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*The effects of an incremental increase in
the Irish carbon tax towards 2030*

Kelly de Bruin^a, Aykut Mert Yakut^a

Abstract: This paper investigates the economic and environmental impacts of an incremental increase in the rate of Irish carbon tax. For this analysis an intertemporal computable general equilibrium (CGE) model, namely Ireland Environment-Energy-Economy (I3E), is developed. This model allows for the investigation of industry level impacts as well as economy wide impacts by explicitly modelling sectoral interlinkages. We examine two potential future paths of carbon tax increases and the impacts of recycling carbon tax revenues through a lump sum transfer to households. Our results show that LPG, diesel and gasoline prices will be impacted most with increases of up to 10% in 2020 compared to a baseline scenario. The energy and transport sectors will be hit the hardest with losses of up to 4% of value added in 2020. Households face higher overall prices, with an up to 2.4% increase in the CPI in 2020 which lowers household real disposable income by 0.24% in 2020. Though income increases as prices rise, households consume less and save more in the medium-run. Driven by this decline in real private consumption, real gross domestic product declines, though at a negligible rate of 0.4% in 2020. Overall emissions in 2020 fall by 18% compared to the baseline. However, this is still far short of EU targets.

Keywords: Carbon tax, Emissions, Welfare, Intertemporal CGE

JEL classifications: C61, D15, D25, H23, O44

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1 Introduction

The adverse impacts of carbon emissions on our climatic system, and in turn societies, have long been recognised by the international academic community. The human-induced increase of atmospheric temperature is estimated to be over 0.8°C to date compared to pre-industrial levels (IPCC, 2014). Climate change involves, in addition to increases in temperature, more variability in temperature and precipitation, increased occurrences of extreme weather events and a rise in sea levels. The concomitant impacts of these climatic changes on societies and economies are uncertain but are expected to be very significant, where at a global level economic damage of approximately 2% of GDP per year for a temperature increase of 2.5°C are estimated (IPCC, 2014). Impacts over longer periods of time and higher levels of climate change are highly uncertain and could result in extremely high impacts, abrupt climate change, and climatic tipping points.

Global recognition of the need to limit climate change has driven negotiations over the past decades to combine efforts to decrease greenhouse gas (GHG) emissions within the United Nations Framework Convention on Climate Change (UNFCCC). In 2015, the Paris Agreement was adopted and to date has been ratified by 194 states and the European Union, though the US has given notice to withdraw from the agreement. Within the Paris Agreement, members of the convention voluntarily submit their national emission targets through Intended Nationally Determined Contributions (INDCs). The main elements of the EU INDCs are summarised in the EU 2030 climate and energy framework which defines three key targets to be reached by 2030: at least 40% GHG emission reduction (compared to 1990 levels), at least 27% share of renewable energy, at least 27% improvement in energy efficiency. The EU has also defined a longer-term perspective on climate and energy policy for 2050, which further decreases emissions by 80-95% of 1990 levels.

To achieve these targets at least cost, the EU has implemented a cap and trade system, namely the EU Emissions Trading System (ETS). It operates in all 28 EU countries as well as in Poland, Liechtenstein, and Norway and covers 45% of EU GHG emissions. In this system, massive energy-using installations (power stations and industrial plants) and airlines in the EU have to buy emission allowances. Companies can trade emissions throughout the EU ensuring that emissions are reduced where it costs the least to do so. The cap is set to decrease emissions from the ETS sectors by 21% in 2020 (compared to 2005) and by 43% in 2030. The overall EU reduction goal in non-ETS sectors is set at 30% (compared to 2005), to achieve this the EU sets individual binding targets for each Member State based on the Effort Sharing Decision.

The non-ETS reduction target for Ireland is set at a reduction of 20% compared to 2005 levels by 2020 and a 30% reduction by 2030. These targets are legally binding and Ireland will face fines should it not meet its targets. Though steps have been made to limit GHG emissions in Ireland through a carbon tax and other policy measures, recent estimates by the Environmental Protection Agency (EPA) of Ireland project that, at best, Ireland will achieve a 1% reduction of emissions by 2020 given the strong economic growth and the expansion of the agricultural sector (EPA, 2018a). It is evident that there is a significant

need to improve climate policy in Ireland to reach its 2020 targets in order to avoid facing EU level fines and to also contribute to the transition to a low carbon global economy.

To create sound carbon tax policies, research is needed to understand both how effective policies may be in reducing emissions and how these policies will affect the overall economy, producers and households. There is relatively no literature addressing both the economic and environmental impacts of increasing the carbon tax in Ireland. This paper attempts to fill that gap.

This paper aims to shed light on the impacts of increasing the Irish carbon tax rate on both the economy and the level of emissions through emission reduction responses to increased prices. A key concern with increasing the carbon tax is the impact this will have on households' expenditures. A carbon tax should incentivise households to decarbonise without making them worse off. One way of achieving this is to recycle the revenues from the carbon tax back to households. In this paper we examine this mechanism and investigate if decarbonisation can be achieved without negatively impacting households.

This analysis applies the Environment, Energy, and Economy (I3E) model. The I3E model is an intertemporal computable general equilibrium (CGE) model with multiple firms, one representative household group (RHG), multiple commodities, government, enterprises, and rest of the world accounts. CGE models examine how inputs and outputs flow between sectors of the economy and finally result in final goods consumed by households. The explicit modelling of sectoral inter-linkages makes it possible to investigate the wider economic impacts of a specific shock or policy through the different transmission channels in the economy and the distributional impacts of policies whose effects may be transmitted through multiple markets. The nature of the methodology makes it very useful to examine the direct and indirect impacts of a carbon tax on the Irish economy.

This paper implements two scenarios, where there are future increases in carbon taxes. In both paths, the tax increases in 2019 to €40 per tonne of CO_2 , after which the carbon tax increases annually by €5 in the less stringent path and €10 in the stringent path. The impacts of these carbon increases are compared with a baseline scenario where the carbon tax of €20 remains at its current level.

