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Macroeconomic impacts of climate-induced damages in Ireland: a CGE analysis of secondary impacts

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ABSTRACT

Designing and implementing effective and efficient climate policies requires an understanding of climate change impacts. However, the estimation of climate change impacts remains lacking, without an understanding of the sectoral details of climate change impacts and their further impacts on the wider economy. In this paper, we apply a production function approach to implement several climate change impacts into an intertemporal computable general equilibrium (CGE) model of the Irish Economy, the I3E model. Our results show that, without adaptation, coastal impacts on the macroeconomy will be the highest, followed by labour productivity impacts. Examining different household types, we find that richer households are impacted more than poorer. In this paper we account for interlinkages between sectors, and show how climate change impacts impact other parts of the economy, which is neither clearly assessed in econometric assessments within the literature, nor in classic Integrated Assessment Models with few consisting of production sectors.

Keywords

Climate change, macroeconomy, impact assessment, CGE modelling, Ireland

1 INTRODUCTION

Anthropogenic greenhouse gas (GHG) emissions from production and consumption in our societies have led to increased GHG concentrations, changing our climate. Climate change is the greatest environmental problem of our time, causing sea level rise, temperature increases and more variability in climate. These climatic changes, in turn, have increasing impacts on societies and economies, affecting, including human health, the occurrence of droughts, floods and other natural disasters, agricultural production and coastal infrastructure. Even if GHG emissions were to be drastically reduced starting today, the world economy is already committed to significant income losses (IPCC, Wenz 2024). Part of these losses can be addressed by adaptation policies, i.e. policies that target the implementation of action which will reduce the impacts associated with a given level of climate change.

Designing and implementing effective and efficient climate policies requires an understanding of climate change impacts and the impacts of climate policies. Applied economic models can be useful tools with which to investigate the benefits and costs of climate policies. These models can estimate the costs of climate change impacts over the medium to long term and the costs of climate policies and their related benefits. Applied modelling in the form of Integrated Assessment models (IAMs) and Computable General Equilibrium (CGE) models have played a significant role in advising mitigation policymaking. The first economic IAM and CGE models examining energy and mitigation policies were developed in the late 1980s and early 1990s, and their application have been countless since. However, adaptation has received far less attention both in the policy and economic modelling spheres, where the first IAMs and CGE models, including adaptation policies, were only developed in the last fifteen years.

CGE models mathematically reproduce the structure of the economy in its entirety, including productive sectors, households, and the government, among others. The nature of all existing economic transactions among households, productive sectors and the government are quantified. As prices change due to policies, producers/consumers change their behaviour in order to maximise their profits/utility given their budget constraints. The explicit modelling of sectorial 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. CGE modelling is highly useful for policy design and evaluation, specifically when policy measures are expected to lead to indirect, as well as direct, effects, as in the case of energy-related policies. CGE models have been applied extensively to examine mitigation policies, particularly in a national context. Their application to examine both climate change impacts and adaptation policies remains limited.

Investigating climate change impacts and adaptation policies within a CGE framework would allow for a better understanding of the economy-wide impacts of climate change and adaptation options. However, the estimation of climate change impacts remains limited. In this paper, we aim to help fill this gap in the literature by including several climate change impacts and adaptation options in an intertemporal CGE model of the Irish Economy, the Ireland-Environment-Energy-Economy (I3E) model. To our knowledge, this is the first application of impacts and adaptation in an intertemporal CGE model.

Applying a production function approach, we implement several climate change impacts into the I3E model. River flooding and coastal impacts are implemented as a decrease in capital by applying a higher depreciation rate of capital. Labour productivity impacts are implemented by applying a negative shock to the productivity of labour. Health impacts are implemented as an increase in health services expenditures by households and the government. Agricultural impacts are implemented as a total factor productivity increase for primary agriculture.

Our results show that firstly, without adaptation, coastal impacts on the macroeconomy (real GDP and employment) will be the highest followed by labour productivity impacts. In terms of household income, most impacts are generally progressive. We find that the initial impacts are much smaller for river and coastal impacts than the secondary impacts while the opposite is true for agricultural and health impacts, though the directions (positive and negative) of initial and secondary impacts differ in the latter two scenarios.

The paper is structured as follows. The next section provides an overview of the existing literature on the macroeconomic impacts of climate change and adaptation options. The third section describes the methodology employed in the study, including a description of the I3E model and how the climate damages and adaptation costs were introduced into the model. The fourth section presents the simulation results, analysing the costs of climate-induced damages and adaptation measures. The fifth section discusses the policy implications of the findings and identifies potential avenues for future research. Finally, the paper concludes by highlighting the importance of addressing the challenges posed by climate change and the need for concerted action at the national and international levels.

2 RELATED LITERATURE

Economic sectors can face output losses from climate change through multiple channels. First, weather affects plant growth and thus directly affect agricultural productivity. The observed increase in average temperature and in the frequency and intensity of extreme weather events (such as droughts) tends to harm agricultural production in already hot areas, but can also increase the growing season and benefit to the sector in Northern areas of the globe such as in Ireland (Ref). Other outdoor exposed sectors, such as the construction or transportation sector are harmed by extreme weather events, through labour supply and productivity losses, total factor productivity or damages to assets and infrastructures. Health impacts lead to increases health expenditures, but also impacts on labour productivity.

Economy-wide models, which consider interactions and interdependencies among various sectors, agents, and markets within an economy, are used to assess the macroeconomic impacts of climate change and different policy options. Two primary types of models, computable general equilibrium (CGE) and integrated assessment models (IAM), are commonly employed for this purpose. While both types aim to assess the impacts of climate change and policy measures, they differ in scope and level of detail.

CGE models mainly focus on the economic impacts of climate change and the costs and benefits of different policy options for the economy. These models simulate interactions between different economic sectors, households, and firms in response to changes in prices and income (Roson & Mensbrugghe, 2012; Dellink et al., 2019). On the other hand, IAM models are more comprehensive and include economic, social, and environmental factors. They capture the interactions between the economy, environment, and society and evaluate the long-term impacts of climate change and policy options (de Bruin et al., 2009).

In terms of the level of detail, CGE models are highly detailed. They are designed to capture the interactions between different sectors of the economy and rely on input-output tables that provide a detailed breakdown of the flows of goods and services between various sectors. In this framework, climate change impacts can therefore be incorporated with great details regarding their sectoral diversity and the different channels. Conversely, IAM models operate at a lower level of detail and often use simplified representations of the economy and the environment. This is because they must incorporate many complex factors and interactions, which can be challenging to adequately represent (Sue Wing & Lanzi, 2014; Piontek et al., 2021). As a result, IAM models mostly consider climate change impacts through a damage function specifying a general relationship between temperature and income losses. Therefore, CGE models are more appropriate to analyze climate change impacts in detail and account for their diffusion in the economy..

