impacts of a pandemic as it takes into account the structure of an economy in its entirety and

can hence investigate secondary impacts. The measures to stop the spread of the virus have different repercussions on the supply- and demand-side of the economy, which can be simultaneously factored into a CGE model. Several earlier studies have been conducted on the impacts of hypothetical pandemics applying CGE models. However, in this previous literature, scenarios with an extensive shut down of the economy have not been considered. These studies focus on impacts mainly through the channel of reduced labour supply. A multi-region global CGE analysis of Keogh-Brown et al. (2008) shows that closure of schools for a four week period will result in a decline in GDP by up to 8%, where U.K. will be the most affected country. In a single country setting, Smith et al. (2011) finds that school closure and prophylactic absenteeism (where a part of the labour force chooses to not work to avoid infection) for three weeks will generate a loss in GDP between 1.1% and 1.4%, compared to a no-pandemic scenario. The impact of a six week period of school closure on GDP varies between 2.9% and 3.7%. A quarterly CGE analysis of Dixon et al. (2010) assumes that due to an H1N1 (a.k.a pig flu) epidemic in the U.S. in 2010, 90 million people are infected and 16,000 die.[2] The results show that real GDP declines by 2.6% and 1.6% in the peak quarter and in the epidemic year, respectively.

Regarding the current coronavirus crisis, Maliszewska et al. (2020) uses the ENVISAGE global CGE model to simulate the impacts of the pandemic, most notably as shocks to labour and capital, trade costs and lower demand. Under a baseline scenario, world GDP contracts by around 2% (around 1.8% for industrial countries). Under the more severe pandemic scenario, global GDP decline increases to around 4%. In addition, McKibbin & Fernando (2020) uses a hybrid CGE-DSGE model to analyse seven different scenarios for the course of the virus, varying in their impacts on consumption, labour supply and business costs. In the case of the euro area, they estimate that GDP will be negatively impacted between 2.1% and 8.4%, between the least and most severe pandemic scenarios, respectively. The associated values for the UK are -1.5% and -6%, respectively.

In this report, we apply an Irish CGE model (I3E) and analyse the impacts of the COVID-19 crisis. The main scenario of the report, namely *COVID*, takes into account several changes in the structure of the Irish economy, including the decline in energy prices, alterations in the structure of production, changes in the composition of consumption, the decline in the labour force participation rate, the government stimulus package, and, finally, changes in the composition of trade. In order to better understand the contributions of each of these structural changes, the results of each of these components are discussed separately. In addition, a set of sensitivity scenarios are run by considering the possible impacts of both lower energy prices for an extended period and a prolonged recovery in the economic structure.

The results show that real GDP in the Irish economy will decline by 13% and 0.26% in 2020 and 2030, respectively, compared to its business-as-usual (*BaU*) pattern. In other words, even if the Irish economy goes back to its structural setting in 2021, the COVID-19 crisis will have a continuing impact on real GDP in the coming decade. The substantial decline in investment expenditure and private consumption will be compensated by the increased government expenditures and the improved trade balance. The crisis' impact on fiscal balances will be more long-lasting: the debt stock-to-GDP ratio will be 14.2% and 8.1%

[2] As of June 15th, the total number of infected and dead people in the U.S. are around 2.17 million and 118,000, respectively.

higher in 2020 and 2030, respectively, compared to a no-pandemic case. The total disposable income of all households will decrease due to the declines in both wage and capital income. The government stimulus package will play a substantially corrective role to reduce the adverse economic impacts of the crisis on disposable income of the most vulnerable household groups in urban and rural areas. If the impacts of the current business interruption will dissipate in 2021 rather than in 2020, the medium-term consequences of the COVID-triggered economic crisis will be larger on real GDP, investment, capital accumulation, disposable income, private consumption and public indebtedness.

The level of economy-wide CO_2 emission will decline by 9.5% in 2020, compared to *BaU*. The low energy prices will limit the impacts of the contraction in the Irish economy. In 2030, on the other hand, lower energy prices will drive the demand for energy commodities up despite the decline in economic activity and will result in an increase in the cumulative emissions by 0.3%, compared to *BaU*. If energy prices keep their lower levels until 2030, the level of cumulative emission will be 1.4% higher in 2030, compared to *BaU*. In case of a slower recovery, the emission figures will be slightly lower compared to the no-pandemic case. If a slower recovery is accompanied by lower energy prices for an extended period, the emissions will be higher than compared to *BaU*.

The results, especially concerning emissions, should be evaluated cautiously. As the expected global slowdown will lower the demand for energy, lower energy prices will invoke energy demand. Moreover, the level of energy prices is also an important determinant of overall economic activity in the future through its impacts on the costs of production. The future of these two effects are extremely uncertain.

The results of the scenario analyses of this report provide strong evidence regarding the coverage of the after-crisis stimulus package of the government. On the fiscal policy side, the results show that a stimulus package focusing on transfers and increasing public demand for commodities would have long-lasting adverse impacts on the public indebtedness. The government should focus on a more detailed stimulus package targeting increasing employment and production. Concerning the environmental impacts, the results reveal that the decline in emissions will be circumstantial and be sensitive to energy prices. Therefore, the government should not change its position regarding environmental policies and should be as flexible as possible to react to the pattern of energy prices in order to prevent the excessive consumption of energy commodities.

The remainder of this report is as follows. The next section is devoted to explaining the details of the scenario design. Section 3 summarises the results regarding macroeconomic aggregates, households, sectoral value-added, and emissions. Section 4 concludes. Appendix A and Appendix B provide the details of the I3E model in a non-technical manner and the lists of activities and commodities defined in the model.

2 Scenario Analyses

In this report, the Ireland Environment, Energy and Economy (I3E) model is applied to investigate the potential impacts of the COVID pandemic. The I3E model is a dynamic general equilibrium model, con-

sisting of 32 production activities (sectors), 39 commodities, 10 representative households (five households in urban and five in rural areas), the government with details on the sources of its income and the composition of its expenditures, and a rest of the world account. Appendix A provides the details on the structure of the model in a non-technical manner, and de Bruin & Yakut (2020) provides technical details.

This report focuses on one main scenario, the *COVID* scenario. After analysing this scenario, we examine several sensitivity scenarios with diverging assumptions concerning energy prices and the duration of the COVID crisis. In this section, we describe the various scenarios and their underlying assumptions and implementation.

The COVID pandemic has created a crisis of an unprecedented nature with diverse and far-reaching impacts throughout societies and economies. The novelty of a widespread pandemic and the diverse impacts make implementing a COVID shock or scenario in a model problematic. Previous CGE literature has only examined pandemics of a limited nature without an associated lockdown (see e.g. Keogh-Brown et al. (2008)). There is a high degree of uncertainty concerning the duration of the pandemic and the scope and duration of measures to limit the spread of COVID-19. Furthermore, the timing and pace of recovery are also highly uncertain. Essentially, the implementation of a scenario will depend on the judgement of the modellers where limited data is available. Given this, it is essential that the implementation method of any COVID shock is discussed in detail in order to highlight the underlying assumptions. In this section, we will describe how such a shock has been implemented in the I3E model.

As mentioned, the COVID crisis has far-reaching impacts throughout the economy. In the I3E *(COVID)* scenario, several different shocks are implemented to represent the impacts of the COVID pandemic and the concomitant lockdown on the Irish economy. These shocks, which we refer to as components, together illustrate the overall impact of the COVID crisis. Each component or shock and where it is implemented in the I3E model is represented in Figure 1. We will discuss each component in turn.

2.1 Production Shock

As a result of lockdown measures, many businesses and factories have been temporarily shut down. These measures have been strictest for firms operating in non-essential production and services. The hardest-hit sectors are expected to be distribution, hotels, arts and recreation, admin and support, real estate and transportation, whereas the energy-related sectors and education services are expected to be less affected.

We assume an increase in the demand of households for nourishment, which includes agricultural products produced largely by the agricultural sector and processed food produced largely by the food, beverage and tobacco sector. Therefore, these sectors are assumed to be positively affected. In addition, the telecommunication services and water and sewerage sectors are also positively affected due to the increase in private demand for those commodities.

Implementing this component we adjust the sectoral shift parameters of the production function of each sector. This leads to level-shifts in a uniform manner across the components of the production function, which are intermediate input (both energy and non-energy) and value-added (labour and capital).

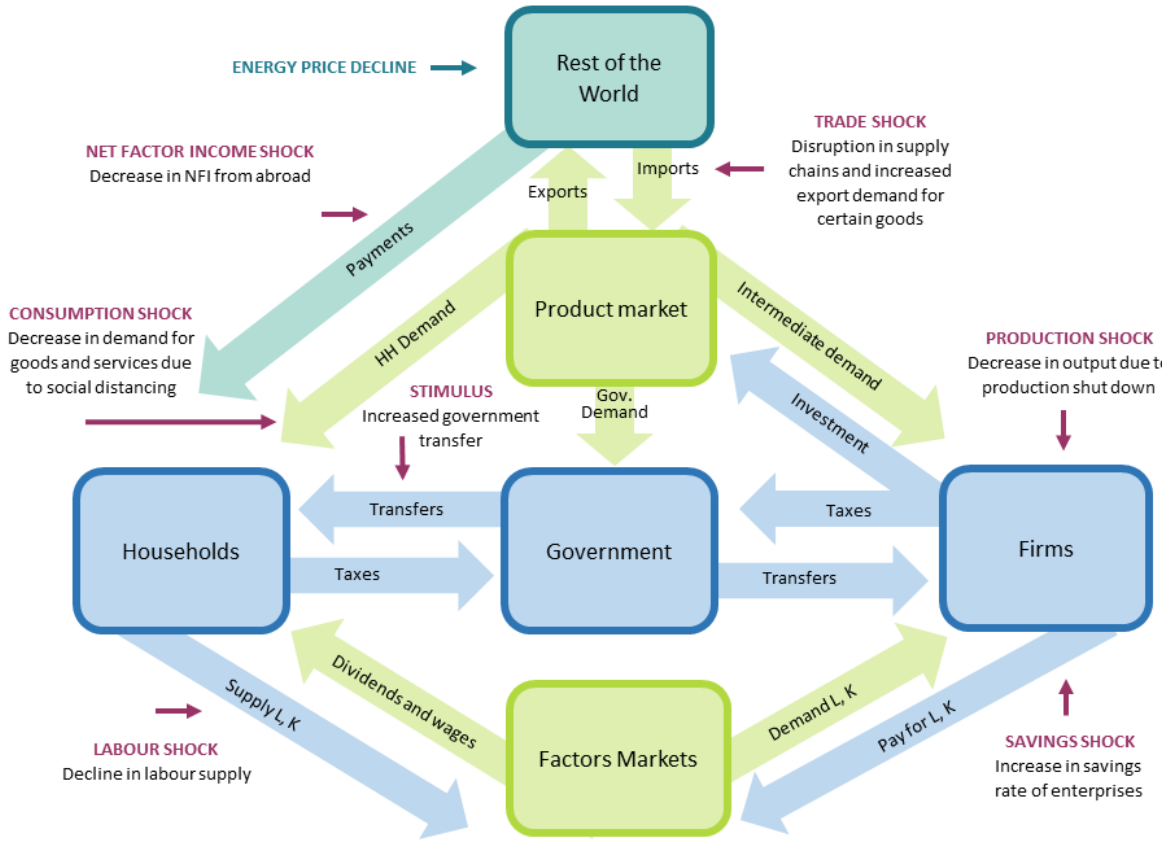

Figure 1: Schematic representation of shocks

In other words, this decreases the production for that specific sector without distorting the relative inputs in production. The change in the shift parameter generates differentiated value-added and emissions impacts across sectors due to *(i)* nonlinear production functions, *(ii)* differences in the composition of output regarding value-added and intermediate inputs, *(iii)* differences in labour-intensity, and *(iv)* differences in energy-intensity. Sector level impacts for Ireland have been investigated by the Central Bank (CBoI, 2020). Note that the applied methodology by the bank estimates only the initial direct impacts and ignores indirect effects, but the I3E model is able to investigate the secondary, i.e. general equilibrium impacts through the sector connections included in the model, where the interdependencies across sectors determine the magnitude of the secondary impacts. Based on CBoI (2020), Walmsley et al. (2020), the unemployment figures per sector presented in DEASP (2020) and the government defined health act restrictions concerning business closure, we estimate the level of production lost in each sector. For example, if the government has ordered the complete shutdown of a sector for 3 months, we assume that 25% of production will be lost in that sector. If a sector is still permitted to produce inputs for essential goods and services, we discount the production loss by the estimated share of production for essential goods and services in total production for that sector. For sectors with high levels of essential production,

such as the food, beverage and tobacco sector, we estimate the increase in production based on additional retail sales presented in McQuinn et al. (2020). Given a large amount of sectors in the model, we do not separately discuss how each sector's output is adjusted.