The results indicate that the overall economic impacts of increasing a the carbon tax are negligible. However, sector level impacts are significant, where the energy and transport sectors are impacted the most, while chemical products, basic pharmaceutical products, food, beverage, and tobacco benefit the most. Prices of energy commodities increase significantly, particularly for diesel and LPG, however households face only a moderate increase in overall prices. Household disposable income, however, increases due to increased transfers from the government from the recycling of carbon tax revenue while wages increase due to a shift towards labour intensive services. As carbon taxes cause prices to rise, households choose to consume less and save more, thereby decreasing their real consumption. The carbon tax increases can successfully decouple emissions from economic growth, but the resulting reductions in emissions still falls far short of the EU targets.

This paper is structured as follows; in the next section, we present a brief survey of literature on the carbon tax by focusing on the case of Ireland. Section 3 describes the ESAM and the I3E model in a non-technical manner. Section 4 is devoted to explain the designs of the conducted scenarios, Section 4

discusses the results and Section 5 draws conclusions.

2 Literature review

For Ireland, the literature to date in this area has examined the potential introduction of a carbon tax, i.e. has focused on the pre-2009 period. [Bergin et al. \(2004\)](#), using the supply-side macroeconomic model, namely HERMES, described in [FitzGerald et al. \(2002\)](#), finds that a carbon tax would modestly reduce CO_2 emissions, mostly through power generation, and the overall macroeconomic impacts depend on how the carbon tax revenue is recycled. If the revenue was used to reduce VAT or social insurance, economic growth would be accelerated, while lump-sum transfers to households or companies would slow growth. [Conefrey et al. \(2013\)](#) examines the implementation of a €20 carbon tax, focusing on revenue recycling and double dividend applying the HERMES model. The results reveal that the effects of a carbon tax on the overall price level, real GDP, household real disposable income, and employment are small. They find evidence of a double dividend when tax is recycled through a reduction in income taxes.

A CGE analysis of [Wissema & Dellink \(2007\)](#) with 23 sectors and a single household investigates the impacts of a carbon energy tax in Ireland. They find that a €15 per tonne tax would result in a 25.8% decrease in emissions compared to levels in 1998. The main shortcomings of their framework are the absence of a distinction between ETS and non-ETS emissions, and the omission of any carbon-tax exempted sectors.

The first study investigating the economic impacts of increasing the carbon tax, [de Bruin & Yakut \(2018\)](#), conducts a static price multiplier analysis based on an Energy Social Accounting Matrix. They find that a doubling of the carbon tax to €40 per tonne of CO_2 affects the prices of diesel and petrol the most. Notably, the production sectors that drive Irish exports are relatively insensitive to a carbon tax increase, suggesting that an increase in the current carbon tax will not have significant impacts on the international competitiveness of Irish exports. Impacts on households are found to be small. The post-multiplier analysis reveals that a doubling of the carbon tax will result in less than a 5% decrease in GHG emissions.

This paper contributes significantly to the current literature as it represents the first dynamic study into the impact of increasing the Irish carbon tax in its current form. Furthermore, this paper utilises the latest available data, representing the significant changes in the Irish economy over the past decades.

3 The I3E Model

The I3E model is an intertemporal computable general equilibrium (CGE) model with multiple firms, one representative household group (RHG), multiple commodities, government, enterprises, and rest of the world accounts. The model describes how firms produce commodities, which are used as inputs to other firms' production processes or consumed by households, the government and the rest of the world. The following subsections explain the characteristics of each agent and the assumptions driving the economic

relationships among these agents in a non-technical manner. For the technical details of the model, see de Bruin and Yakut (2019).

3.1 Households

Households are represented through a single Ramsey-type representative household group. The household maximises her present discounted value of utility subject to her intertemporal budget constraint by choosing the optimal consumption path, represented as the volume of composite total consumption. A composite total consumption commodity is an aggregate of all goods consumed by the household and is created in the interests of simplification. The multiplication of the volume of composite total consumption and its price yields the household's total consumption expenditure. The difference between disposable income and consumption expenditure is private saving. The household has a Constant Relative Risk Aversion (CRRA) type utility function which ensures that the household smooths its consumption over time.

The disposable income of the household is equal to the summation of net-of-tax wage income (including social security premiums) from activities, capital income in the form of dividends from the enterprise account, unilateral and unconditional transfers from the government, net factor income receipts from the rest of the world account, and finally revenue cycling income from the government based on carbon tax collection.

Once the household has determined her optimal total consumption path, she disaggregates the composite total consumption into consumption across the various commodities for the given parameters and prices endogenously solved within the model. The disaggregation process first involves optimising consumption over the composite commodities of transportation, residential energy, nourishment, services, and other commodities. A composite consumption commodity can be treated as a bundle of commodities which are easily substitutable. Then, for example, the service composite commodity is disaggregated across the various services, i.e. the household decides how much educational services, accommodation services, financial services, etc. to consume.

3.2 Activities

The production side of the model comprises 32 representative firms (or industries) that produce multiple products, where these firms are referred to as activities. Examples of industries are agriculture, textiles, chemical producers, construction.¹ Allowing activities to produce multiple products is an important feature of the I3E since activities can change their production composition, to some extent, in reaction to changes in tax rates, international prices, demand-side conditions, etc.

Based on the Social Accounting Matrix (SAM) which is constructed using the Supply and Use Tables (SUTs), activities are divided into two types; single-product producers and multi-product producers.

¹ A full list of the activities is available in Appendix A.1.

Single-product producers are those activities that produce only one commodity or the value of production of a single commodity exceeds 95% of the total production of the activity. For these activities it is assumed that the production of each commodity is a fixed fraction of the total output. Multi-product producers are assumed to decide how much of each commodity to produce through revenue maximisation.