Linking climate damages and adaptation costs to economic activities in a CGE is a nuanced endeavour, particularly given the heterogeneity of impacts and the challenge of distinguishing between damages and the costs of adapting to climate-induced shocks to the economy (Sue Wing & Lanzi, 2014a). Two methods are commonly used: the enumerated bottom-up and the modelled bottom-up or production function approaches (Piontek et al., 2021). The enumeration approach separately evaluates damages from each impact channel, such as agriculture and sea-level rise. This can be done through various methods, including econometric analysis, coupling biophysical impact models with a computable general equilibrium (CGE) model, or using literature-based relations to estimate the impact of temperature changes on the specific channel. Once the damages from each impact channel are assessed, they are summed up to provide an aggregate estimate of the macroeconomic losses from climate change. For instance, (Roson & Sartori, 2016) derived estimates of climate damages by analysing peer-reviewed empirical studies that used different methods, including biophysical and econometric models. The climate damage estimates were introduced in a CGE using appropriate variables and parameters (e.g., factor productivity). They found that the combined impact of climate change (including agricultural productivity, sea level rise, human health, heat effect on labour productivity, households' energy demand, and tourism flows) on Ireland will result in a 0.69% increase in GDP under a 3^{o}C warming scenario. On the other hand, in the production function approach, climate damages are simultaneously linked to variables and parameters in agents' production and demand functions. Such changes influence input demands and output supplies, leading to shifts in market equilibria for factors and commodities. Impacts due to coastal and river flooding have been simulated as decreases in the availability of land as well as damages to physical capital (Eboli et al., 2010; Ciscar et al., 2011; Bosello et al., 2012; Kompas et al., 2018). Agricultural crop yields have been simulated as changes in land productivity and total factor productivity, while labour productivity impacts have been simulated as decreases in the parameter for labour productivity (Kompas et al., 2018; Dellink et al., 2019). Health-related impacts have been modelled as increased private and public health expenditure on demand (Eboli et al., 2010; Dellink et al., 2019).This study uses the production function approach and the I3E model to assess the magnitude and distribution of climate-induced damages and adaptation costs in Ireland. The shocks are derived from an analysis conducted by de Bruin et al. (2024).

3 METHODOLOGY

3.1 THE I3E MODEL

The I3E model is a multi-sectoral, multi-household, single-country small open-economy intertemporal CGE model. The following subsections explain the characteristics of each agent in a non-technical manner. Its technical description and the details of the Irish Energy Social Accounting Matrix (ESAM) used to calibrate the model are available in de Bruin & Yakut (2021a) and de Bruin & Yakut(2021b), respectively.

3.1.1 Households

The model has ten distinct Ramsey-type representative household groups (RHGs) based on the area of residence (urban and rural) and disposable income (quintiles). RHGs maximise their present discounted utility by choosing the optimal volume of total composite consumption. The disposable income consists of net-of-tax factor incomes (wage and dividend), welfare transfer and pensions from the government, and net factor income from the rest of the world.[1] The compositions of private consumption expenditures (across RHGs and commodities) and disposable income items (across RHGs) are retrieved from the Household Budget Survey (HBS) and the Survey on Income and Living Conditions (SILC), respectively.

3.1.2 Activities

The model includes 37 representative firms (or industries/activities) producing 42 commodities, including ten energy commodities. Thirty-three of these sectors maximise the present discounted value of their dividend stream, i.e., the firm's value, by choosing the investment, sector-specific capital, and labour inputs subject to the usual capital accumulation function. This is an extended profit maximisation problem with two features: *i)* the level of physical investment is a choice variable, and *ii)* is intertemporally solved. The firm's value equals the multiplication of the sector-specific capital stock and the well-known Tobin's *q*. For the remaining four (non-dividend maximising) firms, the investment expenditure is a fixed fraction of gross profit. Having intertemporal investment decisions is not a common modelling choice as the bulk of the CGE literature utilises static or recursive dynamic models. Our approach is similar to those used in Goulder (1995) and Goulder & Hafstead (2013), which, in addition to their retained earnings, also allows firms to finance their investment expenditures by issuing new shares and borrowing. Due to the absence of these two options, our approach is more similar to Diao et al. (1999). Our approach differs from these studies since there are non-dividend maximiser firms for which Tobin's *q* is calibrated less than 1.

3.1.3 Government

The total government collects direct and indirect taxes on economic activity and production and also receives half of the total cost of the EU-ETS due to the EU legislation. Government expenditures are public demand for commodities, transfers to households (welfare transfers and pension payments), and interest payments over the outstanding foreign debt stock. The total budget of welfare transfers is a positive function of both the aggregate unemployment rate and overall price level, measured by the consumer price index (CPI), whereas the total pension payments are indexed only to CPI. The welfare budget determination rule is important as the welfare system plays a cushioning role in the case of increased unemployment via unemployment benefits in the case of Ireland (Doorley et al., 2021), which is also confirmed by Yakut & de Bruin (2023)in a CGE setting. Government demand for commodities, by following Cronin & McQuinn (2018), has two components: an autonomous part, fixed in nominal terms, and an induced part, a positive function of nominal GDP. Government savings, the total revenues minus the total expenditures, govern government foreign debt stock.

3.1.4 Dynamics and Equilibrium

In the I3E model, the economic and population growth rates are retrieved from the medium-term projections of Bergin et al. (2017), which are 3.3% and 0.08% per annum, respectively. The implied labour productivity growth is 2.48%. All variables are calibrated based on these growth rates under a balanced growth path assumption. As an intertemporal model, the equilibrium requires both intra-period and terminal conditions. The intra-period conditions are based on the usual supply and demand equilibrium; any market has no excess demand or supply, including factor markets. There are five

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[1] Wage income tax includes social security payments of employees and employers and income tax.

terminal conditions: the value of the sectoral dividend must be equal to the return of a risk-free asset, the level of investment of each firm must be equal to the level of depreciation, government savings must cover the interest payments over the existing foreign debt stock, foreign asset holdings of households are constant, and, finally, there is no arbitrage across different assets in the economy.

The closure rule on the government accounts implies that its savings must be zero in the terminal period, and the total government consumption expenditure adjusts, which reduces the adverse welfare impacts compared to the tax rate adjustments (Holmøy & Strøm, 2013). Due to the evidence of how government expenditures evolve in Ireland, we cannot fix the government size, which has welfare implications when public goods do not appear in the utility function of households (Rausch et al., 2011). However, the level of government savings-to-GDP ratio determines the risk premium value, making the foreign and domestic interest rates different. As the latter appears both in the Euler equation (governing household consumption) and investment function (affecting the dividend maximiser firms' investment decisions), government deficit changes affect the other agent's intertemporal decisions. Zero government savings in the terminal period also ensures no-arbitrage condition.