2.2 Consumption Shock

The COVID crisis impacts consumption through three main mechanisms. Firstly, decreased income due to the economic slowdown will reduce consumption. This impact is automatically taken into account in the model, where household consumption is dependent on household income. Secondly, consumers will adjust their consumption patterns based on their access to goods and services. Finally, in times of uncertainty, consumers reduce their discretionary spending and increase their precautionary savings.

The COVID lockdown measures have created a substantial barrier to the consumption of certain goods and services, where 50% of the consumption is estimated to be under severe restriction (CBoI, 2020). This results in shifts in consumption patterns of consumers towards available goods as well as a decline in consumption. Recent consumption data obtained from Revolut shows a sharp decrease in consumption in late March, but a rapid increase in late April and May indicating that consumers are already beginning to convert back to their old consumption patterns (DoF, 2020a).

In the model, households maximise their intertemporal utility by choosing the volume of total composite consumption. Then, the total composite consumption is distributed across other composite commodities of transportation, residential energy, nourishment, services, and other commodities, which includes manufacturing-related commodities. These composite commodities can be treated as bundles constituting several commodities which are more likely to be substitutes. In the next stage, households further disaggregate these composite commodities into demand for commodities by considering the relative prices of commodities and the elasticity of substitution across commodities in the bundle. In order to implement the alterations in the consumer consumption patterns in the I3E model, we adjust the shift parameters of different goods in consumption. The impact of the pandemic on the consumption pattern of households is assumed to be uniform across households. Accordingly, the shift parameter of nourishment (consisting of agriculture and food, beverage and tobacco products) and residential energy are increased as these composite commodities include essential goods. Similarly, the shift parameters of transportation, services, and other commodities are decreased. As in the case of the production shock, altering the shift parameter of a composite commodity alters the level of consumption of each commodity included in the composite commodity. However, for instance, although demand for composite services decreases due to the pandemic, demand for telecommunication increases. Therefore, in addition to the change in the shift parameter of the composite commodity services, the share parameters of each commodity in the composite commodity are also changed to introduce the distinguished impacts on different commodities.

In the I3E model, the forward looking optimisation behaviour of households results in an increase in savings in times of economic downturn. As agents have perfect foresight and are rational, they take into account the future state of the economy and alter their saving behaviour. They do not further increase

savings due to (perceived) uncertainty of the future. Hence, if consumers are pessimistic about their future economic situation or the global impacts of the pandemic they are likely to further increase savings and suppress demand. This is not accounted for in this report.

2.3 Labour Shock

The labour force participation rates (LFPRs) of each type of labour are assumed to be constant in the I3E model. Since wage rate declines due to the decline in the demand for labour, people will be less willing to work, i.e. to supply their workforce. In order to capture this, the LFPRs are lowered. In order to represent the decline in the supply of labour, the LFPRs of low-, medium-, and high-skilled labour are decreased by 15%, 10%, and 5%, respectively. As the hardest hit sectors are mainly services-related sectors, the decline in demand for low-skilled labour is the highest. The decline in the manufacturing-related sectors affects demand for medium-skilled labour. On the other hand, as working from home is a more prevalent phenomenon for high-skilled labour, the decline in their labour supply is the least affected.

2.4 Stimulus

Due to the economic shutdown, employees and self-employed individuals are supported by the government with the 'COVID-19 Pandemic Unemployment Payment' (PUP) and a Temporary Wage Subsidy Scheme (TWSS) (Beirne et al., 2020). In order to introduce these COVID-19-related transfers which are not means-tested, another variable, namely $NMTTR$, is introduced into the household budget constraint. The value of the new transfer item is positive along the paths of all scenarios only for the year 2020, and in the slower recovery scenarios only in the years 2020 and 2021. The total budget of the new transfer programme is distributed across households are calculated based on DEASP (2020) which uses social security administration data to examine the unemployment impacts of the COVID crisis to date. In this paper, sectors are aggregated into three groups based on unemployment impacts, namely severe, moderate and mild. The share of each sector type in the total amount of PUP receipts is presented as well as the share of each income quintile in PUP receipt, per sector type. Weighting the latter by the former, we estimate the share of each income quintile in the total PUP. Furthermore, in the calculations, the increased fuel allowances of the poorest households in urban and rural areas are also taken into account. The total budget of the new programmes is assumed to be €4.5 billion in 2020 in the main scenarios (DoF, 2020b), and €2.25 billion in 2021 in the slower recovery scenarios.

2.5 Trade Shock

In terms of trade, the COVID crisis has two main impacts for Ireland. Firstly, the pandemic has limited both the production of intermediate inputs abroad as well as the speed at which they can be imported, causing significant disruptions in the supply chain of several Irish production sectors. Secondly, Ireland

has a strong competitive power in the production of basic pharmaceuticals and chemical products.[3]

In the I3E model, domestic production and imports are assumed to be imperfect substitutes of each other. The composition of demand among these two types of commodities, which stems from a cost minimisation problem, depends on the relative price, the share parameters and the elasticity of substitution. On the export side, the composition of sales between the domestic market and abroad, which stems from a revenue maximisation problem, is a function of the relative price, the share parameters and the elasticity of transformation. The relative prices are solved endogenously within the model. Lowering the share parameters of imported and exported commodities in these problems, respectively, means that the share parameters of domestically produced commodities and sales to domestic market increase, respectively.

In order to introduce the trade impacts, the elasticities of substitution and transformation are lowered for the commodities of agriculture, textile, high-tech production and transportation equipment. On the contrary, the elasticities of substitution and transformation are increased for the basic pharmaceuticals and chemical products. A lower elasticity of substitution (transformation) means that substituting a domestically produced commodity for an imported (exported) commodity is harder.

2.6 Reduced Energy Prices

In late 2019, the prices of oil, coal, and natural gas declined by around 20%, 16%, and 19%, relative to their closing prices in 2018. In the first months of 2020, energy prices have plunged to the lowest levels in nearly two decades, which in turn soften the negative economic impacts of the virus crisis by lowering both the cost of production and the import bill of energy commodities for energy-importer countries.[4] In this report, along the path of business-as-usual, hereafter abbreviated to BaU, it is assumed that all energy prices in international markets will remain constant at their 2019 levels. In the COVID-19 scenarios, however, in order to take into account the cushioning impacts of the lower energy prices, it is assumed that energy prices will remain at their current low level for the remainder of 2020 and gradually increase reaching their 2019 levels again in 2025. This assumption is relaxed in certain scenarios where prices reach their 2019 level by 2030. Energy price data is obtained from the SEAI for natural gas, LPG, kerosene and fuel oil.[5] Current trading prices are applied for coal and crude oil, whereas the gasoline and diesel prices are obtained from the CSO.[6]

[3] See McQuinn et al. (2020, Box 2) for the contributions of the basic pharmaceuticals production sector during the global financial crisis.

[4] The main reason for the lower prices was the price war between OPEC+ members. As of the 13^{th} of April, the war seems to have subsided as the members have agreed to cut the oil production by 9.7 million barrels per day (bpd) in May-June. The reduction in daily production will be 7.6 million bpd until the end of the year, and 5.6 million bpd in 2021 (Economic Times, 2020).

[5] http://www.seai.ie/publications/Commercial-Fuel-Cost-Archives.pdf

[6] https://statbank.cso.ie/multiquicktables/quickTables.aspx?id=cpm04_cpm12

2.7 Net Factor Income Shock

The net factor income (NFI) is the difference between factor income of households earned abroad and brought into the country and the factor income of foreigners who transfer their incomes/profits earned in the country abroad. In the case of Ireland, the NFI is historically negative due to the strong presence of multinational companies which transfer part of their profits to countries in which their headquarters are located. Although the level of profits is expected to decline due to the economic crisis triggered by the health crisis, those companies would prefer transferring a substantial portion of their profits. In the I3E model, the net factor income of households is a fixed variable in real terms. The summation of the NFI and GDP is equal to the gross national product (GNP). The results of McQuinn et al. (2020) indicate that GDP and GNP will shrink by 12.4% and 14.2% in 2020, compared to *BaU* in their baseline scenario. The growth accounting calculation indicates that there will be a 7% decline in the NFI in 2020, compared to *BaU*. This value is applied in the *COVID* scenario. In the gradual recovery scenarios, it is further assumed that the NFI will be 3.5% lower in 2021, compared to its level in *BaU*.

2.8 Enterprises Savings

In the model economy, the enterprises account saves a fraction of its total profit receipts from production sectors in the model. Due to uncertainty emerging from the economic crisis, it is assumed that the account will increase its saving rate by 5% in 2020, compared to *BaU*. The higher savings rate will affect the level of distributed dividends and thus the capital income of households in 2020. It should be noted that in all scenarios, including the gradual recovery analyses, its value will go back to its *BaU* level in 2021.

2.9 Sensitivity Scenarios

As discussed before, there is a large amount of uncertainty concerning the future energy price, the duration of COVID-19 measures and the speed of economic recovery. Hence, in this report, we develop several sensitivity scenarios, where the assumptions concerning energy prices and economic recovery are relaxed. Firstly, we assume that energy prices remain at a lower level for a longer period of time. Energy prices will increase from 2021, but return to their 2019 level in 2030 as opposed to 2025. In this case, however, the EU-ETS price is still assumed to return to its 2019 level in 2025. The reason for keeping this assumption is that the EU Commission changes the structure of EU-ETS auctioning or the supply of allowances to ensure that the system is an effective tool in reducing emissions by preventing a substantial decline in the price of allowances. In order to indicate that the scenario incorporates this assumption, its name includes the term "ExtdLowEnPr" which stands for *extended low energy prices*.

Secondly, we implement a more gradual economic recovery, where structural parameters and policy variables impacted by the COVID crisis do not return to their initial levels in 2021 but in 2022. However, in 2021, the impacts are assumed to be less than in 2020. Say that an activity's shift parameter in the production function is lowered by 10% compared to its *BaU* level in 2020 in the *COVID* scenario. In the scenario of *COVID with Grad_Rec*, its value is assumed to be 10% and 5% lower than its *BaU* level

in 2020 and 2021, respectively, and the level of the shift parameter in 2022 will be equal to its level in 2019, i.e. its *BaU* level. On the fiscal policy side, the government will pay half of the COVID-19-related non-means-tested transfers to households but it will not increase its demand for commodities in 2021. The reason for the removal of this assumption is that the government has increased its demand for

Table 1: Details of Scenarios

Scenario	included shock components	energy prices reduction	economic recovery by
BaU	none	NA	NA
COVID	all	up to 2025	2021
LowEnPr	energy prices only	up to 2025	NA
ExtdLowEnPr	energy prices only	up to 2030	NA
COVID with Grad_Rec	all	up to 2025	2022
COVID with ExtdLowEnPr	all	up to 2030	2021
COVID with ExtdLowEnPr and Grad_Rec	all	up to 2030	2022
COVID without stimulus	all but stimulus	up to 2025	2021

commodities mainly to cover the increased demand for public goods, including health services and public services. If there is no additional health crisis triggered by the pandemic, the increased demand for public goods will dissipate in 2021. In order to indicate that the scenario incorporates this assumption, its name includes the term "Grad_Rec" which stands for *gradual recovery*. Though there is an ongoing debate regarding the coverage of the stimulus package to overcome the medium-run impacts of the COVID crisis both at national and EU-level, as yet there is no announced plan regarding an increase in the total budget or a change in the composition of government expenditures in 2021.[7] Therefore, the government demand for commodities will be equal to its *BaU* level in 2021 and onward.[8] To sum up, the sensitivity scenarios assume that the structure of the Irish economy will be fully restored in 2022 and 2021 can be seen as a transition year. An overview of all scenarios presented in this report is given in Table 1.