The activities are assumed to produce a composite product which is an aggregate of value added, business energy, and other inputs. This structure describes how the activities use value added (factors of production), business energy and other inputs to produce its final product. Value added is an aggregate of capital and labour, i.e. the factors of production, while the composite commodity of other inputs comprises all intermediate inputs besides the energy commodities, which are peat, coal, crude oil, gasoline, kerosene, fuel oil, liquid petroleum gas, diesel, electricity, natural gas, and other petroleum products. The composite commodity of business energy is an aggregate of other model-defined composite commodities, namely business heating and fuel, which are also aggregates of the aforementioned energy commodities. The substitution elasticities across energy commodities within the composite commodity of business energy differs across activities to reflect the distinct energy needs of the various production processes. For instance, the business energy of the water transportation sector is a Leontief aggregate (i.e. the elasticity of substitution is zero) of the energy commodities as diesel constitutes more than 90% of the total energy demand of the activity.

Another important characteristic of the I3E model is that the determination of investment for the majority of activities (27 out of 32), i.e. the investment by destination, is an endogenous decision based on a dividend maximisation problem. Dividend maximising activities are introduced to better represent the economic dynamics. If the investment decision is not made by activities endogenously, all model dynamics would rely on the consumers' consumption smoothing. Firms maximise the present discounted value of the firm, i.e. the dividend stream, subject to capital accumulation function. Sectoral dividend is equal to net-of-corporate tax sectoral profit minus total investment expenditure, which includes the cost of new investment equipment and the adjustment costs. Adjustment costs are an increasing and convex function of investment; for a given level of sectoral capital stock, the cost of installing new capital equipment will be greater. Adjustment cost is measured by the price of the value added since it is assumed that the installation of new capital requires an interruption of the production process resulting in losses of output. In this structure, firms choose the level of physical investment, capital stock, and labour demand. The Lagrange multiplier of this maximisation problem is the well-known Tobin's q which is the ratio of the market value of existing capital to its replacement cost [Hayashi \(1982\)](#). For the remaining five (non-dividend maximising) firms, the investment expenditure is a fixed fraction of gross profit.

3.3 Enterprises

The model includes an "enterprises" account, where a representative enterprise is assumed to be the owner of all firms. This specification helps to simplify some details of the model and also solves the issue of a lack of a sector-specific data such as corporate tax payments. The enterprise 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.

3.4 Government

The I3E model has an explicit representation of the government sector. The government collects direct taxes on labour incomes and on sectoral profits (corporate tax), indirect taxes on sales of commodities, carbon tax on energy commodities, export tax on exported commodities², and production activities. Carbon tax collected on the domestic consumption of energy-commodities is implemented as a fixed price of per-tonne equivalent of carbon, i.e. the carbon tax, $\overline{PCAR}_{c,t}$, which is exogenously determined by the government,

$$CTAXS_{c,t} = \alpha_c \overline{PCAR}_{c,t} \text{carcon}_c QS_{c,t} \quad (1)$$

where carcon_c is the carbon content of commodity c . The parameter α_c equates the carbon tax collection of the government on commodity c for the given levels of variables and parameters.

The government allocates her total revenues to consumption of commodities, transfers to households (fixed in real terms), transfers to enterprises (fixed in nominal terms), recycling of carbon tax receipts to households, and interest payments over the outstanding foreign debt stock.

The total government consumption on commodities has an autonomous part which is fixed in nominal terms and an induced part which is a positive function of the current period's nominal gross domestic product. This structure indicates that the Irish fiscal policy is pro-cyclical, and is consistent with the findings of Cronin & McQuinn (2018).

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).

3.5 Commodities

The I3E model includes 39 commodities, 37 of which are domestically produced and imported, and two of which are not domestically produced but imported.³ In the Supply and Use Tables, as the trade flows are shown by commodities, the exporter or importer activity is not known. For each commodity which is exported, a composite commodity⁴ is created whose supply comes from the productions of several activities while it is either sold in the domestic market or exported. The volume of export and domestic sales are determined by a revenue maximisation problem for the given levels of the elasticity of substitution, the share parameters, and the endogenously solved prices.

² The domestic sale of electricity is exempted from the carbon tax but its export is subject to a carbon tax. Export tax is positive only for electricity.

³ A full list of the commodities is available in Appendix A.2.

⁴ It is a constant elasticity of substitution aggregate of different products. This means that each activity's product is an imperfect substitute of another.

The supply of domestically sold commodities comes from imported commodities and domestically produced commodities, which are imperfect substitutes of each other. Total domestic demand comes from five sources; intermediate input demands of activities, private demand of households, government demand, investment demand, and trade and transportation margins. The level of intermediate input demand stems from the activities's cost minimisation problem, while the level of consumption demand stems from the household's utility maximisation problem. The government demand per commodity is a fixed fraction of the total government consumption. The investment per commodity, i.e. the investment by origin is a fixed fraction of the total investment expenditures of the activities. As the capital composition matrix which shows the sectoral capital stock's composition across commodities is unknown for the Irish economy, the composition of commodity demand by investment purpose is assumed to be fixed through time.

The last component of domestic demand comprises trade and transportation margins, which are necessary to deliver commodities from factories and docks to markets. Each commodity demands margin as a fixed fraction of its total composite supply, and the total volume of these demands is equal to the total supply of margins. The total demand is met by the trade activity in the model as the CSO announces only the trade margins, although the convention is announcing the total of trade and transportation margins separately.

3.6 Economic Growth

I3E is a dynamic model, which incorporates economic growth over the modelling horizon which runs from 2014 to 2050. Economic growth originates from three sources; the growth of employment driven by population growth, the growth in capital stock driven by investment, and finally the growth in total factor productivity which is predominantly a residual (known as the Solow residual) of the economic growth that is not explained by growth in the factors of production (labour and capital).