3.2 INCLUSION OF IMPACTS IN I3E

In this paper, we include estimated climate change impacts from agriculture, labour productivity, coastal flooding, riverine flooding, and healthcare. Estimates of impacts are taken primarily from (de Bruin et al., 2024), which we will shortly discuss here. Note that this is by no means a comprehensive list of climate impacts in Ireland, where various impacts are not included, such as impacts to ecosystems, energy demand and extreme events.

3.2.1 Climate Impacts

One of the major concerns related to climate change is its impact on river flooding (Winsemius et al., 2013; IPCC, 2023). As our climate continues to warm, there is an increasing risk of more frequent and intense precipitation events, resulting in overflowing rivers and a greater likelihood of flooding. The impacts of climate change on river flooding are complex and influenced by various factors such as hydrology and geography. To assess the direct economic impacts of river flooding on infrastructure, the GLOFRIS (i.e., GLObal Flood Risks with IMAGE Scenarios) model is commonly used. This global grid-based framework covers all major river basins worldwide and encompasses the three key factors that influence flood risk: hazard (which involves expected climate shifts or climate projections), exposure (representing socioeconomic variables like GDP and population), and vulnerability (such as flood protection standards or measures of flood adaptation)(IPCC, 2013; Winsemius et al., 2013). We employ the estimates derived from the GLOFRIS model, which were generated as part of the COACCH project, to evaluate the economic consequences of river flooding in Ireland.

The consequences of climate change, such as rising sea levels, heightened occurrences of high tides, and increased storm-surge flooding, have significant impacts on social, economic, and ecological systems (Hinkel et al., 2013). To assess the climate change-induced coastal impacts, we apply the Coastal Impact and Adaptation Model (CIAM) developed by Diaz (2016). Building upon the work of Hinkel et al. (2014), Diaz (2016) introduced CIAM, a global modelling tool aimed at estimating costs and adaptation strategies for the impacts of sea-level rises on our coasts. It subdivides the coastlines of the world into over 12,000 linear segments across the globe of varying lengths; Ireland consists of 22 unique segments. These segments are associated with physical, ecological, and socioeconomic parameters, allowing for a comprehensive analysis of impacts. A significant innovation in CIAM was its capacity to enable each segment to choose between the construction of protective dikes, as previously done by Hinkel et al. (2014), and the adoption of managed or reactive retreat strategies.

CIAM addressed six categories of costs related to relative sea-level rise and extreme sea levels: (a) expenses associated with immobile capital or land inundation, (b) capital damages related to extreme sea levels, (c) costs linked to mortality, (d) outlays for protection (e.g., infrastructure), (e) costs of relocation, and (f) wetland loss. In this analysis, we exclude mortality impacts, given the general concerns and critiques of economically valuing lives.

To assess the impacts of climate change on the agricultural sector, we apply the results of the COACCH project (Boere et al., 2019), which couple crop simulation models (Environmental Policy Integrated Climate (EPIC) and Geographic Information System (GIS)-based EPIC) with a partial equilibrium model of the agricultural and forestry sectors at the European level (the GLOBIOM model). The crop simulation models consider various factors such as genetic characteristics, soil properties, water availability, temperature, humidity, and tillage practices to predict different stages of crop growth and outcomes like emergence, flowering, and grain yield. In addition to simulating plant growth under changing climatic conditions at a global scale including Ireland, these models also incorporate carbon and water cycles. They account for the positive impact of elevated CO2 levels on crops' productivity, thus mitigating some yield losses caused by climate change stressors. These crop simulation models then give predicted yields for the main agricultural crops, which are then fed into a partial equilibrium model of the agricultural sector called GLOBIOM (Havlík et al., 2014). The GLOBIOM model is a partial equilibrium model that focuses on the agricultural and forestry sectors, as well as bioenergy. It divides the agricultural sector into various small regions where agricultural commodities are produced and traded. The model represents the decision of farmers within these regions to modify their crop allocation to sustain their profit optimum in reaction to the climate induced yield change. The main outcome of this assessment are changes in land allocation for different crops, adjustments in inputs used, as well as changes in overall areas dedicated to agriculture versus those dedicated to forestry and natural land.

It should be noted that this crop model, like others, have some important limitations. Firstly, they examine the impacts on crop yield of changes in climate, i.e. average temperature and precipitations, but they do not include the impacts of extreme weather and weather variability. Extreme hot days, extreme cold days, extreme winds and storms are expected to increase as global temperatures increase. These models focus on average changes in climate stimuli, which would underestimate the actual impacts of climate change. Secondly, these models focus on specific “subsistence” crops, such as wheat, barley, fodder or maize, not considering other agricultural product such as milk, fruit and vegetable tillage. These subsistence crops represent approximately 57% of Irish Crop Gross Value Added (GVA) and only 5% of total agricultural GVA.

There are two major pathways by which climate change impacts labour productivity. The first of these pathways involves the number of hours worked by individuals, often referred to as labour supply (Dasgupta et al., 2021; Graff Zivin & Neidell, 2014; Somanathan et al., 2021). Sectors with high exposure to extreme temperatures, such as agriculture, are particularly vulnerable to this effect. When temperatures rise beyond specific thresholds, workers may reduce their working hours to safeguard their long-term health, steering clear of the risks associated with heat exhaustion or heat stroke. Secondly, climate change has a significant influence on the quality and efficiency of work during the hours employees are on the job (Kjellstrom et al., 2009; Sahu et al., 2013; Dasgupta et al., 2021). Heat stress is one of the most prominent factors contributing to this decline in productivity. de Bruin et al. (2024) estimate an impact function that relates changes in labour productivity in Ireland with the Wet Bulb Globe Temperature (WBGT) whilst considering seasonal and interaction effects. The findings indicate that, in Ireland, increased temperatures and humidity in work environments can result in decreased productivity. Their results suggest that a 1°C increase in outdoor WBGT results in a 1.6% decline in labour productivity.

Climate change has various detrimental impacts on human health, which can significantly increase rates of morbidity and mortality (Watkiss & Ebi, 2022; Woodland et al., 2023). As temperatures rise, heat waves are projected to become more frequent and severe, which will lead to a rise in cases of heat-related illnesses such as heat stroke and heat exhaustion. These conditions often place a significant strain on the cardiovascular system, particularly among individuals with pre-existing heart conditions (Liu et al., 2022). Duffy et al. (2024) investigate the potential impact of temperature changes on healthcare by combining data on emergency in-patient hospital admissions for Ireland from the Hospital In-patient Enquiry (HIPE) system with meteorological data from Met Eireann using panel fixed-effects methods. The empirical results indicate that higher temperatures can contribute to an increase in emergency hospital admissions. In terms of providing hospital services, the annual economic burden associated with this varies from €156,000 to €364,000 for every 100,000 population, contingent on the length of stay. Note that these estimates only include effects of temperature on medical emergency, and does not account for morbidity and mortality effects, health impacts and should not be interpreted as estimates for the overall impacts of climate change on human health.