3 Results

3.1 Macroeconomic Impacts

3.1.1 The I3E Results in Comparison to Other Studies

In this subsection, we focus on the macroeconomic results of our main scenario, namely *COVID*. The macroeconomic aggregates of this scenario are summarised and compared with other macroeconomic

[7] The initial stimulus of the government has focused on assisting firms to stay in business and keeping employees connected to their place of employment. This will only help the economy in reducing the consequences of the economic slowdown during the pandemic. When the pandemic is over, on the other hand, the government should implement a policy package to boost the production and thus employment in the economy. The discussion related to the possible coverage of the policy package is beyond the scope of this report.

[8] The government demand for commodities has two parts. An autonomous part which is fixed and an induced part which is a function of nominal GDP. In all scenarios, the autonomous part of the government demand has been increased, whereas its induced part and thus the total expenditure for commodities are endogenously solved in the model.

estimates from the literature in Table 2. The results of the I3E model's main scenario indicate that the Irish real GDP will be 13% lower than its *BaU* level in 2020. The real total investment expenditure plunges in 2020 by 33%, compared to its *BaU* level due to both shrinking profits and a slowdown in economic activity. Although the government supports individuals with several policies to compensate their income losses, the private consumption expenditure is estimated to decline by 15.5% due to the decline in disposable income and the disruption of consumption due to the COVID related lock down.

The decline in economic activity and disruption in global supply-chains of commodities leads to a decline in exports and imports. However, the trade balance, i.e. net exports, improves by 5.3% and the trade balance-to-GDP ratio improves by 11.5% in 2020, compared to *BaU*. There are two underlying causes driving this result. On the export side, having a comparative advantage in sectors such as basic pharmaceuticals and chemical products has a positive impact on Irish exports, as these sectors are expected to see a boost in production due to the pandemic. On the imports side, the import bill of energy commodities declines due to both a reduction in demand and the decline in international energy prices.

Table 2: Macroeconomic Impacts, & change w.r.t. *BaU*

	Unit	I3E	DoF	CBoI	IMF	QEC-Summer		
						Baseline	Severe	Suppression
Real GDP	% change	-13.0	-10.5	-8.3	-6.8	-12.4	-17.1	-8.6
Private Consumption	% change	-15.5	-14.2	-9	/	-13.3	-19.7	-12
Investment	% change	-33.0	-37.3	-24.3	/	-27.6	-39	-18.4
Imports	% change	-20.5	-9.3	Decline	/	-12	-13.2	-9.9
Exports	% change	-16.4	-7.7	Decline	/	-8.2	-9.7	-6.7
Trade Balance	% change	5.3	/	Improves	6.3*	5.4	13	18.4
Trade Balance-to-GDP ratio	% of GDP	20.8	35.7	/	/	17.3	21.7	17.1
Government Expenditures	% change	10.5**	13.3***	7.5**	/	11	14.5	10.5
General Government Balance	% of GDP	-12.4	-7.4	-6		-9	/	/
Debt Stock	% change	14.2	/	/	/	13.7	/	/
Unemployment Rate	% of Labour Force	18.5	13.9	14.1	12.1	17.4	19.4	15.2

Sources: DoF: DoF (2020b), CBoI: CBoI (2020), IMF: IMF (2020), and QEC-Summer: McQuinn et al. (2020).
****:*** Current account balance.
*****:*** Public demand for commodities.
******:*** Gross voted expenditures.

The effects of business interruption are observed in the public fiscal balances. The total government revenue shrinks by 14% in 2020. Among its sub-components, the total production tax (tax minus subsidies) collection shrinks by 76.4%[9], while the carbon tax collection and the EU-ETS revenues[10] decline by

[9] The share of this item in the total tax revenue is quite negligible. Such a substantial decline is mainly driven by the increased agricultural production as the production tax rate of the sector is negative, i.e. subsidies exceed tax on agricultural products.

[10] Due to the Emission Trading System (ETS) legislation of European Union (EU), half of the revenues emerging from the

12.5% and 49.7%, respectively. The total sales tax, wage income tax and corporate tax revenues decline by 13.2%, 8%, and 1.7%, respectively, in 2020 compared to their *BaU* levels. As a result, the level of government savings (i.e. the difference between revenues and expenditures, including interest payments over the outstanding foreign debt stock) plummets, leading to a 14.2% increase in the debt stock in 2020, relative to its *BaU* level. In the labour market, the level of the unemployment rate, as a per cent of the total labour force, increases to 18.5% due to decreasing labour demand and labour force participation.

The results of the I3E model are generally in line with those of the other studies presented in Table 2. The figures are much closer to those of the summer issue of the QEC's baseline scenario, whereas they are higher than those of the Department of Finance, the Central Bank of Ireland, and the IMF. These latter three studies were published at the start of the COVID crisis in April when there was limited data available regarding the COVID impacts and the assumed period of lockdown was shorter. I3E results, however, show significantly higher impacts on imports and exports, this can be explained by the inclusion of explicit assumptions regarding the trade disruption on the import side and the positive export impacts of certain commodities in which Ireland has a comparative advantage.

3.1.2 The I3E Results on Macroeconomic Aggregates in Detail

Underlying Sources of Impacts

As summarised in Section 2, the main scenario consists of changes in several structural parameters of the I3E model. These parameters can be grouped into six separate components as discussed in 2: the decline in energy prices, alterations in the structure of production, changes in the composition of consumption, the decline in the labour force participation rate, the government stimulus package, and, finally, changes in the composition of trade. To understand how each component of the COVID shock contributes to the final impacts, we have defined several separate scenarios, which have been run under the assumption of *ceteris paribus*, i.e. all other things being constant. In the *Production* scenario, for instance, only the changes in the structure of production are taken into account while the changes in the other components are ignored by assuming that the values of parameters and exogenous variables are constant at their *BaU* levels. The results of these six scenarios and the main scenario, namely *COVID*, are depicted in Figure 2.

Examining real GDP impacts, we see that the impact of a production shock alone, stemming from the interruption of business that resulted in both a decline in the level of production and a change in the sectoral composition of total output, decreases real GDP by 11.7%, under the assumption of *ceteris paribus*. Under the same assumption, both the decline in the labour force participation rate (2.2%) and the change in the composition of consumption (0.7%) drags the overall economic activity down. On the other hand, lower energy prices (0.47%), the stimulus package of the government (0.16%), and the change in the trade composition (0.07%), *ceteris paribus*, positively affect real GDP. The combined impact of these six elements[11] decreases the level of real GDP by 13% along the path of *COVID*, represented by

auctioning of emissions allowances are received by the central governments of member states.

[11] Note that the *COVID* scenario also takes into account the declines in both net factor income of households and the saving

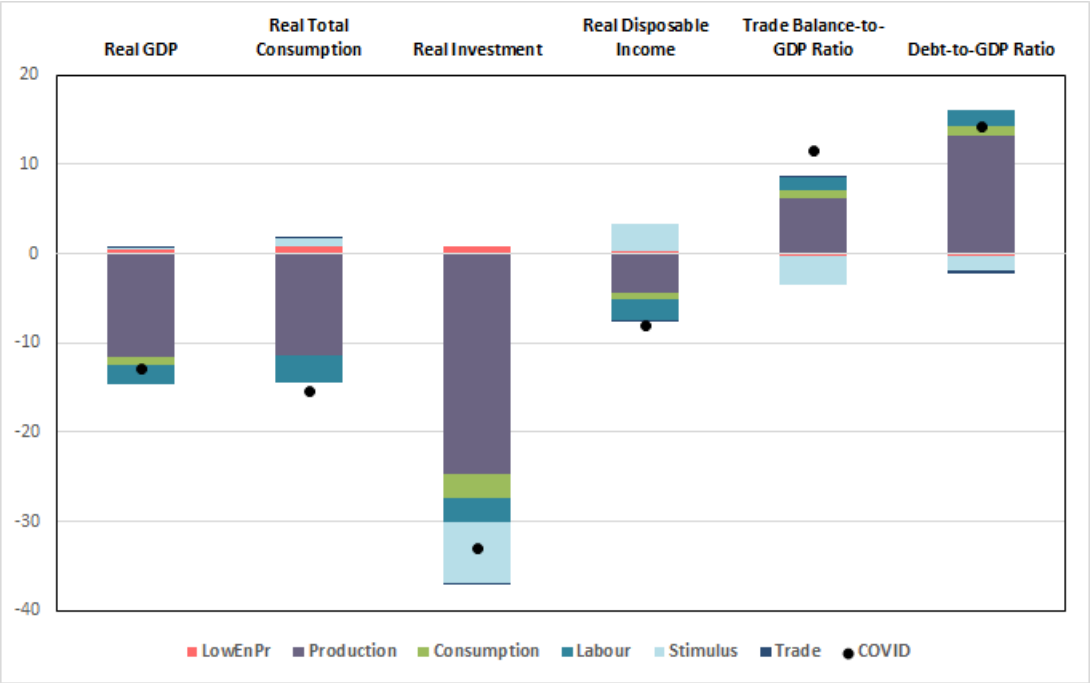

Figure 2: The Impacts of Sub-scenarios in 2020

a dot in the figures, compared to its *BaU* level. The production shock is also the main driver of the overall impact on other major macroeconomic aggregates, including private consumption, investment expenditure, disposable income, trade balance, and public indebtedness largely.

For some macroeconomic aggregates such as real GDP and investment expenditures, the negative impacts of some components of the *COVID* scenario are compensated by the positive impacts of the other components. However, the combined impact of the six components amplifies the impact on some macroeconomic variables such as total consumption and trade balance-to-GDP ratio. For the former variable, for instance, lower energy prices and the government stimulus package put upward pressures on demand and thus commodity prices which, in turn, lead to a decline in total consumption. In the *Stimulus* scenario, although the trade balance itself slightly worsens, the trade balance-to-GDP ratio decreases because of the increase in GDP as the government package boosts economic activity. However, in the *COVID* scenario, the trade balance improves and the overall economic activity shrinks. As a result, the combined effect of the six components suppresses the negative impact coming from the *Stimulus*. On the other hand, the government stimulus has a significant positive impact on real disposable income, which will be discussed in more detail in the next section

Medium term Impacts of the Stimulus Package

In this section, we discuss the impacts of the COVID crisis in the medium-term by comparing the

rate of enterprises.

macroeconomic impacts in 2030 with and without the stimulus package.

As shown in the table, the stimulus package lowers the impact of the COVID crisis on the overall economic activity measured by real GDP by 0.26 percentage point (pp) in 2020, 13.01% compared to 13.27%. The crowding-out impact of the stimulus package on investment expenditure accounts for up to 6pp. The stimulus package plays a substantial role in cushioning consumption by increasing disposable income by around 2.9pp, decreasing the total impact on disposable income by 27% in the *COVID* scenario in 2020, compared to the *COVID without Stimulus* scenario.