It is assumed that the total population grows at a constant rate and the technology, i.e. the productivity of labour force, grows at a constant rate. In the current version, the values of population growth and economic growth are retrieved from the medium-run estimates of the macroeconometric forecast model of the ESRI, namely COSMO (COre Structural MOdel for Ireland), (Bergin et al., 2017). Accordingly, the former and the later are calibrated as 0.8% and 3.3%, respectively, and implied labour productivity growth is calculated as 2.48%.

4 Results

In this section we present the results from our analysis. We first discuss the baseline results and the implementation of the carbon tax scenarios. We then discuss the results concerning energy prices, the overall economy, individual sectors and households.

4.1 Baseline

The baseline scenario is where there is no change in any policy variables/parameters; the economy is assumed to evolve according to its internal dynamics. For instance, since the internal dynamics of the I3E model are driven by the population and labour productivity growths, the Irish economy would grow at 3.3% per annum without any policy intervention. Since there are no external interventions in the economy, the baseline scenario is also called the business-as-usual path. Therefore, in the base path, the current carbon tax of €20 is continued but not increased.

The baseline of the I3E model does incorporate some significant changes in the Irish economy between 2014 and 2017. Firstly, there was an almost 50% decline in the international oil price in 2015, which also affected the prices of other oil-related commodities including kerosene, fuel oil, liquid petroleum gas, etc. On the other hand, the international price of coal had a positive trend in the same period. Such large variations in international prices, in addition to the strong economic growth profile of the Irish economy, have inevitable repercussions on demand for these fossil fuels and hence emissions. According to the Energy Protection Agency's figures, total emissions of Ireland has increased by 6.4% between 2014 and 2017 (EPA, 2018b). Moreover, changes in international prices have also affected trade and thus current account balances.

Secondly, another significant recent development in the Irish economy has been the decline in peat production, and hence consumption as only small amounts of peat are traded internationally. According to the Energy Balances, the total peat production including changes in inventories declined by 10.6% between 2014 and 2017 (SEAI, 2019). In line with the vision of a non-peat economy by 2030, the peat sector has switched her production to biomass and the total indigenous production of biomass, renewable and waste have been increased by 33.2% from 2014 through 2017.

In order to capture the effects of these issues on the Irish economy, we have applied the following changes in order to produce the baseline of I3E. International energy prices are lowered for the period of 2015-2017 and it is assumed that their values in 2018 and onwards will be equal to their values in 2017, i.e. the baseline of the model does not consider any other changes in international energy prices beyond 2018. The decline in peat production has also been introduced. Since biomass, renewable and waste commodities have not been defined explicitly in the I3E model due to lack data in order to disaggregate electricity production activity, it has been assumed that the peat sector has switched her production to electricity as peat production falls.

We now briefly discuss key results from the baseline scenario, which are relevant for interpreting the results of the carbon tax scenarios. Under the baseline scenario, we find that the decreasing international prices of carbon commodities affect the domestic purchaser, i.e. retail prices of energy commodities directly and the prices of other commodities indirectly. The domestic purchaser price of liquid petroleum gas (LPG) is the most affected with a 13.5% price reduction between 2014 and 2030, while the prices of diesel, fuel oil, kerosene, and natural gas decline by around 5% over the same period. The effect is the lowest for gasoline with a decline of around 3% in 2030, relative to its price in 2014. In line with

the positive trend of the coal price, the domestic retail price of coal increases by 40% between 2014 and 2030, which also affects the price of peat since these two commodities are almost perfect substitutes. This results in a 13.5% decrease in the price of peat between 2014 and 2030. The effects of the movements in the primary energy prices also shift the cost of production and thus the domestic price of electricity, although the price increase is relatively small (1.2% up to 2020).

Along the baseline, labour demand of the peat sector increases by on average 0.7% per annum. This increase in labour demand is lower than the growth rate of real GDP, indicating that the weight of the peat sector in total employment weakens. This is due to the government policy of transition to a non-peat economy by 2030.

As the prices of energy commodities decrease, the cost of production in all sectors decrease which, in turn, puts downward pressure on domestic prices. However, decreasing prices increase commodity demands, relaxing the downward pressures on prices. For instance, domestic purchaser prices of agricultural products, food, beverage, and tobacco, and textile slightly decline, but the magnitudes are less than 0.3%, in absolute terms.

The joint effect of declining international prices and peat production has negligible impacts on the real gross domestic product. The growth rate of real GDP slightly declines in the short-run, but it returns to its medium-run average, i.e. to 3.3%, by 2030. On the other hand, the total economy-wide emissions increase by 13.9% in 2018, relative to 2014, as declines in international prices spur demand for energy commodities in the domestic market. Moreover, under the assumption of constant energy prices (fixed at their 2017 levels) during the period of 2018-2030, the growth rate of economy-wide CO_2 emissions will reach an average of 3.32% per annum along the baseline. In other words, emissions grow at a slightly higher rate than GDP.

4.2 Carbon Tax Scenarios

In CGE modelling, a change in a policy variable/parameter or a set of policy variables/parameters is defined as a shock process or scenario. The effects of the scenario are given as the paths of variables that are solved within the model and are reported in terms of a percentage change with respect to the baseline. To investigate the impacts of an incremental increase in the carbon tax, we develop two carbon tax scenarios. In the first scenario, namely *CT1*, the carbon tax per ton equivalent of CO_2 is increased to €40 in 2019 and then increased by €5 per annum reaching €95 in 2030. In an alternative policy scenario, namely *CT2*, the carbon tax per ton equivalent of CO_2 is increased to €40 in 2019 and then increased by €10 per annum reaching €150 in 2030.

In the following subsections, the results of scenarios defined above will be presented relative to the baseline. The main results from the baseline that should be kept in mind when interpreting the scenario results are the decline in energy prices and strong economic growth.