3.2.2 Production Function Approach

Impacts are introduced applying the production function method. The I3E model's production functions are complex, therefore we will use a representative production function based on Sue Wing & Lanzi (2014) here to illustrate the implementation of impacts. We introduce further two elements, namely capital accumulation and consumption behaviour.

Output for a specific sector ($Q_{a,t}$) is produced by labour ($L_{a,t}$), capital ($K_{a,t}$) and other inputs ($I_{a,t}$) according to the production technology represented by the function $FQ[\cdot]$ as shown in equation **(1)** below.

$$Q_{a,t} = \eta_{Q_{a,t}} \cdot FQ\left[\eta_{L_{a,t}} L_{a,t}, \eta_{K_{a,t}} K_{a,t}, \eta_{I_{a,t}} I_{a,t}\right] \tag{1}$$

This function represents how inputs can be substituted in the production of output for a specific production sector. η represents the technological augmentation factors, which represent the productivity of the various production elements. The shift parameter $\eta_{Q_{a,t}}$ represents an equiproportional shift in productivity of all inputs while keeping substitution possibilities the same. A shift in $\eta_{K_{a,t}}$, $\eta_{L_{a,t}}$ and $\eta_{I_{a,t}}$ represent an inequiproportional shift in productivity, increasing or decreasing the relative productivity of either capital, labour or other inputs. Such a shift will change the substitutabilities across inputs as they are imperfect substitutes for each other.

Capital is accumulated over time with the following process:

$$K_{a,t+1} = K_{a,t}\left(1 - \delta_{a,t}\right) + INV_{a,t} \tag{2}$$

In Equation (2), productive capital ($K_{a,t}$) is built up over time through investments ($INV_{a,t}$), however capital is depreciated over time at the rate of $\delta_{a,t}$. A shock on capital is introduced as an increase in the depreciation rate $\delta_{a,t}$. This will decrease the level of capital which feeds into equation **(1)**.A CGE model is build based on the concept of economic markets, where supply-demand equilibrium determines the equilibrium price. The quantity of supply of goods defined by the production function (eq. 1) should equal the demand.[2] Total demand (D_{x_t}) is the sum of demand for each commodity, defined by a share (α_{c_t}) per agent (x): households (HH), government (GOV) and production sectors (A), as follows: [3]

$$D_{x_t} = \sum_{c=1}^{C} \alpha_{c,x_t} D_{c,x_t} \tag{3}$$

where $c = 1, 2, 3, \dots, C$ and $\sum_{c=1}^{C} \alpha_c = 1$.

These share parameters α_{c_t} are calibrated based on the utility maximisation problem of households, on the dividend maximisation of production sectors, and on the composition of government expenditures on commodities Climate impacts can lead to increased demand of certain commodities, which is introduced by increasing the share parameters of these commodities α_{c_t}, resulting in reduced consumption of other goods. In this analysis, the share of health care expenditures is increased for households and the government. We assume, in line with current spending patterns of the Irish public health system, that the government pays 90% of the additional costs and households pay the rest.

Table 1 gives the impacts assessed in this paper and the resulting shock in the production function, consumption function, and capital accumulation function.

Table 1: Introduced impacts in their implementation the production function

Scenario	Description	Sector	function	Element	Parameter
River	Riverine flooding	All	Capital accumulation	Capital depreciation	δ_{ALL}
Coast	Coastal flooding	All	Capital accumulation	Capital depreciation	δ_{ALL}
Agri	Agricultural yield losses for a subset of crops	Agriculture	Production	Output productivity	$\eta_{K_{AGR}}$
Labour	Labour productivity decreases	All	Production	Labour productivity	$\eta_{L_{ALL}}$
Health	Health care costs: Emergency admittances	Health Services	Consumption	Consumption share	α_{hs,gov_t} α_{hs,hh_t} *hs= health services* *gov=government* *hh=households*

4 RESULTS

Our results are generally presented as percentage changes compared to a counterfactual scenario where no climate change impacts arise, the so-called Business as Usual (BaU), where no additional policies are undertaken and no climate change impacts exist. Unless otherwise indicated, the results

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[2] This is a simplification, where in the I3E model supply is a complex nested structure of inputs and includes imports from other regions.

[3] This is a simplification, where in the I3E model demand is a complex nested structure of consumption goods and includes exports to other regions.

presented are estimated under the RCP 4.5 scenario[4]. Note also that the results here do not include adaptation policies.

4.1 DIFFERENT IMPACTS

To understand the magnitude of the impact due to each individual climate change shock, we implement them individually and then collectively. Figure 1 shows how real GDP (as a percentage change from BaU) would evolve over time under each impact. The largest impact on real GDP comes from coastal flooding (a decline of around 2%). This is followed by a shock to labour productivity (a decline of around 0.5%). The impacts are generally growing over time. Much smaller in comparison, river flooding and a shock to agricultural productivity have negative and positive impacts on real GDP, respectively. Once again, it is important to note that the estimation of agricultural impacts is extremely limited, focussing on a small number of crops and examining yield changes due to temperature increase only (not considering extreme weather). A shock to the healthcare system has negligible impacts on real GDP. If all shocks occurred simultaneously, the overall impact would be a reduction in real GDP greater than 2.5% compared to BaU.