The stimulus package lowers the total exports by 0.45pp as increasing domestic economic demand increases domestic prices and makes Irish commodities less competitive on international markets. The decline in imports, on the other hand, in the *COVID* scenario is higher in absolute terms than the *COVID without Stimulus* scenario by 0.5pp. The reason for this is that the stimulus package crowds-out investment expenditure which, in turn, decreases demand for the import of investment commodities. The trade balance-to-GDP ratio improves by 11.6% in 2020 in the *COVID* scenario, compared to *BaU*, but the stimulus package drags it down by around 4pp.

Table 3: The Impacts of Stimulus Package

		COVID		no Stimulus	
		2020	2030	2020	2030
%Δ from BaU*	GDP	-13.01	-0.26	-13.27	-0.18
	Investment	-33.0	-0.14	-27.04	-0.05
	Consumption	-15.45	-0.95	-16.32	-0.64
	Disposable Income	-8.07	-0.22	-10.98	-0.15
	Trade Balance	5.33	1.44	5.45	0.77
	Exports	-16.40	0.00	-15.94	-0.04
	Imports	-20.55	-0.29	-20.03	-0.20
	Trade Balance-to-GDP Ratio	11.55	0.92	15.60	0.71
	Debt-to-GDP Ratio	14.23	8.11	16.42	4.36
	Mean Wage	-3.89	-0.09	-4.57	-0.06
Δ from BaU**	Net Migration	-3.93	-0.31	-3.37	-0.11
	Total Employment	-281.56	-3.03	-288.49	-1.96
Level	Government Balance-to-GDP Ratio	-12.42	-6.62	-8.97	-6.53

* All variables are in real terms except for the ratios.
** In thousand.

The decline in real mean wage would be 0.68pp higher without the stimulus package in 2020. The positive impact of the stimulus package reduces the decline in total employment by as much as 6930.

In the *COVID* scenario, the decline in economic activity lowers government revenues and the stimulus package increases total government expenditure. As a result, the government balance, i.e. the difference between the total revenue and expenditure, deteriorates and it declines up to 12.4%, as a per cent of GDP. Consequently, the public indebtedness (measured as the debt stock-to-GDP ratio) increases by 14.2% in 2020, compared to *BaU*. Although the stimulus package lowers the government balance-to-GDP ratio by around 3.45pp in 2020, compared to the *COVID* scenario, the package lowers the debt-to-GDP ratio by 2.2pp. This result is driven by the fact that the increased government expenditure prevents larger declines

in the overall economic activity and disposable income of households.

In 2030 the main economic aggregates decline compared to their *BaU* levels. The adjustment process of energy prices will be completed in 2025 and the level of prices will be equal to their 2019 levels and the impact of energy prices on macroeconomic aggregates will dissipate by 2030, compared to *BaU*. Therefore, the impacts observed in 2030 are the result of the COVID-19 related economic measures, specifically the disruption in production, where for the *Production* scenario, the level of overall economic activity measured by real GDP will be 0.2% lower in 2030, compared to its level in *BaU*.[12] Along the path of *Stimulus* scenario, the stimulus package, under the assumption of *ceteris paribus*, lowers real GDP by around 0.09%, whereas it leads to a 4.1% increase in the debt stock-to-GDP ratio in 2030 compared to *BaU*. In other words in the medium term the stimulus package further decreases impacts on GDP, where without the stimulus package, GDP reduction would be 0.08pp lower in 2030 compared to *COVID*. The impacts of the other components in the *COVID* scenario will completely vanish by 2030. Again note that these results are based on the assumption that the Irish economy goes back to its 2019 structure in 2021.

Another important repercussion of decreased investment expenditure in 2020 is that the level of aggregate capital stock will be 0.3% lower in 2030, compared to its level along the path of *BaU*. As a result of the combined impacts, the *COVID* scenario indicates that real GDP will be 0.26% lower than its *BaU* level in 2030. A negligible decline in disposable income, 0.2% compared to *BaU*, leads to a 0.95% decline in private consumption. Since households in the I3E model are rational forward-looking agents under perfect foresight, they prefer to increase their savings in case of a negative economic shock. Although the decline in imports is negligible, it drives the improvement in the trade balance in 2030 as the positive export impact vanishes.

The stimulus package still has a crowding-out effect on investment expenditures by around 0.1pp in 2030. The *COVID without Stimulus* scenario indicates that on the contrary to its cushioning role in 2020, the stimulus package lowers private consumption by around 0.3pp but keeps the level of employment slightly higher in 2030, compared to the *COVID* scenario. The most interesting result regarding the impact of the stimulus package is that the package increases the debt-to-GDP ratio by around 3.75pp in 2030. This highlights the need for additional stimuli focussed on the medium term economic recovery

The Impacts of a Gradual Recovery

As mentioned above, in the main scenario of this report, namely *COVID*, it is assumed that all structural parameters and policy variables except for energy prices return to their 2019 levels in 2021. Energy prices, including the EU-ETS price, on the other hand, are assumed to be fully restored in 2025 at their 2019 levels. Given the large amount of uncertainty concerning the future energy price, the duration of COVID19 measures and the speed of economic recovery, in the scenarios presented in this subsection, the assumptions of energy prices and recovery are varied. Firstly, energy prices follow a more gradual pattern and return to their 2019 levels in 2030 rather than in 2025 as discussed in Section 2. Scenarios including this assumption include the term "ExtdLowEnPr", which stands for *extended low energy prices*

[12] The results of scenarios for each component are not presented in the report but available upon request.

in their name.

Secondly, the scenarios in this subsection assume a gradual recovery in the structural parameters and policy variables. In order to indicate that the scenario incorporates this assumption, its name includes the term "Grad_Rec" which stands for *gradual recovery*.

Table 4: The Impacts of a Gradual Recovery

		COVID			COVID with ExtdLowEnPr		COVID with Grad_Rec		COVID with ExtdLowEnPr & Grad_Rec	
		2020	2021	2030	2021	2030	2021	2030	2021	2030
%Δ from BaU*	GDP	-13.01	0.06	-0.26	0.09	-0.25	-7.18	-0.43	-7.16	-0.41
	Investment	-33.01	0.49	-0.14	0.50	-0.14	-16.78	-0.23	-16.78	-0.22
	Consumption	-15.45	-0.42	-0.95	-0.33	-0.90	-7.65	-1.44	-7.58	-1.39
	Disp. Income	-8.07	-0.06	-0.22	-0.04	-0.21	-3.25	-0.36	-3.23	-0.35
	Trade Balance	5.33	1.35	1.44	1.36	1.35	4.05	2.06	4.06	1.97
	Exports	-16.40	0.13	0.00	0.14	0.00	-9.16	-0.05	-9.16	-0.06
	Imports	-20.55	-0.03	-0.29	0.01	-0.28	-11.66	-0.47	-11.66	-0.46
	Trade Balance-to-GDP Ratio	11.55	0.65	0.92	0.67	0.88	6.93	1.30	6.96	1.25
	Debt-to-GDP Ratio	14.23	14.31	8.11	14.38	7.62	23.60	11.68	23.69	11.19
	Mean Wage	-3.89	0.16	-0.09	0.20	-0.09	-2.09	-0.14	-2.07	-0.14
Δ from BaU**	Net Migration	-3.93	-0.14	-0.31	-0.12	-0.29	-2.26	-0.47	-2.24	-0.45
	Total Employment	-281.56	7.74	-3.03	9.05	-2.94	-152.10	-4.61	-150.96	-4.52
Level	Government Balance-to-GDP Ratio	-12.42	-4.82	-6.62	-4.81	-6.61	-7.92	-6.74	-7.91	-6.73

* All variables are in real terms except for the ratios.
** In thousand.

The differences between the results of the *COVID* and *COVID with ExtdLowEnPr* scenarios show the impacts of a gradual increase in energy prices. In the latter scenario, energy prices are lower compared to both *BaU* and *COVID* in 2021, whereas they are equal to their 2019 levels in the year 2030 in all three scenarios. Accordingly, lower energy prices lead to improvements in all macroeconomic aggregates in 2021 compared to the *COVID* scenario. For instance, the decline in the level of private consumption becomes 0.09pp lower and the level of employment increases by 1300 more in 2021 compared to the *COVID* scenario. In 2030, the macroeconomic outlook in *COVID with ExtdLowEnPr* remains better than that of *COVID* except for imports and thus trade balance as lower energy prices invoke energy demand and lead to a slower decline in total imports. The impacts of lower energy prices on the trade balance and trade balance-to-GDP ratio are 0.09pp and 0.04pp in 2030, respectively. Compared to the *COVID* scenario, a slightly better economic performance of the Irish economy saves more jobs and lowers the public indebtedness as a per cent of GDP in the *COVID with ExtdLowEnPr* scenario in 2030.

The results of the *COVID Grad_Rec* scenario show that the macroeconomic outlook of the Irish economy will be worse over the next decade if the negative effects of the COVID-19 crisis will continue to a lesser degree in 2021. The level of real GDP will be 7.2% and 0.17pp lower than its level in *BaU* and

COVID, respectively, in the case of a gradual recovery. The substantially decreased investment of firms in 2020 and 2021 will have important adverse impacts on the economic growth performance of the Irish economy in 2030, compared to both *BaU* and *COVID*.

The impacts of a gradual recovery in the COVID-crisis on household disposable income and thus private consumption expenditure will be substantially negative in 2021, compared to a rapid recovery. Even in 2030, household disposable income and private consumption expenditure will decline by 0.14pp and 0.5pp, respectively, more in the *COVID Grad_Rec* scenario compared to the *COVID*.

Due to the assumptions on the trade elasticities, the improvements in trade balance and its ratio to GDP in 2021 will still be strong in case of slower recovery. The positive impacts of a gradual recovery will still be valid on the trade balance and the trade balance-to-GDP ratio in 2030: these two variables will improve by 0.6pp and 0.38pp more, respectively, compared to the *COVID* scenario as the lower level of the overall economic activity lowers import demand more than export demand.

In the labour market, the deterioration in real mean wage will still be strong along the path of the *COVID Grad_Rec* scenario, which will hinder the net migration inflows to Ireland more compared to *COVID*. In the case of a slower recovery, the total employment will decline by 152,100 compared to *BaU* and 144,400 compared to the *COVID* scenario in 2021. The cost of a slower recovery in terms of total employment will be around 1,600 more job losses compared to the *COVID* scenario in 2030.

Although the government only keeps paying half of the non-means-tested transfers in 2021 compared to 2020, a slower recovery worsens its overall balance as a per cent of GDP by 7.9% and 3.1pp, compared to *BaU* and *COVID*, respectively. As a result, the public indebtedness as a per cent of GDP will increase by 23.6% and 9.3pp compared to *BaU* and *COVID*, respectively. A gradual recovery will still lead to a 3.6pp higher debt stock-to-GDP ratio in 2030, compared to a rapid recovery case.

The scenario *COVID with ExtdLowEnPr & Grad_Rec* accompanies the impacts of low energy prices for a decade and a slower recovery in the COVID-19-related economic crisis. The results indicate that the overall macroeconomic outlook is slightly better than that of the scenario *COVID with & Grad_Rec* in 2021 as the adverse impacts of a slower recovery suppress the positive impacts of lower energy price for an extended period.

In summary, as would be expected a gradual recovery increases the negative macro economic impacts, to a substantial degree for 2021 and to a limited degree in 2030. Extended low energy prices in combination with COVID boost the economy slightly in 2021, and limit the negative impacts in 2030, where again the impact is small. These two counteracting forces are highly uncertain, which results in uncertain projection for the future economic situation in Ireland. Our results do indicate that a gradual recovery, e.g. a second wave of the pandemic would have larger impacts then energy prices.