4.3 Energy Prices

We first examine how the implementation of a higher carbon tax impact the prices of energy commodities. Table 1 shows the percentage changes in energy commodity prices for 2019, 2020, 2025 and 2030 compared to the baseline. Note that along the baseline, all prices of the major energy commodities decline, relative to their levels in 2014, due to the downward international trend. However, incremental increases in the carbon tax reverse this downward trend significantly.

Table 1: Changes in Purchaser (Retail) Prices of Energy Commodities
percentage changes with respect to baseline

	Peat		Coal		Gasoline		Kerosene	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	2.72	3.67	3.54	4.22	4.82	5.50	2.99	3.68
2020	3.02	4.30	4.17	5.46	5.77	7.38	3.48	4.64
2025	4.49	7.77	7.35	11.76	10.55	16.87	5.96	9.54
2030	5.91	11.47	10.59	18.20	15.39	26.48	8.51	14.59
	Fuel oil		LPG		Diesel		Natural gas	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	1.93	2.66	6.41	7.08	6.40	7.08	3.09	3.85
2020	2.14	3.06	7.76	9.77	7.75	9.76	3.60	4.84
2025	3.25	5.09	14.57	23.34	14.55	23.32	6.18	9.88
2030	4.37	7.11	21.46	37.10	21.43	37.07	8.82	15.03

Along the scenario path of *CT1* (€40 in 2019 and increasing by €5 each year after that), the results show that the prices of gasoline, diesel, and LPG are particularly impacted. With an over 6% increase in the price of diesel and LPG in 2019, rising to a more than 20% in 2030. Gasoline prices increase by almost 5% in 2019 and over 15% in 2030. Though a significant portion of coal used is exempt from the carbon tax of €20 and imposed a minimum fee of €4 per tonne of carbon, we assume here that this minimum charge increases in line with the carbon tax. The resulting impacts on coal prices are an increase of more than 3% in 2019 and more than 10% in 2030. The prices of kerosene and natural gas also increase quite sharply by 3% in 2019 and more than 8% in 2030. The price of peat increases by almost 3% in 2019 and 6% in 2030. As domestic peat production declines, the price of peat increases due to slow switching process in the consumption profiles of final users. Fuel oil is the least impacted, with a less than 2% increase in 2019 and more than 4% in 2030. Naturally, the magnitudes of price increases are larger along the path of *CT2* than the path of *CT1*. These are shown to illustrate the potential impacts of a further increase in the carbon tax and to illuminate whether there are any non-linearities in the impacts. The results show that prices increase uniformly with the carbon tax increases, meaning that doubling the carbon tax will result in approximately double the price impacts.

4.4 Impacts Across Sectors

Here we examine the impacts across sectors of an increasing carbon tax. Though some sectors will experience significant negative impacts from a carbon tax increase, others will benefit. Changes in the sectoral value-added of the major carbon-emitting sectors (and hence the largest users of carbon commodities) are shown in Table 2. The transportation sectors and petroleum production are the most negatively affected sectors due to the increasing costs of production. The water transportation sector has no substitution opportunity across energy commodities due to the structure of production. As the sector's demand on diesel is inevitable and diesel is the most affected commodity concerning changes in its price, the decline in the economic activity of the water transportation sector is significant.

Table 2: Changes in Value-added of Selected Activities
percentage changes with respect to baseline

	Agriculture		Chemical Prod.		Basic Pharm. Prod.		Food-Bev.-Tobacco	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	0.08	0.13	0.23	0.35	0.24	0.37	0.06	0.12
2020	0.09	0.14	0.28	0.42	0.30	0.45	0.07	0.12
2025	0.14	0.23	0.53	0.82	0.58	0.89	0.12	0.18
2030	0.19	0.31	0.79	1.24	0.86	1.34	0.18	0.28
	Peat		Petroleum		Electricity		Public Trans.	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	-2.93	-3.28	-2.81	-3.31	-0.72	-0.88	-1.12	-1.21
2020	-3.48	-4.43	-3.47	-4.48	-0.89	-1.19	-1.41	-1.76
2025	-6.10	-10.06	-6.59	-9.79	-1.74	-2.68	-2.86	-4.42
2030	-8.45	-15.27	-9.36	-14.24	-2.52	-4.02	-4.25	-6.86
	Accom & Hotels		Financial Ser.		Health		Water Trans.	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	0.54	0.71	0.16	0.24	0.14	0.07	-2.13	-2.19
2020	0.60	0.84	0.20	0.29	0.19	0.18	-2.65	-3.18
2025	0.87	1.37	0.39	0.60	0.42	0.64	-5.06	-7.46
2030	1.08	1.76	0.59	0.92	0.59	0.95	-7.17	-10.85

On the other hand, chemical products, basic pharmaceutical products, food, beverage, and tobacco, accommodation and hotels, and financial services are affected positively as households and firms switch their consumption patterns towards less energy-intensive commodities.

Sectoral labour demands also change in line with declining sectoral economic activities as can be seen in Table 3. Notice that the dramatic decline in the labour demand of peat sector comprises not only changes in the carbon tax but also the effects of switching of peat production to electricity. Notice that although peat production declines, the sectoral employment has an upward trend along the baseline. On the other hand, increasing the carbon tax reverses this process and leads to a decline in sectoral employment and allows the Irish economy to reallocate the employees in the peat sector to other sectors. It is also evident from Table 3 that services sectors, chemical products, and basic pharmaceutical products

increase their labour demands, in line with the increasing volumes of sectoral value added.