Figure 1: Real GDP by impact scenario, % change w.r.t. BaU by year for RCP4.5

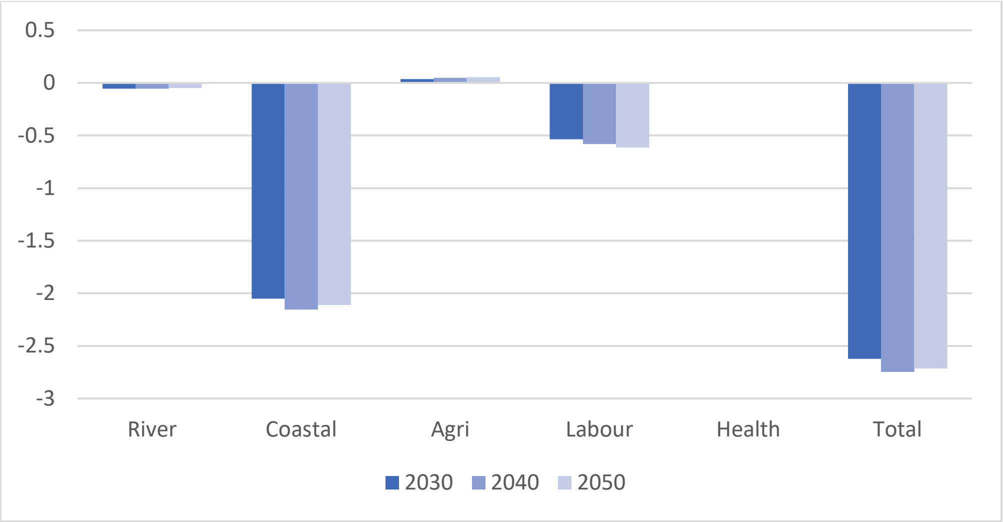

Figure 2 shows the percentage change in total employment for each labour skill level across each climate change impact and in total in 2030. The largest changes are found in the coastal impact scenario, with an almost 1.5% decrease in total employment. As capital losses decrease, employment follows as capital and labour are imperfect substitutes for each other. Impacts are highest for high-skilled labour. With agricultural impacts, low-skilled labour is impacted the most. In the case of labour impacts, as labour productivity decreases, employment increases across all skill types, where low-skilled labour has the highest increase.

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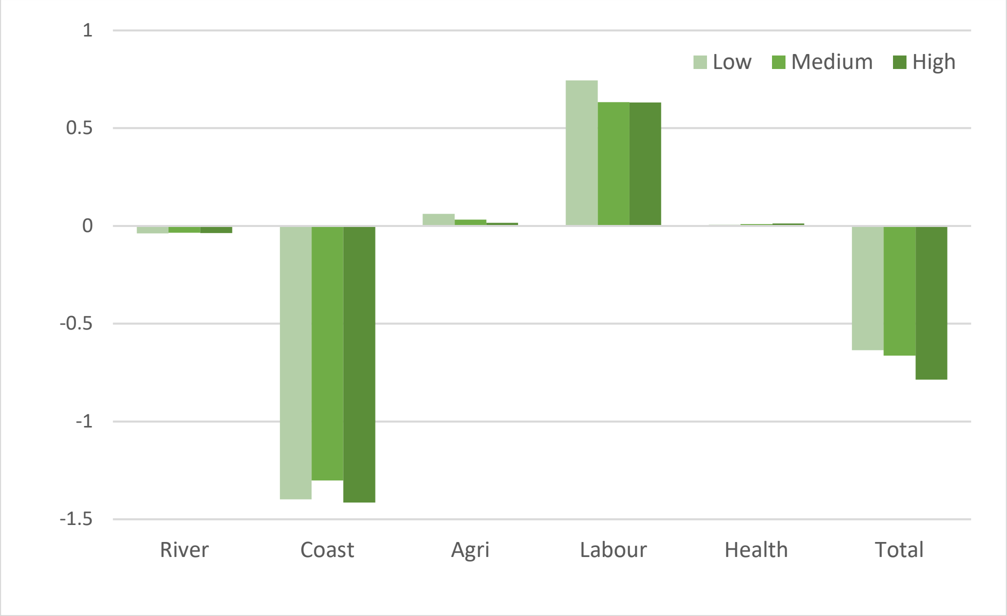
[4] RCP 4.5 is described by the IPCC as an intermediate scenario or stabilisation scenario. Emissions in RCP 4.5 peak around 2040, then decline resulting in a temperature increase of approximately 2.4 °C.

Figure 2: Employment, % change w.r.t. BaU by skill type for RCP4.5



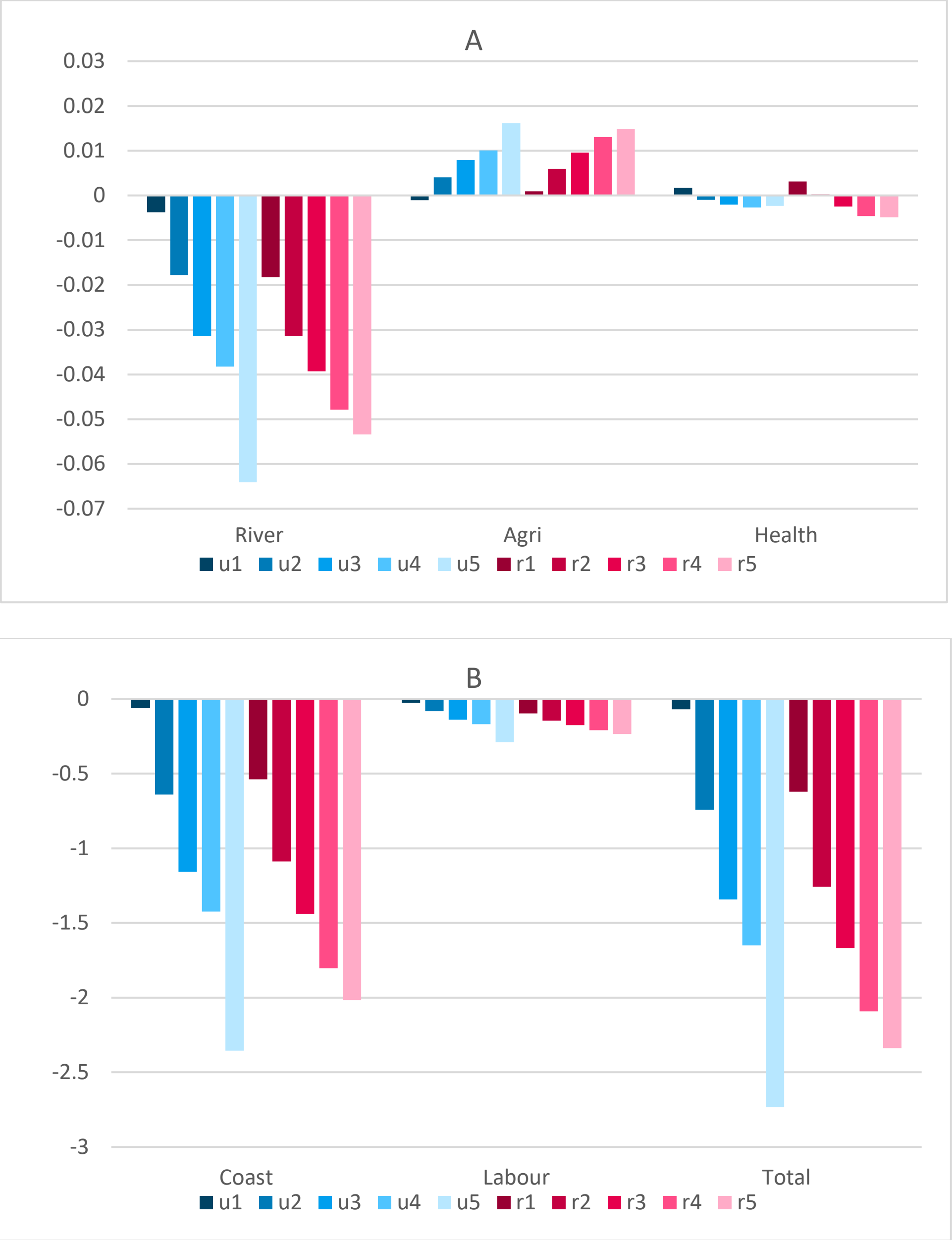
In terms of impacts on wage rates, table 2 shows the percentage change in real wage rates for the different skill types in 2030. In all cases, low-skilled labour's wage is impacted the most, and, except for the health impacts scenario, high-skilled labour sees the smallest impacts. These impacts are driven by the skill composition of labour demand across production sectors. Depending on which sectors are impacted most by the specific climate change impacts, the demand for labour by skill type will change.