3.2 Sectoral Impacts

The impacts on sectoral output by aggregated sectors are provided in Table 5. Except for agriculture (5.7%) and public services (5.2%), all sectoral impacts at the aggregate level are negative in the *COVID*

scenario. The most negatively affected sectors are transportation (40.2%), accommodation and hotel services (30.6%), and the manufacturing industries (5.9%). The construction sector experiences an 18.7% decline in its output which comes from both the termination of the activity and the decline in the aggregate investment expenditures. In the I3E model, the sectoral investment expenditures, i.e. investment by destination are determined endogenously via maximising the present discounted value of dividend stream and its total is distributed across commodities based on fixed shares to calculate the demand for a commodity for investment purposes, i.e. investment by origin. Since the share of construction and construction works (NACE code 41-43) is around 25% in Ireland, the decline in total investment diminishes demand for the output of the construction sector most.[13]

Table 5: Output Impacts for Aggregate Sectors, % change w.r.t. *BaU*

	COVID		COVID with ExtdLowEnPr	Grad_Rec	
				COVID	COVID with ExtdLowEnPr
	2020	2030	2030	2030	2030
Accomm. & Hotel Ser.	-30.63	-0.79	-0.75	-1.16	-1.12
Agriculture	5.66	0.04	0.06	-0.03	0.00
Construction	-18.69	-0.23	-0.23	-0.35	-0.35
Electricity Production	-12.32	-0.47	-0.44	-0.72	-0.69
Financial Serv.	-12.46	-0.17	-0.17	-0.25	-0.25
Manufacturing	-5.90	0.02	0.01	-0.09	-0.10
Mining	-17.71	-0.47	-0.43	-0.68	-0.64
Aggregate Serv.	-27.34	-0.22	-0.22	-0.33	-0.33
Public Serv.	5.26	-0.51	-0.48	-0.78	-0.75
Trade	-19.31	-0.23	-0.23	-0.35	-0.34
Transportation	-40.22	-0.57	-0.51	-0.83	-0.77

Note: Sectoral output changes for each individual sector is available in Table C.1.

Within the aggregate manufacturing sector, the level of output of basic pharmaceutical products and chemical products sectors increase as these sectors are the two main exporter sectors in Ireland, Table C.1. Even if the trade elasticities (elasticity of substitution for imports and elasticity of transformation for export) for these two sectors has not been changed in the *COVID* scenario, the levels of output would be increased by 1%, and 1.4% in 2020, compared to *BaU*. The level of output of the food, beverage and tobacco and water and sewerage sectors also increase in line with the change in the composition of private consumption towards the essential commodities. On the other hand, the output of the production of the high-technology products (-41.4%), other manufacturing which mainly covers furniture (-39.2%), transportation equipment (-38.7%), and textile (-34.4%) are hit the hardest sectors within the aggregate manufacturing sector.

[13] In 2016, the share of the construction sector's output in the total investment demand was 14.5%. After the adjustment of CSO in the accounting principle in national accounts regarding the intellectual property rights (IPR) in 2015, the investment demand for the commodities produced by the scientific research and development services sector (NACE code 72) increased from €500 million in 2014 to €40 billion 2016, according to the Supply and Use Tables. When the investment demand for the IPR is excluded, the share of demand for the construction sector's output in total investment demand becomes stable around 25%.

Among the aggregate services sectors, the output of public services and health services sectors increase as the government demand for the commodities produced by these sectors has increased during the health crisis. In addition, the telecommunication sector also experiences an increase in the level of output which also falls within the category of essential commodities. On the other hand, the real estate (-29.7%) and other services sector which mainly covers entertainment, arts, etc. (-35.6%) are the sectors that the COVID-19 crisis hits the hardest. The output in the financial services, including insurance activities, also decreases.

All sub-sectors of the transportation sector face a severe decline in the level of output due to the restrictions on the movement of both people and non-essential commodities within and between countries. The impact is higher for the air transportation sector (-45%) than that of the land transportation sector (-30%) in 2020, compared to *BaU*. In the *COVID* scenario, the sectoral impacts are negative for all aggregate sectors in the medium term (2030) except for agriculture and manufacturing, although the magnitude of the positive impact is less than 0.05%, compared to *BaU*. The negative impacts of the COVID-19 crisis are still around -0.8% in accommodation and hotel services sector, and around -0.5% for the electricity production, mining, and transportation in 2030, relative to their output levels in *BaU*. Even when energy prices gradually increase and reach their 2019 levels in 2030, the output impacts for the accommodation and hotel services, mining, and transportation will be non-negligible in 2030, according to the results of the *COVID with ExtdLowEnPr* scenario.[14]

The *COVID* and *COVID with ExtdLowEnPr* scenarios assume that the structural parameters of the Irish economy will be fully restored in 2021, i.e. there will be a quick recovery. If this assumption is relaxed by considering the possibility of a slower recovery in which the structural parameters go back to their *BaU* levels in 2022, the level of output in each sector will be lower in 2030, compared to a rapid recovery case and the magnitude of the impacts vary between 0.1pp and 0.27pp. If the slower recovery is accompanied by lower energy prices for an extended period, the level of output in 2030 will still be lower than *BaU* but slightly better than the slower recovery alone case in 2030.

The level of sectoral output is a function of value-added (payments to the factors of production), intermediate input demand for energy commodities and other commodities. The lockdown measures affect the level of output of the majority of sectors but the change in sectoral value-added depends on the sector's energy-intensity and labour-intensity. The results of sectoral value-added by the aggregated sectors are provided in Table 6. The real value-added in the agriculture and public services sectors increases by 5.3% and 4.7%, respectively, in 2020 in the *COVID* scenario, compared to *BaU*. The decline in real value-added of the transportation, accommodation and hotel services, and construction sectors are the biggest across sectors and they are in line with the decline in sectoral outputs.

Since the food, beverage and tobacco sector constitutes more than one-fifth of the entire manufacturing value-added, an increase in its sectoral value-added reduces the decline in the aggregate manufacturing sector's real value-added, Table C.2. The basic pharmaceutical production and chemical production

[14] The output impact for the public services sector is also non-negligible but the source of the decline is the decline in the overall economic activity measured by GDP. See Footnote 8 for further details.

Table 6: Value Added Impacts for Aggregate Sectors, % change w.r.t. *BaU*

	COVID		COVID with ExtdLowEnPr	Grad_Rec	
				COVID	COVID with ExtdLowEnPr
	2020	2030	2030	2030	2030
Accomm. & hotel services	-23.61	-0.75	-0.72	-1.09	-1.05
Agriculture	5.32	0.11	0.14	0.06	0.09
Construction	-19.86	-0.24	-0.24	-0.36	-0.36
Electricity Production	-3.57	-0.49	-0.41	-0.76	-0.68
Financial Services	-2.91	-0.24	-0.23	-0.34	-0.34
Manufacturing	-3.94	-0.02	-0.03	-0.17	-0.17
Mining	-8.26	-0.48	-0.44	-0.70	-0.66
Other Services	-5.91	-0.29	-0.27	-0.44	-0.42
Public Services	4.72	-0.45	-0.42	-0.69	-0.66
Trade	-9.20	-0.27	-0.26	-0.40	-0.39
Transportation	-24.58	-0.69	-0.56	-1.01	-0.89

Note: Sectoral value added changes for each individual sector is available in Table C.2.

sectors also reduce the decline in the real value-added of the aggregate manufacturing sector.

The sectoral value-added impacts in the other scenarios are in line with those of the sectoral output impacts. If energy prices stay at their lower levels for a decade, the sectoral impacts will be slightly better in 2030, compared to a rapid increase in energy prices. On the other hand, if the impacts of the COVID-19-related interruptions in the economic activity will be valid to a lesser extent in 2021, the declines in the sectoral real value-added will be more severe in 2030.

3.3 Household Impacts

In this section, the impacts on households are presented. Household real disposable income is the sum of five items: the net-of-tax wage income, net-of-tax capital income, welfare transfers and pension income from the government, and lastly net factor income from abroad. In the *COVID* scenario, each of these components are impacted and we discuss each in turn.

Net-of-tax wage income of households decreases by 15.2% and 16.5%, on average, in real terms in urban and rural areas, respectively, in 2020. However, the declines in the wage income of the richest households are lower than the average; 12.5% and 13.6% in urban and rural areas, respectively. The reason being that the majority of high skilled labour come from richer households, which is the least affected labour type. Therefore, poorer households are in a relatively disadvantaged position regarding the decline in net-of-tax wage income.

In the I3E model, the enterprise account distributes its dividends across households with fixed shares calibrated from the HBS, where richer households receive the highest portion. In 2020, the value of distributed dividends in real terms decreases by 3.5%, compared to *BaU*. Since the bulk of the dividend payments are received by richer households, the decline in the profits hit those household groups harder.

The welfare transfers of the government cover all means-tested transfers, and its total budget is dis-

tributed across households based on fixed shares calibrated by using the Household Budget Survey - HBS-2015-2016. In the model, the total real values of welfare transfer and pension are kept constant and the government adjusts their nominal values by the change in the mean wage. Although the mean wage declines, the real values of these income items are not affected and they have no impacts on real disposable income. However, the government stimulus increases the value of recently added transfer items into household disposable income, namely $NMTTR$, as the share of a household group's disposable income in total disposable income decreases, i.e. poorer households get more non-means-tested transfers. The value of $NMTTR$ is deflated by using the consumer price index in the calculation of real disposable income.

As mentioned in Section 2, net factor income from abroad is decreased by 7%. Since the total net factor income is distributed across households based on fixed shares, the impact of it on real disposable income is uniform across households.

The combined impacts of these developments result in declines in disposable income in both areas of residence. Rural resident households face a larger decline in their disposable income, -10%, on average, compared to urban resident households, -5.9%, on average. In rural areas, the disposable income of each household group decreases and the impact follows a u-shaped pattern. The richest household group benefits from the increase in economic activity in agriculture. In urban areas, on the other hand, the poorest household group has a limited increase in its disposable income, compared to *BaU* in 2020. The average decline in disposable income in urban areas is 7.5% when the poorest quintile is excluded, and the impact for each household group is very close to the average impact. In other words, the disposable income effect of the COVID-19 crisis is almost uniform in urban areas.

Table 7: Household Real Disposable Income, % change w.r.t. *BaU*

	COVID		COVID with ExtdLowEnPr	Grad_Rec	
				COVID	COVID with ExtdLowEnPr
	2020	2030	2030	2030	2030
Rural poorest	-2.95	-0.24	-0.23	-0.40	-0.39
r2	-12.22	-0.28	-0.26	-0.45	-0.43
r3	-13.21	-0.24	-0.23	-0.39	-0.38
r4	-12.83	-0.23	-0.22	-0.36	-0.35
Rural richest	-8.60	-0.21	-0.20	-0.34	-0.33
Urban poorest	0.70	-0.26	-0.25	-0.43	-0.42
u2	-7.94	-0.21	-0.20	-0.34	-0.33
u3	-7.28	-0.18	-0.17	-0.29	-0.28
u4	-7.31	-0.20	-0.19	-0.32	-0.31
Urban richest	-7.54	-0.25	-0.23	-0.41	-0.39

Note: For more details about the problem of households, see Appendix A.

In 2030, the adverse impacts of the COVID-19 crisis will still be felt. In the *COVID* scenario under the assumption of a rapid recovery, all household groups will still have a lower level of disposable income, compared to *BaU*, by 0.23%, on average. Households at the bottom of the income distribution will suffer more due to the decline in economic activity and thus wage rate, whereas richer households' dividend

income will also be lower due to both economic contraction and the decline in the capital stock.

If energy prices stay at lower levels for an extended period, the disposable income effect will still be negative, compared to *BaU*, but households will be slightly better off compared to the *COVID* scenario, in the *COVID with ExtdLowEnPr* scenario. If there will be a slower recovery, the disposable income of households will be 0.14pp lower in 2030, compared to a rapid recovery scenario. In the *COVID with Grad_Rec & ExtdLowEnPr* scenario which considers the possibility of a gradual recovery accompanied by lower energy prices for an extended period, the disposable income impacts will be slightly better off compared to *COVID with Grad_Rec*.