Table 3: Changes in Labour Demand of Selected Activities
percentage changes with respect to baseline

	Agriculture		Chemical Prod.		Basic Pharm. Prod.		Food-Bev.-Tobacco	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	0.15	0.30	0.37	0.56	0.42	0.61	0.07	0.20
2020	0.14	0.27	0.43	0.64	0.49	0.72	0.05	0.15
2025	0.09	0.16	0.73	1.13	0.86	1.32	-0.01	0.00
2030	0.07	0.12	1.07	1.67	1.25	1.95	-0.01	-0.03
	Peat		Petroleum		Electricity		Public Trans.	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	-4.79	-4.36	-4.04	-4.04	-0.96	-0.83	-1.55	-1.43
2020	-6.13	-6.94	-5.01	-5.92	-1.23	-1.37	-1.97	-2.26
2025	-12.66	-18.64	-9.50	-14.01	-2.55	-3.86	-4.03	-6.17
2030	-18.89	-28.73	-13.42	-20.36	-3.79	-6.08	-5.97	-9.66
	Accom & Hotels		Financial Ser.		Health		Water Trans.	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	0.64	0.84	0.21	0.28	0.15	0.07	-2.50	-2.44
2020	0.70	0.98	0.25	0.34	0.21	0.20	-3.12	-3.64
2025	0.99	1.56	0.46	0.70	0.47	0.71	-5.95	-8.74
2030	1.22	1.99	0.70	1.09	0.65	1.05	-8.39	-12.69

4.5 Macroeconomic Impacts

In this section we discuss the overall macroeconomic impacts of an increasing carbon tax. Table 4 shows the percentage changes in selected macroeconomic aggregates up to 2030 along the two carbon tax scenario paths with respect to the baseline. The results indicate that incremental increases in the carbon tax have insignificant effects on the level of real GDP. For example, along the path of *CT1*, the real GDP decreases by 0.5% by 2030, relative to its level along the baseline. Similarly, *CT2* with an incremental increase in the carbon tax by €10 towards 2030 affects the level of real GDP by 0.66%. The results indicate that the growth rate of real GDP drops to 3.28% and 3.27%, respectively, in the medium-run from its medium-run projection of 3.3%. Comparing *CT1* and *CT2*, it is evident that a carbon tax that increases at twice the rate does not double the impact on GDP. The increase in the overall consumer price index, i.e. the overall cost-of-living, increases by less than 2% until 2025 and reaches to 2.5% in 2030, relative to the baseline, along the path of *CT1*.

Although the price elasticities of energy commodities are low, their domestic consumptions (variable $QS_{c,t}$ in equation 1) decline as the carbon tax rises. However, as the relative changes in carbon tax outweigh the declines in quantities, the total carbon tax collection of the government increases, relative to its baseline level. Note that in the baseline there was a positive trend in carbon tax collections due to increasing domestic consumption. Along the path of *CT1*, the total carbon tax collection of the government in nominal terms doubles in 2020, triples in 2025, reaching 3.8 fold its baseline level in 2030. On the other

hand, it reaches 2.3, 3.95, and 5.23 fold its baseline level along the path of *CT2*.

Table 4: Changes in Main Macroeconomic Aggregates
percentage changes with respect to baseline

	Real GDP		Real Gov. rev.		Debt-to-GDP Ratio		Carbon Tax Rev.*	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	-0.30	-0.36	-0.30	-0.32	-3.08	-4.98	87.78	87.82
2020	-0.31	-0.39	-0.35	-0.40	-2.76	-4.72	108.00	127.74
2025	-0.40	-0.52	-0.64	-0.80	-0.91	-2.19	200.23	295.49
2030	-0.49	-0.66	-0.94	-1.20	0.98	0.84	279.84	423.07
	Capital Stock		Overall CPI		Wage Rate*		Real Trade Bal.	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	-0.37	-0.60	1.47	2.21	0.93	1.58	-0.10	-0.21
2020	-0.36	-0.57	1.55	2.36	0.92	1.54	-0.07	-0.18
2025	-0.29	-0.46	1.98	3.17	0.89	1.45	0.20	0.18
2030	-0.23	-0.37	2.47	4.10	0.93	1.50	0.67	0.90

Note: The variables in real terms are measured in 2014 prices. The variables with the sign “**” are in nominal terms.

Along both carbon tax scenario paths, the total tax collections on both production and domestic sales decrease in real terms. Tax collections on production decrease by around 5% due to a decline in economic activity and tax collections on domestic sales decrease by around 2% due to the decline in domestic consumption. Since the share of the carbon tax in total revenues of the government is quite low in 2014 (around 2.3%), the total government revenue declines in real terms. The effects are within the range of 0.95% and 1.2%, relative to the baseline, along the scenario paths of *CT1* and *CT2*, respectively.

The results show an initial improvement in the debt-to-GDP ratio, however, towards the medium-run, the public savings decline and the debt-to-GDP ratio increases, although the effect is less than 1%. The initial improvement is due to an increase in nominal GDP. Though economic activity slows down in real terms, increasing commodity prices lead to a higher nominal GDP and a lower debt-to-GDP ratio. The nominal GDP growth is boosted by government expenditure behaviour. Firstly, as the GDP increases, government consumption also increases due to its pro-cyclical behaviour and, in turn, refuels the GDP growth. Secondly, as the overall CPI increases, the government’s unilateral transfers to households also increase, increasing households’ consumption. Thirdly, the government’s revenue cycling scheme also increases household disposable income. In the very short-run, the increase in GDP outweighs the increase in government’s total expenditures and the debt-to-GDP ratio declines. In the medium run government expenditures increase further, resulting in a decline in the public savings and an increase to debt-to-GDP ratio.

Increasing labour demand due to a shift towards consumption of services, which are more less carbon intensive and more labour intensive, rises the wage rate, increasing wage income of households.⁵

⁵ Note that the current version of the I3E does not include the labour supply decision of households or unemployment. Therefore, increasing wage rate has entirely transmitted to an increase in wage income of household since they have a perfectly

Although the cost of labour increases, firms also lower their capital demand due to declining economic activity.