Table 2: Real wages, % change w.r.t. BaU

	LSL	MSL	HSL	Mean
RCP45_RIV	-0.004	-0.002	0.001	-0.001
RCP45_COA	-0.167	-0.073	0.009	-0.059
RCP45_AGR	-0.030	-0.012	0.000	-0.010
RCP45_LAB	-0.043	-0.016	-0.009	-0.015
RCP45_HHS	-0.004	-0.001	-0.002	-0.002
RCP45	-0.256	-0.109	-0.005	-0.092

Impacts across different households are important from a policy perspective. Figure 3A and 3B show the effects of the different climate impacts on the various households types in the model in terms of changes in their real disposable income in 2030. Across most impacts, richer households face a relatively larger negative impact than poorer households. In other words, impacts are generally progressive. The reason for this is that a larger share of richer households income is composed of capital income. As River flooding and coastal impacts affect capital, this leads to higher impacts for richer households. In the case of agricultural impacts, richer households see higher benefits than poorer households. In this scenario, the reduction in the total budget of welfare transfers due to lower inflation and aggregate unemployment rate drags down poorer household income more compared to richer ones. In addition, the total value of distributed dividends increases, compared to BaU, in line with the overall economic activity, which affects richer households more than poorer households. The combined effect of these two generates regressive impacts across households, although all households become better off.

Figure 3: Real disposable income, % change w.r.t. BaU by household type for RCP4.5



Notes: u refers to urban households, r refers to rural households. 1 refers to the poorest quintile, 5 refers to the richest quintile.

4.2 SECONDARY IMPACTS

Incorporating climate shocks into a CGE model allows us to investigate the secondary or general equilibrium impacts of an initial climate change impact. To understand the mechanisms driving secondary impacts, we shortly discuss the channels through which initial impacts have further impacts. Figure 4 provides a visual representation of these for two production sectors (A and B). Each sector produces output (goods) using capital, labour and other inputs. If sector A is impacted by climate change through reducing its capital stock, capital productivity, labour productivity or general productivity, this will result in higher production costs for sector A. Higher production costs will necessitate a price increase for good A produced by sector A. This higher price will reduce the demand for good A by both households, the government and sector B. Hence, due to the market conditions, sector A output will decrease. As output decreases, the value added of sector A will also decrease. Note that the ratio of output to value added differs considerably across sectors, i.e., output impacts on valued added will be larger in some sectors than others.

Sector B is also impacted by the impacts on sector A. If sector B uses good A as an input to its own production, sector B's production costs will increase as the price of good A increases. This results in an increase in the price of good B and negative impacts for sector B. Furthermore, if sector B supplies inputs to sector A's production, reduced production in sector A will result in reduced demand for good B. However, as demand for good A decreases due to its higher price, demand will increase for good B as it is relatively cheaper. These different counteracting mechanisms will be of different magnitudes depending on various factors. Generally, we would expect secondary impacts to be positive, adding to the total cost of climate change impacts.

Figure 4: Visual representation of mechanisms driving secondary impacts in a CGE setting

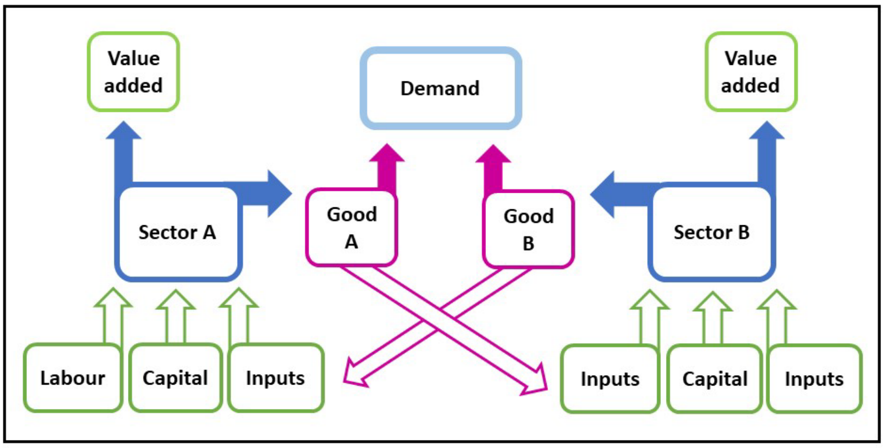


Figure 5A shows the share of initial and secondary impacts to total under each scenario in 2030. The total impact is negative for both river and coastal flooding, but the initial impact is greatly outweighed by the secondary impact. This is due to the impacts directly affecting a production factor, namely capital. To replace destroyed capital takes time and installation costs. In the I3E model, the total investment expenditure of 35 out of 39 sectors, i.e., dividend maximiser sectors, has two components; new additions to the existing capital stock times the price of investment and the installation/adjustment cost measured by the price of value added. Adjustment cost, by following the literature (Hayashi, 1982; Goulder, 1995; Diao et al., 1999; Goulder & Hafstead, 2013) is 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.

Similarly, the initial impact of a shock to the healthcare system is negative; however, the secondary impact is positive and around the same proportion. This is because though additional healthcare expenditures constitute a cost, these expenditures are considered productive, i.e., they generate value added for others. Expenditures in healthcare cover labour income for healthcare workers, medications bought from pharmaceutical firms and medical machinery. However, increased expenditures on healthcare do crowd out demand for other goods that may have higher value added.

Conversely, the initial impact of a shock to agricultural production is positive, while the secondary impact is negative, though much smaller in comparison. As the production costs of agricultural products decrease, their price decreases, increasing demand for agricultural goods and crowding our demand for other goods. Given that the production of agricultural goods has a lower ratio of value added/output (0.28 versus 0.48 average across all sectors), this results in a decrease of total value added across the economy (GDP).