To our best knowledge, Beirne et al. (2020) and O'Donoghue et al. (2020) are the only studies providing a household-level analysis of the COVID crisis. The former includes five groups of households based on disposable income. The authors analyse the impacts of three unemployment shocks in which unemployment increases by 400, 600 or 800 thousand. As our main scenario suggests that the decline in employment would be 285 thousand in 2020, compared to *BaU*, we can compare our results with the "low unemployment" scenario of Beirne et al. (2020, Figure B.2, p.17). The results of the authors suggest that only the poorest household group's disposable income will increase due to the increase in means-tested transfers and the emergence of the non-means-tested transfers during the COVID pandemic in 2020. The impact on the second poorest household group's disposable income will be negligibly negative. The other three household groups will be negatively affected and the impact will be progressive such that the magnitude of the shock increases, in absolute terms, as disposable income increases. When we aggregate the household groups in I3E into five income groups, we end up with the following results in the *COVID* scenario. The disposable income effect is negative for all households, the impact is around -0.3% for the poorest quintile, and the disposable income effect is regressive across households when the poorest quintile is excluded. The methodologies applied in this report and Beirne et al. (2020) have substantially distinct characteristics. The main drivers leading to the two different household impacts can be summarised as follows. Beirne et al. (2020) considers the direct impacts of unemployment, whereas I3E considers the general equilibrium impacts as well, where the wage rate will adjust due to the COVID shock. Hence the I3E model considers the changes in each component of the total disposable income, including wage income (through the changes in both employment and wage rate), capital income in the form of dividends and net factor income from abroad. Beirne et al. (2020), on the other hand, analyses the impacts of each welfare policy item in detail but does not take into account the change in wage rate and excludes the impacts of the latter two items on total disposable income. Furthermore, Beirne et al. (2020) was published before sector level unemployment data was available, where they assign sectors into low, medium and high unemployment impacts and distribute the total amount of unemployment based on this. Subsequently, DoF (2020a) published detailed sectoral impacts regarding the decline in employment. Furthermore, Beirne et al. (2020) assume that the risk of unemployment is equal across skill types, whereas I3E distinguishes between skill types.

Table 8 shows the percentage change in real private consumption for selected commodities. The private consumption of essential commodities, including nourishment (8.5%), telecommunication services

Table 8: Total Private Consumption by Commodity, % change w.r.t. *BaU*

	COVID		COVID with ExtdLowEnPr	Grad_Rec	
				COVID	COVID with ExtdLowEnPr
	2020	2030	2030	2030	2030
Total	**-15.45**	**-0.95**	**-0.9**	**-1.44**	**-1.39**
Nourishment					
Agriculture	8.53	-0.94	-0.88	-1.44	-1.38
Food, beverage, and tobacco	8.59	-0.96	-0.90	-1.46	-1.40
Services					
Telecommunication	4.64	-0.94	-0.88	-1.42	-1.36
Accomm. & hotel services	-31.73	-0.91	-0.86	-1.36	-1.31
Education	-8.31	-0.79	-0.75	-1.20	-1.16
Financial services	-12.77	-1.06	-1.00	-1.61	-1.54
Real estate services	-32.31	-0.95	-0.89	-1.43	-1.37
Other	-20.28	-0.96	-0.91	-1.45	-1.39
Manufacturing					
Textile	-26.94	-1.04	-0.98	-1.58	-1.52
Transportation equipment	-27.79	-1.06	-1.00	-1.61	-1.55
Other manufacturing	-23.07	-1.05	-0.99	-1.58	-1.52
Transportation					
Land	-43.46	-0.97	-0.95	-1.45	-1.43
Air	-66.18	-0.97	-0.95	-1.45	-1.43
Private transportation					
Diesel	-28.22	-1.01	-1.01	-1.50	-1.50
Electricity	-36.15	-1.01	-0.91	-1.53	-1.43
Gasoline	-27.20	-0.96	-0.94	-1.44	-1.42
Residential Energy					
Coal	2.88	-0.81	-0.77	-1.24	-1.19
Peat	4.19	-1.06	-0.95	-1.61	-1.51
Natural Gas	4.68	-0.91	-0.86	-1.38	-1.33
Kerosene	12.80	-0.97	-0.94	-1.46	-1.43
Electricity	6.82	-0.95	-0.90	-1.43	-1.38

(4.6%), and residential energy increases in 2020, compared to *BaU*. The household demand for energy differs based on the area of residence and disposable income. For instance, urban resident households mainly use electricity and natural gas for heating purposes, whereas rural resident households are more dependent on kerosene (15% of the total energy demand, on average), diesel, and electricity. It should be noted that I3E distinguishes between household demand for electricity for lighting, heating, and transportation purposes, and demand for diesel for heating and transportation purposes. Therefore, increasing expenditure on residential energy and decreasing demand for transportation have different implications on private demand for these commodities. Within the residential energy commodities, kerosene demand increases by 12.8%, which is followed by electricity (6.8%) and natural gas (4.7%) in 2020, compared to *BaU*.[15] Demand for peat and coal also increases at a relatively small rate compared to other energy

[15] In the model, residential energy demand consists of several layers in which all solid and liquid energy commodities are in separate bundles. The bundle for liquid commodities includes kerosene, LPG, and diesel and these commodities are assumed

commodities.

Private demand decreases for all services (except for telecommunication), manufacturing, and transportation commodities substantially. The declines in demand for land (covers freight, public transportation, and transportation via pipeline) and air transportation are the highest across all commodities. The government's roadmap for reopening envisages that all employees who can work remotely do not go back to their offices until the end of August. In addition, companies which want to reopen their offices have to comply with the regulations set out in the Return to Work Safely Protocol[16] Therefore, private demand for land transportation declines to almost its half in 2020 due to both the lockdown and the restrictions on returning back to offices. Even if all restrictions on international travelling are lifted today, people will not choose to travel as they wish to avoid spending more time in airports, shuttle busses and planes. In addition, as people have increased their experience in attending meetings and conferences remotely during the lockdown, they may continue to do so in the near future rather than travelling to work, where many companies have committed to support working from home throughout 2020. Therefore, demand for air transportation decreases to one-third its level in *BaU* in 2020. Demand for gasoline, diesel and electricity for private transportation purposes also plunge in 2020 by around 30%, on average, compared to *BaU*, in the *COVID* scenario. Private demand for manufacturing commodities decreases substantially and textile, transportation equipment and other manufacturing which mainly covers furniture are the most affected commodities, compared to *BaU* in 2020.

The changes in private consumption demand in the other scenarios in Table 8 are generally in line with the changes in disposable income effects presented in Table 7. In the *COVID with ExtdLowEnPr* scenario, rapid economic recovery with lower energy prices for a decade lessens the negative impacts on private demand for all commodities but the impacts are negligible for transportation and residential energy commodities in 2030, compared to the *COVID* scenario. In the case of a gradual recovery, private demand for each commodity will be around 0.5pp lower in 2030, compared to a rapid recovery scenario. Low energy prices for a decade in a slower recovery case has negligible impacts on private consumption demand in 2030.

3.4 Income Distribution and Welfare

As a CGE model, the I3E model is able to measure the change in between-group income distribution as the household sector comprises *representative* household groups rather than individual households available in a survey, such as the HBS. In this respect, three indicators are generated. The indicator *urban* shows the distribution of income between urban resident households, and it is calculated by dividing the richest household's real disposable income to the poorest household. Similarly, the indicator *rural* is calculated by dividing the rural resident richest household's real disposable income by the rural resident poorest households' disposable income. The last indicator, *urban-to-rural*, measures the distribution of disposable income across urban and rural areas and it is calculated by dividing the sum of urban resident

to be perfect complements. Therefore, the demand for these three commodities changes at the same rate.

[16] https://www.gov.ie/en/publication/22829a-return-to-work-safely-protocol/.

households' real disposable incomes by the sum of rural resident households' real disposable incomes. Table 9 displays the percentage changes in these indicators relative to *BaU*. For these indicators, a positive value implies a deterioration, whereas a negative value means an improvement in the between-group income distributions. In addition, the per capita values of real GDP and private consumption are also presented as welfare measures. Note that the total Irish population grows by both birth (at a fixed growth rate) and the net migration into Ireland. Since the net migration into Ireland is negative due to the COVID-crisis, total population decreases compared to *BaU*, which hinders larger declines in the levels of per capita indicators.

Table 9: Income Distribution and Welfare Indicators

	COVID				COVID with ExtdLowEnPr		Grad_Rec	
	with Stimulus		without Stimulus		with Stimulus	without Stimulus	COVID	COVID with ExtdLowEnPr
	2020	2030	2020	2030	2030	2030	2030	2030
Per capita								
Real GDP	-12.94	-0.26	-13.21	-0.18	-0.24	-0.16	-0.42	-0.40
Consumption	-15.38	-0.95	-16.26	-0.64	-0.90	-0.58	-1.43	-1.38
Income Distribution								
Rural	-5.83	0.03	4.69	0.03	0.03	0.02	0.06	0.06
Urban	-8.19	0.02	7.54	0.01	0.01	0.01	0.03	0.03
Urban-to-Rural	3.87	0.01	2.94	0.01	0.01	0.01	0.01	0.01

Note: The term *urban* (*rural*) is for the ratio of the richest household's real disposable income to the poorest household's real disposable income in urban (rural) areas. The term *urban-to-rural* is the ratio of the sum of real disposable incomes of urban resident households to the sum of real disposable incomes of rural resident households.

The results indicate that the economic measures taken to lessen the negative impacts of the COVID-19-related lockdown substantially lower the decrease in the per capita levels of real GDP and consumption, and these outcomes are in line with the results presented in Table 3. The COVID-crisis plays a corrective role in the between-group income distribution in 2020, compared to *BaU*, and the impact is bigger in urban areas than that of rural areas. The income distribution between urban and rural resident households, on the other hand, worsens to the detriment of rural households. Since the majority of employees live in urban areas, a greater bulk of the non-means-tested COVID-related transfers are received by urban resident households. In each area of residence, the poorest quintile of households gets a higher portion of the transfers, including the increased fuel allowances. In 2030, the between-group income distribution deteriorates to a negligible level in both areas of residence, as well as between urban and rural areas.

The impacts of the stimulus package on income distribution and welfare indicators are substantial. The package reduces the decline in per capita real GDP and per capita consumption by around 0.25pp and 0.9pp in 2020. Its impacts on per capita real GDP and consumption will still be positive in 2030 by 0.08pp and 0.3pp, respectively. More importantly, the stimulus package plays a crucial corrective

role on the between-group income distribution indicators. Without the stimulus package, the COVID-19-related economic crisis would make the richest richer and makes the poorest poorer both within and between areas of residence. This effect is also found in O'Donoghue et al. (2020), where they find an increase in the Gini coefficient during the crisis for market income but a decrease for gross income when the stimulus is taken into account. Without a stimulus, the I3E model finds that the ratio of the richest household group's disposable income to the poorest household group's disposable income will increase by 7.5% and 4.7% in urban and rural areas, respectively, in 2020. Moreover, rural resident households' disposable income will be eroded more compared to urban resident households by around 3% in the absence of the stimulus package in 2020.

In the other scenarios, the income distribution indicators follow a pattern in line with the economic activity and household disposable income of households as explained in the previous subsections.

3.5 Emissions

3.5.1 Economy-wide Emissions

In this subsection, the results concerning the level of economy-wide CO_2 emissions are discussed. Note that I3E only models energy related emissions and does not include agricultural non energy combustion emissions, which constitute the bulk of agricultural emissions. Figure 3 depicts the impacts of low energy prices and the COVID crisis on emissions over time. Along the path of *BaU*, the emissions will be 1.07% higher in 2020 compared to 2019. The sole impact of low energy prices on emissions would increase emissions by 9.4% in 2020, compared to *BaU*, as shown in the path of *LowEnPr*. In this scenario, energy prices start to increase in 2021 but remain lower than their 2019 level up to 2025 resulting in on average 5% higher emission up to 2025 compared to *BaU*. As a result, the level of cumulative emissions in 2025 and 2030 will be 3.2% and 1.85% higher, compared to *BaU*.[17] The COVID crisis with lower energy prices (the *COVID* scenario), on the other hand, reduces the level of emissions in 2020 by 9.5% compared to *BaU*, where the reduction of energy demand due to the economic slowdown outweighs the increased demand due to lower prices. However, after 2020 as the economy starts to recover, energy demand picks up resulting in a higher level of cumulative emissions of 0.5% and 0.3% in 2025 and 2030 respectively, compared to *BaU*.