The real trade balance, i.e. the net exports in 2014 prices, slightly declines in 2019 and 2020 after the sharp increases in the carbon tax. However, the incremental increases in the carbon tax have positive impacts on the trade balance of Ireland, with an increase of up to 0.9% in 2030, relative to the baseline. In other words, the Irish economy is able to absorb the cost-push effects of increasing carbon tax in 5 years.

4.6 Emissions Impacts

Table 5 shows the changes in emissions of the selected major emitter sectors, in addition to the residential emissions and the total economy-wide emissions.⁶ The emissions provided in Table 5 include total sectoral emissions. Changes in the sectoral emissions, which are calculated based on their intermediate input demands are substantial for the transportation sectors, peat, electricity, and petroleum sectors which also saw declines in their economic activities, as shown in Table 2. However, although the value-added

Table 5: Changes in Emissions
percentage changes with respect to baseline

	Agriculture		Peat		Petroleum		Residential	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	-8.33	-8.20	-14.15	-16.32	-4.48	-4.68	-2.56	-2.51
2020	-10.27	-12.00	-16.91	-21.97	-5.50	-6.63	-3.23	-3.83
2025	-19.08	-27.72	-29.33	-44.08	-10.20	-15.04	-6.52	-10.11
2030	-26.55	-39.32	-39.73	-58.56	-14.30	-21.66	-9.64	-15.85
	Electricity		Pub Transp.		Water Transp.		Economy-wide	
	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
2019	-4.67	-4.80	-11.01	-10.96	-11.59	-11.57	-5.23	-5.27
2020	-5.73	-6.90	-13.51	-15.82	-14.19	-16.62	-6.46	-7.66
2025	-10.73	-16.41	-24.65	-35.33	-25.66	-36.50	-12.17	-18.07
2030	-15.25	-24.45	-33.86	-49.00	-34.99	-50.10	-17.21	-26.39

of agriculture increases (due to increased demand), total carbon emissions of agriculture decline which indicates that the sector switches its intermediate input demands towards non-energy commodities, to some extent, and its energy demand to electricity.

The residential emissions, i.e. the emissions based on residential heating and lighting, drops by around 3% in the short-run, along both carbon tax scenario paths. This predominantly due to decreasing energy demand of households, but there are limited amounts of switching towards less-carbon intensive energy commodities. The effects become more prominent in towards 2030 and reaches almost 16% along the path of *CT2*.

inelastic supply of labour. However, a labour market distortion may cause the opposite result depending on the modelling choice and the level of rigidity in the labour market.

⁶ Since the introduction of the Emission Trading System (ETS) to the I3E framework is still in progress, the sectoral emissions in the distinction of ETS and non-ETS cannot be reported.

The most important implication of increasing carbon tax is a decline in economy-wide emissions by 17.2% and 26.4% by 2030, along the carbon tax scenario paths, respectively. In other words, the annual average growth rate of total emissions drop to 3.27% and 3.24%, along the paths of *CT1* and *CT2*, respectively. This indicates that emissions grow at a lower rate than GDP. The total economy-wide CO_2 emissions of Ireland reach 51.6 and 45.9 million ton equivalent by 2030 along the carbon tax scenarios paths, respectively. These results indicate that the carbon tax breaks the link between carbon emissions and economic growth which helps Ireland in her transition to a decarbonised economy. It should also be noted that the level of the economy-wide emissions was 48.1 million ton equivalent of CO_2 in 2005. The economy-wide emission figure by 2030 indicates that the total Irish emissions will be 7.2% higher than its 2005 emissions if the government follows the path of *CT1*. On the other hand, along the path of *CT2*, the economy-wide emissions will be 4.6% lower in 2030. These results indicate that Ireland will not reach its EU targets with a carbon tax alone, even she follows the path of *CT2*.

4.7 Household Impacts

In this section, we discuss how households will be impacted by an increasing carbon tax. For the household sector, the I3E model defines several composite commodities such as transportation, residential energy and residential heating. Table 6 shows the changes in the household-specific prices of these composite commodities, and also the changes in the overall consumer price index. Accordingly, the cost of transportation increases by less than 5% in the short-run and the effect is slightly more than 10% along the path of *CT1*. The increase in price of residential heating is higher (8.3% in 2030 for *CT1*) than the increase in price of residential energy (6.2% in 2030) due to the fact that the substitution elasticities across the commodities in the former is lower than those of in the latter. As the price of residential energy increases (middle-lower panel of Table 6), households consume less residential energy (left-upper panel of Table 6).

Table 6: Household Level Results
percentage changes with respect to baseline

	Residential Energy		Real Disp. Income		Real Consumption	
	CT1	CT2	CT1	CT2	CT1	CT2
2019	-2.10	-2.04	-0.23	-0.35	-0.20	-0.17
2020	-2.67	-3.15	-0.24	-0.36	-0.26	-0.29
2025	-5.50	-8.52	-0.26	-0.40	-0.60	-0.89
2030	-8.22	-13.48	-0.28	-0.43	-0.98	-1.56
	Changes in Prices					
	Transportation		Residential Energy		Residential Heating	
	CT1	CT2	CT1	CT2	CT1	CT2
2019	3.53	4.25	2.42	3.16	2.97	3.70
2020	4.14	5.46	2.75	3.81	3.44	4.63
2025	7.24	11.51	4.46	7.14	5.84	9.35
2030	10.36	17.57	6.20	10.54	8.28	14.13

Table 6 also provides the results of changes in household disposable income and real consumption of households. i.e. changes in the level of the composite commodity. Although nominal disposable income of households increases due to both increases in wage income and recycling of carbon tax revenues by the government, real disposable income decreases due to inflation. Theoretically, households have pre-cautionary savings; as they observe an adverse shock in the economy, they smooth their nominal consumption expenditures to keep the level of utility constant through time and increase their savings. As prices increase due to an increasing carbon tax, Irish households lower their real consumption and increase their savings in nominal terms with the help of increasing nominal disposable income.