Figure 5: Initial versus secondary impacts by year for RCP4.5

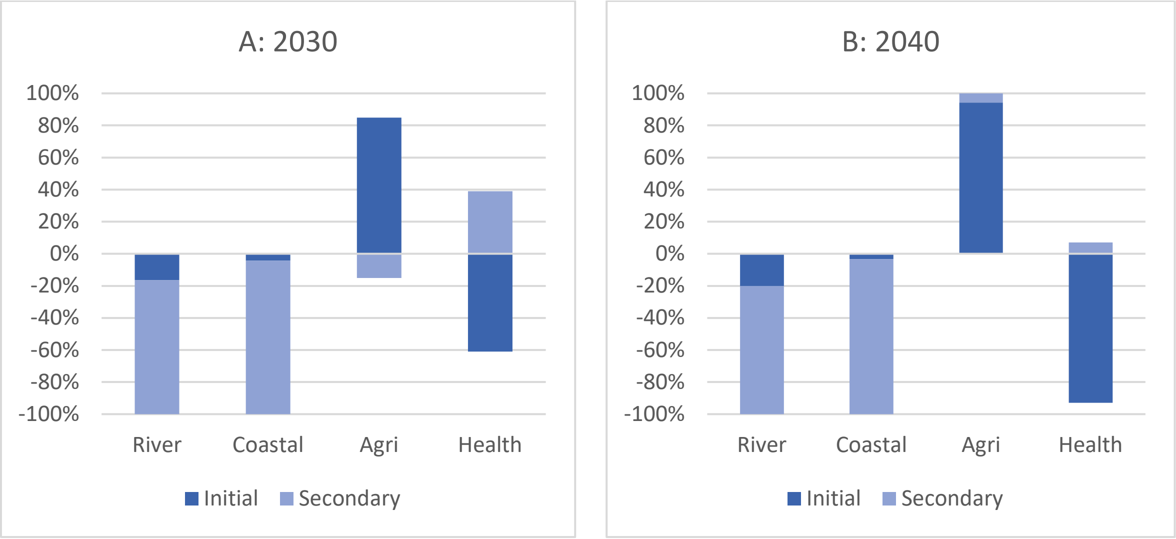


Figure 5B shows the same for 2040. The share and direction of initial and secondary impacts for river and coastal flooding remain relatively unchanged. The direction of initial and secondary impacts of a shock to the healthcare system stays the same (negative and positive, respectively); however, the secondary impacts are less. As climate change induced additional healthcare expenditures increase over time, this increases the negative impacts of crowding out of demand of other goods decreasing the initial secondary benefits of increased healthcare production.

The initial impact of a shock to agricultural production remains positive and a larger share of the impact but unlike 2030, the secondary impacts are also positive. In this case the positive impacts on the agricultural sector as well as sectors using high levels of agricultural inputs outweighs the negative demand crowding out effect.

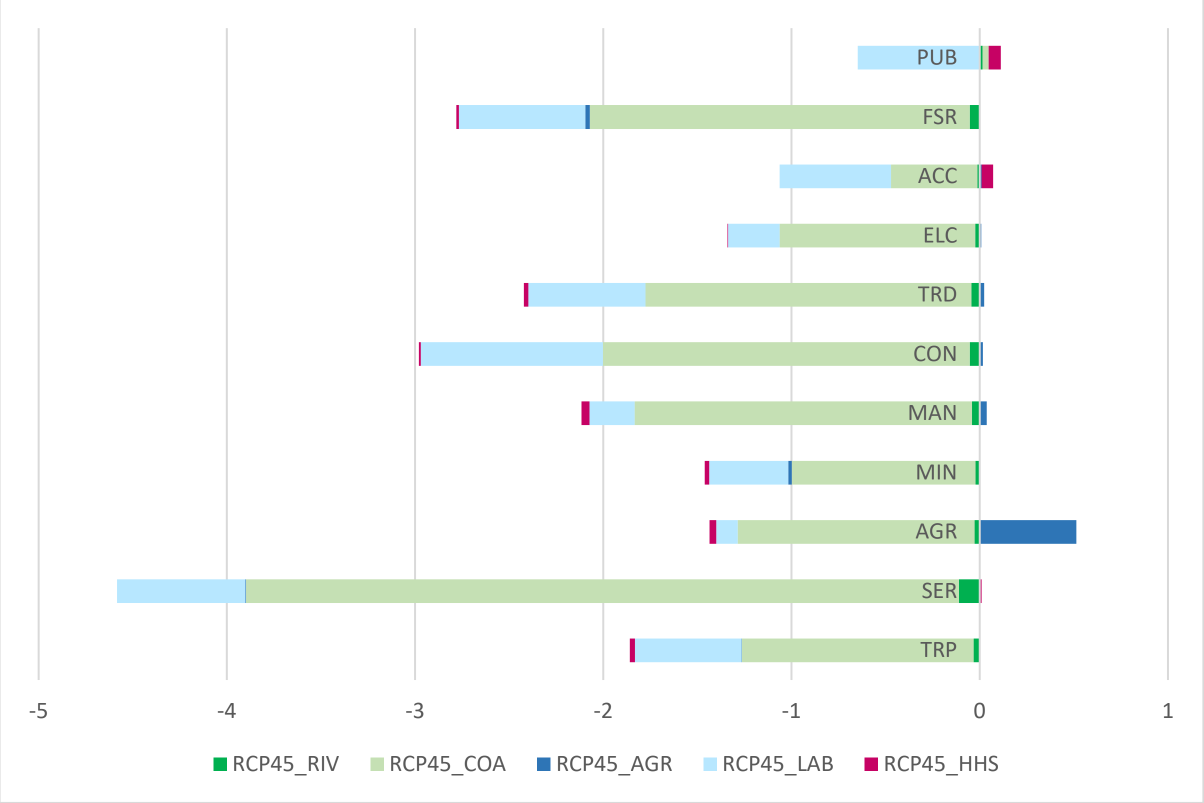
4.3 SECTORAL IMPACTS

Figure 6 shows the impacts on value added across aggregate sectors in the economy in 2030. In the case of river and coastal impacts, we find that all sectors are impacted negatively (except the public service sector under river flooding, which is positive). The relative level of impacts across sectors depends on the importance of capital in their production process (as capital is reduced in these scenarios) and the ratio of value added to output. The services sectors show the largest impacts. Agricultural impacts have a positive effect on sectors that use a large amount of agricultural inputs in total intermediate inputs, such as manufacturing (6.7%) and construction (1.4%), as well as sectors that supply a large amount of inputs to the agricultural sector, such as manufacturing (52%), construction (0.9%) and trade (2.4%). All other sectors see a small decrease in value added due to agricultural impacts.