If energy prices stay at lower levels until 2030 compared to their 2019 levels, as in the *ExtdLowEnPr* scenario, the level of cumulative emissions will be 4.7% and 3.2% higher in 2025 and 2030, respectively. If the COVID crisis impacts occur under the assumption that energy prices will be lower for a decade, the level of cumulative emissions will be 2% and 1.37% higher in 2025 and 2030, compared to *BaU*, shown in the *COVID with ExtdLowEnPr* scenario.

[17] The cumulative emissions cover the period beyond 2018.

Figure 3: The Impacts of Low Energy Prices and the COVID Crisis

Note: Economy-wide million tonne equivalent CO_2 emissions between 2018 and 2030

Figure 4 shows the impacts of gradual recovery scenarios on the economy-wide CO_2 emissions under different energy price trajectories. If the COVID-19 crisis impacts will partially continue through 2021 as modelled in *COVID with Grad_Rec*, the level of cumulative emissions in 2025 and 2030 will be 4.1 and 4.9 million tonnes lower, compared to the path of the *COVID* scenario. These values correspond to 0.71% and 0.81% declines in the level of cumulative emissions, compared to *BaU*. In other words, the impacts of slower economic activity for two consecutive years will suppress the impacts of lower energy prices even a decade after the crisis. However, if a slower recovery takes place with low energy prices for an extended period, the level of cumulative emissions will be higher by 0.71% and 0.5% in 2025 and 2030, compared to *BaU*, i.e. the impacts of low energy prices on emissions will be greater than that of the lower economic activity for two years.

The emissions results must be evaluated cautiously by considering counterbalancing impacts which are not taken into account in the scenario analyses. For instance, a global prolonged downturn in economic activity will lessen the upward pressure on international energy prices and lower energy prices invoke higher energy demand. On the other hand, lower global and domestic economic activity for a longer period of time will lower energy demand. The future of the emissions figures depends on which one of these two effects will be dominant, both of which are highly uncertain.

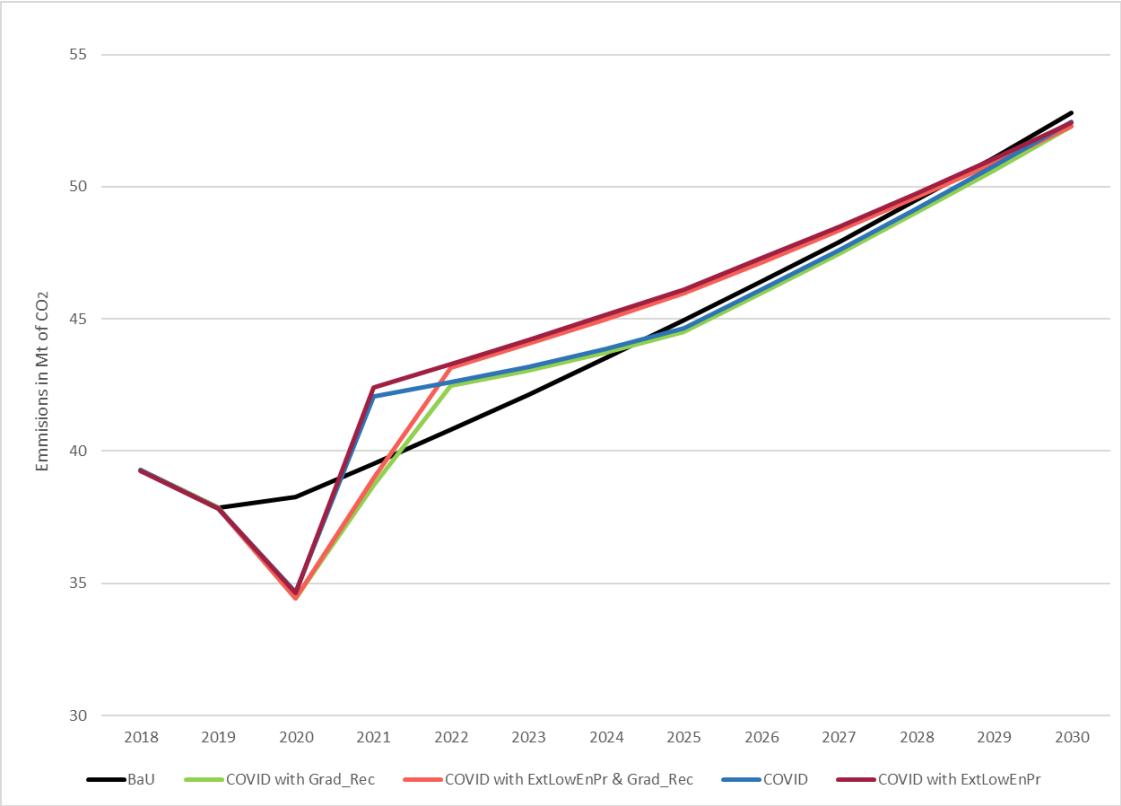

Figure 4: The Impacts of the COVID Crisis and Gradual Recovery Scenarios

Note: Economy-wide million tonne equivalent CO_2 emissions between 2018 and 2030

3.5.2 Sectoral Emissions

The level of sectoral emissions consists of the sum of the ETS and non-ETS emissions. The ETS emissions include the combustion-related and process emissions of those sectors which are subject to the EU-ETS regulation. The non-ETS emissions, on the other hand, is the sum of sectoral emissions not subject to the EU-ETS, and emissions based on private consumption (households' emissions), public demand (government emissions) and investment-demand.

The economy-wide non-ETS emissions decline by 9.5% in 2020, compared to its *BaU* level. Households' residential emissions increase by 7.1% due to higher residential energy demand and lower fossil fuel prices, whereas the total household emissions, including emissions stemming from the consumption of energy commodities for transportation purpose, decrease by 9.8% in 2020, compared to *BaU*, along the path of *COVID*. The government emissions also increase by 6.4% due to the government's increased demand for commodities.[18]

The only sectors which present with increasing emissions in 2020 are the agriculture and public services sectors due to their increased levels of output. The increase in agricultural non-ETS emissions

[18] In the model, the sector "public administration" (NACE code 84) is responsible for producing public goods, whereas the agent "government" is responsible for conducting fiscal policy. The former's emissions are presented in Table 10.

Table 10: Non-ETS CO_2 Emissions of Aggregate Sectors, % change w.r.t. *BaU*

	COVID		COVID with ExtdLowEnPr	Grad_Rec	
				COVID	COVID with ExtdLowEnPr
	2020	2030	2030	2030	2030
Total	**-7.49**	**-0.80**	**-0.80**	**-1.19**	**-1.19**
Accomm. & hotel services	-24.00	-0.82	-0.84	-1.21	-1.23
Agriculture	13.51	-0.01	-0.11	-0.04	-0.14
Construction	-20.72	-0.15	-0.24	-0.22	-0.30
Financial Services	-6.84	-0.02	-0.07	-0.03	-0.08
Manufacturing	-7.77	-0.21	-0.25	-0.28	-0.32
Mining	-15.92	-0.35	-0.40	-0.50	-0.55
Other Services	-12.97	-0.31	-0.36	-0.45	-0.50
Public Services	4.87	-0.60	-0.65	-0.89	-0.94
Trade	-7.28	-0.16	-0.24	-0.22	-0.30
Transportation	-20.55	-0.51	-0.64	-0.73	-0.85

Note: Since the entire emissions of the electricity production sector are covered by the ETS, the sector does not have any non-ETS emissions. The transportation sector covers the land, air, and water transportation sectors, but its non-ETS emissions exclude the air transportation sector as it does not have any non-ETS emissions.

is larger than that of the output impact (5.66% in the *COVID* scenario in 2020) due to both the increased level of output and lower energy prices. The sector demands more energy commodities to produce more output, and at the same time, substitute energy commodities for real value-added in the cost minimisation process.[19] The declines in other sectors' non-ETS emissions are in line with the change in their sectoral output. In the other scenarios, the declines in sectoral non-ETS emissions are in line with the sectoral output impacts presented above.

Putting these results in context of the Irish EU non-ETS emissions targets for 2020 and 2030, we need to consider agricultural non-combustion emissions. Non-ETS emissions consist of non-ETS emissions from combustion as modelled in I3E and agricultural emissions. These agricultural emissions are estimated to be around 20 Mt CO_2 in 2020 and 2030 (EPA, 2019). Ireland's non-ETS emission target for 2020 is a 20% reduction compared to 2005 levels, equivalent to an emission level of 37.7 Mt CO_2. For 2030, the target is a 30% reduction compared to 2005 levels, equivalent to 32.9 Mt CO_2 emissions. Non-ETS emissions modelled in I3E are estimated at 21.5 Mt in 2020 and 32 in 2030, in the *COVID* scenario. This would mean the Ireland would still miss its 2020 and 2030 targets by 3.8 Mt CO_2 and 19.1 Mt CO_2 in 2020 and 2030, respectively.

The level of the ETS emissions varies based on the ETS-emissions-to-total-emissions ratio (a calibrated parameter), the free-allowance-to-ETS-emissions ratio (endogenously calculated in the model) of an activity, and the composition of sectoral energy demand across energy commodities. In each scenario analysis, including *BaU*, the free allowances of each activity have a negative trend (until the end of 2030)

[19] As the other pollutants such as methane and nitrous oxide are not defined in the model yet, the emissions figure for the agriculture sector covers only combustion emissions, whereas the bulk of agricultural emissions arise from livestock.

and the yearly values of the ETS price are factored in. Note that in addition to the prices of energy commodities, the decline in the ETS price is also incorporated into all scenarios evaluated in this report. Therefore, the lower economic activity due to the COVID-19 crisis lowers the energy demand but, at the same time, the lower ETS price incentivises firms to use more fossil fuels.

Table 11: ETS Results of Aggregate Sectors, % change w.r.t. *BaU*

	COVID		COVID with ExtdLowEnPr	Grad_Rec	
				COVID	COVID with ExtdLowEnPr
	2020	2030	2030	2030	2030
	Emissions				
Total	**-21.74**	**-0.41**	**-0.43**	**-0.59**	**-0.57**
Electricity Production	-6.90	-0.39	-0.40	-0.59	-0.61
Manufacturing	-10.15	-0.29	-0.40	-0.38	-0.48
Other Services	-15.03	-0.20	-0.27	-0.27	-0.34
Transportation	-40.23	-0.53	-0.47	-0.75	-0.69
	Cost				
Total	**-49.65**	**-0.54**	**-0.57**	**-0.78**	**-0.75**
Electricity Production	-25.52	-0.39	-0.40	-0.59	-0.61
Manufacturing	-35.11	-0.41	-0.56	-0.53	-0.68
Other Services	-32.40	-0.20	-0.27	-0.28	-0.35
Transportation	-93.21	-0.80	-0.71	-1.13	-1.04

Note: The ETS emissions of the manufacturing sector include the process emissions of the other non-metallic minerals sector. The transportation sector's emissions include process emissions resulting from its fuel purchases outside of Ireland. See de Bruin & Yakut (2019, 26) and de Bruin & Yakut (2020, Section 3.2.3) for details.