5 Conclusion

Ireland is under significant pressure to reach her EU GHG emissions targets for 2020 and 2030. Designing efficient and effective climate policies is imperative to achieve these targets. A carbon tax is considered the cornerstone of an effective climate policy, where pricing carbon usage results in economically efficient emission reduction, i.e. reductions are made where they have least impact on the economy. A mayor concern when implementing a carbon tax increase, is its impact on households. Several suggestions have been put forward to lighten the burden felt by households, the most notable of these is the concept of recycling carbon tax revenues back to households. Currently, the Irish carbon tax stands at 20€ per tonne of CO_2 , in this paper we examine the economic and emission reduction impacts of an incremental increase in the Irish carbon tax. Understanding the economic impacts and emission reduction potential of an increase in the carbon tax as well as the potential of a revenue recycling scheme to assist households is essential for formulating a sound carbon tax policy in Ireland.

In this paper we develop a computable general equilibrium model; the Ireland, Environment, Energy and Economy (I3E) model. This model uses data to describe the interactions between various production sectors, the government, the rest of the world and households. In this manner it can estimate sector level impacts as well as macroeconomic impacts of a carbon tax increase. Applying I3E, we examine two potential carbon tax paths including a revenue recycling scheme of a lump transfer of carbon tax revenues to households. In the first, the carbon tax is set to €40 in 2019 and then increased by €5 per annum until 2030. In other words, the carbon price per ton equivalent of CO_2 emission is doubled in 2019, relative to 2018, and again doubled in 2027, relative to 2019. In order to provide a policy alternative, the carbon tax is set to €40 in 2019 and then increased by €10 per annum until 2030. In other words, the carbon price per ton equivalent of CO_2 emission is doubled in 2019, tripled in 2021, four-folded in 2023, relative to its level in 2018.

Our results show that energy and transport sectors will be hit hardest by an increase in the carbon tax, while chemical products, basic pharmaceutical products, food, beverage, and tobacco, accommodation and hotels, and financial services benefit the most. Due to a consumption shift towards services, which are less carbon intensive, but more labour intensive, labour demand with a concomitant increase in wages. The overall macroeconomic impacts, i.e. GDP impacts, are negligible.

Households face significantly higher energy prices, overall price levels, however, increase only moderately. Due to the increased wages and government transfers from the carbon tax revenue recycling scheme, households' nominal disposable income increases. Though disposable income increases, due to price increases households decide to consume less and save more. Due to higher overall price level, i.e. the cost-of-living, real disposable income decreases, although the effect is less than 0.3% in 2030.

Concerning the potential emission reductions of an increased carbon tax, our estimates show that an increased carbon tax can reduce emissions significantly. Due to the strong projected economic growth, however, even a stringent carbon tax path will not bring Ireland close to her emissions targets.

Though the I3E model presents a significant improvement to the literature on the impacts of an Irish carbon tax, further research is needed to address the shortcomings of the modelling framework applied here. Firstly, a more detailed representation of the ETS sector, including future ETS price projections, would need to be developed to fully understand the potential impacts of an increased carbon tax. Secondly, international energy price projections should be included to present a more realistic representation of energy prices. Finally, a distinction between household types would allow for a better understanding of the distributional impacts of an increase in the carbon tax.

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Appendix A Lists of Activities and Commodities

Table A.1: Activities

Abbreviation	Name	NACE Codes	σ_{BEN}	σ_{FUE}	σ_{BH}	σ_{OTE}
ACC	Accommodation and Hotel Services	55-56,79	1.3	0	0	
AGR	Agriculture	1-3	1.3	0	0	
ATS	Air Transportation	51	0	1.1	1.1	
BFM	Basic Metal Manufacturing	24-25	1.3	1.1	1.1	
BPP	Basic Pharmaceutical Products	21	1.3	0	0	
CHE	Chemical Products	20	1.3	1.3	1.3	
CON	Construction	41-43	1.3	0	1.3	
EDU	Education Sector	85	1.3	1.1	1.3	
FBT	Food, Beverage and Tobacco	10-12	1.3	1.3	1.3	
FSR	Financial Services	64-66,77	1.3	0	0	
HHS	Health Sector	86-88	1.3	1.1	1.1	
HTP	High-Technology Products	26-28	1.3	1.3	1.3	
LTS	Land Transportation	49	1.1	0	1.1	
NGS	Natural Gas Supply		0	1.1	0	
OIN	Other Industrial Products	17,18,33	1.3	1.3	1.1	
OMN	Other Mining Products		1.3	1.1	1.3	
ONM	Other Non-metallic Products	23	1.3	1.1	1.3	
OTM	Other Manufacturing	31-32	1.1	1.3	0	
PEA	Peat		1.3	1.1	1.3	
PET	Petroleum		0	0	0	
PUB	Public Sector	84	1.3	1.1	1.3	
RES	Real Estate Services	68	1.3	0	0	
RUP	Rubber and Plastic Products	22	1.3	1.3	1.1	
SER	Other Services	remaining*	1.3	0	0	
TEL	Telecommunication Services	61	1.3	0	0	
TEX	Textile	13-15	1.3	1.3	1.1	
TRD	Trade	45-47	1.3	1.3	0	
TRE	Transportation Equipment	29-30	1.3	1.3	0	
WAT	Water and Sewerage	36,37-39	1.3	1.3	1.1	
WTS	Water Transportation	50	0	0	0	
WWP	Wood and Wood Products	16	1.3	1.1	0	
ELC	Electricity		1.1			1.3

*: 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 A.2: Commodities

AGR	Agriculture	BFM	Basic Metal Manufacturing
PEA	Peat	HTP	High-Tech 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 Sector
CHE	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

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