As Table 11 indicates, the total ETS emissions decline by 21.7% in 2020, compared to their *BaU* level. The transportation sector, within which only the air transportation sector is subject to the EU-ETS and 100% of its emissions are covered by the system, is hit the hardest, followed by manufacturing and services. The electricity production sector's emissions, which are fully covered by the EU-ETS, decrease due to both lower prices of fossil fuels and 12.3% decline in sectoral output.[20] The decline in the cost of ETS is substantially larger than then decline in emissions due to the 25% decline in the ETS price in 2020, compared to 2019. Since the ETS price goes back to its 2019 level in 2025 in all scenarios, the declines in sectoral ETS emissions are stronger than those of non-ETS emissions as the price of ETS drives sectors to use less fossil fuels. In the other scenarios, the declines in ETS emissions are in line with the output impacts.

4 Conclusion

This report analyses the impacts of the measures taken by the Irish government to stop the spread of the novel COVID-19 virus on the Irish economy and its emissions. To this end, one main COVID scenario is developed and analysed by using the Ireland Environment-Energy-Economy (I3E) model. This scenario takes into account several changes in the structure of the Irish economy, including the decline in energy prices, alterations in the structure of production, changes in the composition of consumption, the decline in the labour force participation rate, the government stimulus package, and, finally, changes in the composition of trade. In order to better understand the contributions of each of these structural changes, the results of each of these components are analysed and the production impacts are found to dominate total impacts.

The impacts of the business interruption on the overall economic activity measured by the gross domestic product will be 13% in 2020. The plunge in investment expenditures in 2020 will lead to a lower level of aggregate capital stock which will, in turn, affect the production capacity of the economy. As a result, the economic shutdown will continue to have repercussions on GDP in the coming decade. In addition to the lower investment expenditure, the deterioration in private consumption expenditures will be offset by the increased government spending and an improved trade balance. The cost of the crisis on the public balance sheet will result in higher indebtedness of the government. In the household sector, the total disposable income of households will decrease due to the declines in both wage and capital income. The government stimulus package will play a substantially corrective role to reduce the adverse economic impacts of the crisis on disposable income of the most vulnerable household groups in urban and rural areas. Where the inequality increasing impact of the COVID crisis is addressed and the stimulus results in decreased inequality across households.

If the health crisis ends in 2020, but the associated economic impacts of the pandemic continue to be effective, even to a lesser degree, in 2021, then the deterioration in the overall economic outlook, public

[20] As renewable energy sources are not included in the current version of the model, the electricity production sector substitutes natural gas for peat and coal. Therefore, the sector's emissions results should be considered as the upper bound.

finances, disposable income and income distribution will be larger in 2030. The longer the economic shutdown, the larger the medium term impacts.

On the environment side, the lower levels of energy prices will partially offset the impacts of the contraction in economic activity on energy demand resulting in a decline of economy-wide CO_2 emissions of 9.5% in 2020. These reduction are only seen in 2020, after which emissions rise again until 2025, when the energy prices return to their 2019 levels. If energy prices stay at lower levels until 2030, compared to 2019, the decline in emission figures due to the contraction in economic activity will be lower. Once the energy prices have decreased, the residual economic impacts of the COVID crisis result in small decreases in emissions. However, as the reductions in the emissions are circumstantial, rather than behavioural, the government's position on the environmental policies should not change. Furthermore, Irelands emissions will still far exceed the Irish legally bindign EU targets of 2020 and 2030.

This report provides a set of results regarding the possible impacts of the already taken measures on the Irish economy. The next step will be searching for possible policy options to answer the question of "what should the government do?". A well designed medium term government stimulus package will be crucial in limiting the economic impacts of the COVID crisis in the future.

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Appendix A The I3E Model

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

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

2. **Firms and Production:** The production sector comprises 32 representative activities/firms which represent the main producers in the Irish economy regarding total value-added, labour demand, sectoral emissions. Twenty-seven out of 32 activities determine the level of physical investment by

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

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

4. **Labour Types:** There are low-, medium-, and high-skilled labour in the I3E model. For the fixed supply of each type of labour, the labour market equilibrium conditions solve for the optimal wage rate. The SILC and LFS are utilised to get the compositions of wage income of households and labour demand of sectors, respectively. In the surveys, individuals with no formal/primary and lower secondary education are low-skilled, individuals with upper secondary, post leaving cert, and third level (non degree) education are medium-skilled, and finally individuals with third level (with a degree or above) education are high-skilled labour.

5. **Enterprises:** The model includes an "enterprises" account, where a representative enterprise is assumed to be the owner of all firms. The account collects all gross sectoral profits and receives transfers from the government, which are fixed in nominal terms, and pays corporate tax to the government. The remaining amount is either saved by the enterprise account (fixed fraction of net-of-tax profit receipts) or paid to households as dividend payments.

6. **Government:** The I3E model has an explicit representation of the government sector. The government collects direct taxes on labour incomes and sectoral profits (corporate tax), indirect taxes on

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

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

Appendix B Lists of Commodities

Table B.1: Commodities

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

*: Not subject to private consumption.

Appendix C Sectoral Results in Detail

Table C.1: Sectoral Output, % change w.r.t. *BaU*

	NACE Codes	COVID		COVID with ExtdLowEnPr	Grad_Rec	
					COVID	COVID with ExtdLowEnPr
		2020	2030	2030	2030	2030
Accom. & hotel services	55–56,79	**-30.63**	**-0.79**	**-0.75**	**-1.16**	**-1.12**
Agriculture	1-3	**5.66**	**0.04**	**0.06**	**-0.03**	**0.00**
Construction	41–43	**-18.69**	**-0.23**	**-0.23**	**-0.35**	**-0.35**
Electricity production		**-12.32**	**-0.47**	**-0.44**	**-0.72**	**-0.69**
Financial services	64–66,77	**-12.46**	**-0.17**	**-0.17**	**-0.25**	**-0.25**
Public services	84	**5.26**	**-0.51**	**-0.48**	**-0.78**	**-0.75**
Trade	45–47	**-19.31**	**-0.23**	**-0.23**	**-0.35**	**-0.34**
Manufacturing		**-5.90**	**0.02**	**0.01**	**-0.09**	**-0.10**
Basic metal	24–25	-28.38	-0.34	-0.31	-0.30	-0.28
Basic pharmaceuticals	21	8.79	0.39	0.40	0.20	0.20
Chemical products	20	7.97	0.33	0.34	0.22	0.23
Food, beverage and tobacco	10–12	8.58	0.33	0.35	0.40	0.42
High-tech products	26–28	-41.39	-0.60	-0.59	-0.71	-0.69
Natural gas		-8.06	-0.41	-0.42	-0.60	-0.62
Other industry	17,18,33	-26.67	-0.29	-0.27	-0.42	-0.41
Other non-metallic	23	-24.89	-0.29	-0.28	-0.38	-0.37
Other manufacturing	31–32	-39.21	-0.74	-0.72	-0.90	-0.89
Petroleum		-10.45	-0.67	-1.16	-0.82	-1.31
Rubber and plastic	22	-27.72	-0.28	-0.28	-0.39	-0.39
Textile	13–15	-34.38	-0.45	-0.42	-0.58	-0.56
Transportation equipment	29–30	-38.69	-0.29	-0.28	-0.43	-0.42
Water and sewerage	36,37–39	5.72	-0.57	-0.54	-0.86	-0.84
Wood and wood products	16	-37.34	-0.27	-0.26	-0.37	-0.35
Mining		**-17.71**	**-0.47**	**-0.43**	**-0.68**	**-0.64**
Other mining		-18.42	-0.46	-0.43	-0.65	-0.61
Peat		-15.52	-0.49	-0.44	-0.76	-0.71
Other Services		**-27.34**	**-0.22**	**-0.22**	**-0.33**	**-0.33**
Education	85	-5.91	-0.54	-0.51	-0.82	-0.79
Health	86–88	4.60	-0.66	-0.62	-1.01	-0.97
Real estate	68	-29.73	-0.81	-0.77	-1.22	-1.18
Other	remaining*	-35.57	-0.01	-0.02	0.00	-0.01
Telecommunication	61	3.33	-0.55	-0.52	-0.82	-0.79
Transportation		**-40.22**	**-0.57**	**-0.51**	**-0.83**	**-0.77**
Air	51	-44.94	-0.59	-0.49	-0.84	-0.74
Land	49	-30.09	-0.59	-0.57	-0.89	-0.87
Water	50	-54.08	-0.26	-0.28	-0.36	-0.37

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

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

Table C.2: Sectoral Value Added, % change w.r.t. *BaU*

	NACE Codes	COVID		COVID with ExtdLowEnPr	Grad_Rec	
					COVID	COVID with ExtdLowEnPr
		2020	2030	2030	2030	2030
Accom. & hotel services	55–56,79	**-23.61**	**-0.75**	**-0.72**	**-1.09**	**-1.05**
Agriculture	1-3	**5.32**	**0.11**	**0.14**	**0.06**	**0.09**
Construction	41–43	**-19.86**	**-0.24**	**-0.24**	**-0.36**	**-0.36**
Electricity production		**-3.57**	**-0.49**	**-0.41**	**-0.76**	**-0.68**
Financial services	64–66,77	**-2.91**	**-0.24**	**-0.23**	**-0.34**	**-0.34**
Public services	84	**4.72**	**-0.45**	**-0.42**	**-0.69**	**-0.66**
Trade	45–47	**-9.20**	**-0.27**	**-0.26**	**-0.40**	**-0.39**
Manufacturing		**-3.94**	**-0.02**	**-0.03**	**-0.17**	**-0.17**
Basic metal	24–25	-29.83	-0.37	-0.33	-0.32	-0.28
Basic pharmaceuticals	21	2.73	0.40	0.41	0.13	0.14
Chemical products	20	4.33	0.27	0.28	0.19	0.20
Food, beverage and tobacco	10–12	6.45	0.29	0.32	0.34	0.37
High-tech products	26–28	-19.34	-0.72	-0.71	-0.87	-0.86
Natural gas		-2.20	-0.44	-0.46	-0.65	-0.68
Other industry	17,18,33	-10.84	-0.25	-0.24	-0.39	-0.38
Other non-metallic	23	-27.78	-0.33	-0.31	-0.41	-0.40
Other manufacturing	31–32	-23.89	-0.95	-0.93	-1.18	-1.15
Petroleum		-11.63	-1.12	-2.37	-1.21	-2.46
Rubber and plastic	22	-11.16	-0.25	-0.23	-0.37	-0.35
Textile	13–15	-18.91	-0.47	-0.45	-0.62	-0.60
Transportation equipment	29–30	-22.05	-0.29	-0.28	-0.44	-0.43
Water and sewerage	36,37–39	-0.52	-0.52	-0.49	-0.78	-0.75
Wood and wood products	16	-23.27	-0.31	-0.28	-0.42	-0.40
Mining		**-8.26**	**-0.48**	**-0.44**	**-0.70**	**-0.66**
Other mining		-8.62	-0.48	-0.44	-0.68	-0.64
Peat		-7.27	-0.50	-0.44	-0.77	-0.71
Other Services		**-5.91**	**-0.29**	**-0.27**	**-0.44**	**-0.42**
Education	85	-4.83	-0.50	-0.47	-0.76	-0.73
Health	86–88	3.92	-0.60	-0.56	-0.93	-0.89
Real estate	68	-0.87	-0.78	-0.74	-1.18	-1.14
Telecommunication	61	3.27	-0.50	-0.48	-0.75	-0.73
Others	remaining*	-12.20	0.09	0.07	0.13	0.12
Transportation		**-24.58**	**-0.69**	**-0.56**	**-1.01**	**-0.89**
Air	51	-28.10	-0.80	-0.61	-1.15	-0.97
Land	49	-17.89	-0.59	-0.54	-0.90	-0.84
Water	50	-48.00	-0.31	-0.30	-0.43	-0.41

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

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

Whitaker Square,
Sir John Rogerson's Quay,
Dublin 2
Telephone **+353 1 863 2000**
Email **admin@esri.ie**
Web **www.esri.ie**
Twitter **@ESRIDublin**
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