Labour productivity impacts are negative for all sectors. Labour is a key factor of production; therefore, a negative shock to labour productivity will naturally decrease the value added of all sectors.

Health impacts have positive impacts on services, public services, and accommodation. Health services fall within the services category and hence results in a positive impact for this sector. Increased health expenditures crowd out demand in other sectors.

Figure 6: Value added across aggregated production sectors, % change w.r.t. BaU in 2030 for RCP4.5



The acronyms of sectors are as follows: PUB is Public Services, FSR is Financial Services, ACC is Accommodation, Hotels & Restaurants, ELC is Electricity Production, TRD is Trade, CON is construction, MAN is Manufacturing, MIN is Mining, AGR is Agriculture, SER is Other Services, and TRP is Transportation.

4.4 DIFFERENT CLIMATE CHANGE FUTURES

Given the uncertainty of what future GHG emissions will be, different scenarios have been developed by the international community of climate researchers. These scenarios of GHG emissions are an integral part of climate change modelling and are useful for several purposes, including understanding and predicting future climate change. They help in establishing a connection between atmospheric GHG concentrations and changes in global temperature and other climate variables. By simulating various emissions scenarios in climate models, climate scientists can assess the climate system's sensitivity to various amounts of greenhouse gases.

To ensure consistency across research applying future climate change scenarios, the IPCC developed a Special Report on Emissions (SRE) with concomitant scenarios (SRES) in 2000. These scenarios were replaced by the Representative Concentration Pathway (RCP) scenarios for the IPCC Fifth Assessment Report (AR5) in 2014. RCPs represent the different future trajectories of GHG concentrations in the atmosphere based on a wide range of assumptions regarding population growth, economic development, technological innovation and attitudes to social and environmental sustainability (IPCC, 2014). For instance, all RCPs include the assumption that air pollution control becomes more stringent over time as a result of rising income levels (Van Vuuren et al., 2011). There are four main RCPs with numerical values 2.6, 4.5, 6.0, and 8.5. These numbers represent the radiative forcing (i.e., the difference between the incoming and outgoing energy from the sun) values in the year 2100.

The four RCPs comprise a mitigation scenario (RCP2.6) that results in a very low forcing level, two stabilisation scenarios (RCP4.5 and RCP6.0), and a scenario (RCP8.5) that has extremely high GHG emissions. In other words, RCP2.6 represents a pathway where GHG emissions are significantly reduced, leading to an estimated 1.6°C increase in global average temperature by 2100 relative to the pre-industrial period (1850-1900). This can be interpreted as an ambitious interpretation of the Paris Agreement reflecting the goals of the agreement and does not refer to the current pledges under the Paris Agreement which would result in significantly higher concentrations. RCP8.5 is a pathway where GHG emissions continue to grow unmitigated, resulting in a best estimate global average temperature rise of 4.3°C by 2100. We will refer to this pathway as the “no mitigation” pathway, acknowledging that this is an extreme interpretation of no climate action and refers to the worst-case scenario. RCP4.5 and RCP6.0 are two medium stabilisation pathways with varying levels of mitigation (Met Office, 2018). RCP4.5 is referred to as the “most likely” scenario and has hence been the focus of this paper so far.

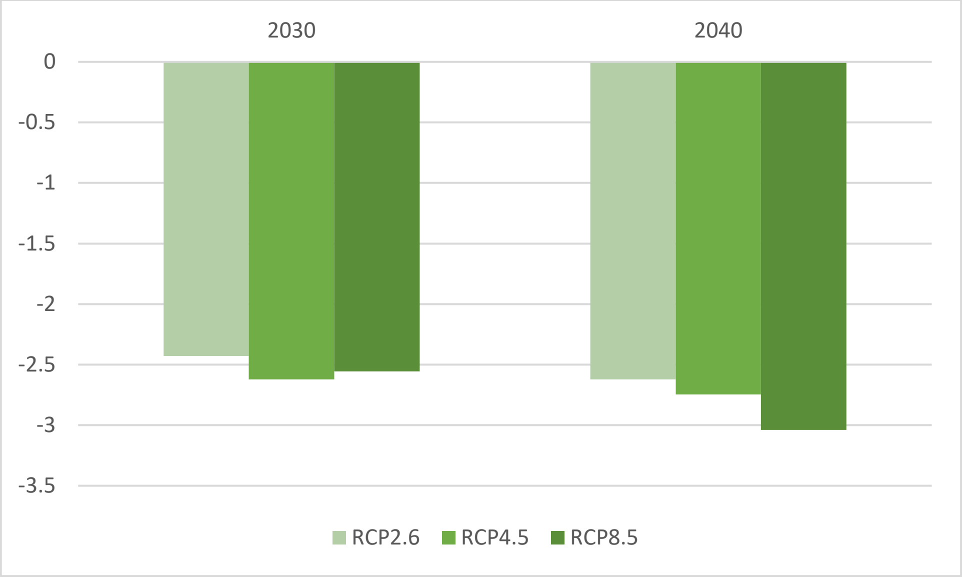
Here we examine the impacts under three RCP pathways: 2.6, 4.5 and 8.5. The increase in global mean temperature predicted by the RCP pathways for the late 21st century is shown in table 3.

Table 3: The increase in global mean temperature compared to Preindustrial level across scenarios

SSP Scenario	RCP Scenario	Change in temperature (°C) by 2081-2100
SSP 1	RCP2.6 “Paris Agreement”	1.6 (0.9 to 2.3)
SSP 2	RCP4.5 “most likely”	2.4 (1.7 to 3.2)
SSP 5	RCP8.5 “no mitigation”	4.3 (3.2 to 5.4)

In 2030, impacts are highest in the RCP4.5 scenario as sea level rise is estimated to be higher in this scenario in the short run. In 2040, impacts are highest in the RCP8.5 scenario and lowest in the RCP2.6 scenario. The differences across climate scenarios are limited when examining impacts in the short run.

Figure 7: Real GDP, % change w.r.t. BaU across RCP scenarios



5 CONCLUSION

Climate change impacts are a key concern in policy making because of the damage they can have on people, capital and the economy. As such, understanding the extent of these impacts is needed to inform the country's adaptation and mitigation decisions. Understanding both the initial and secondary impacts are important for these decisions but to the authors' knowledge this is the first paper to use a CGE model for Ireland to provide this knowledge.

This paper has shown that climate impacts on agricultural, health, labour productivity, coastal flooding and riverine flooding and that coastal flooding has the largest percentage decrease on GDP with respect to BaU in 2030, 2040 and 2050 compared with the other impacts. This is likely because coastal flooding damages capital which is expensive and takes time to replace. Labour productivity has the second largest reduction in GDP.

Additionally, both coastal and riverine flooding are associated with a reduction in employment relative to BaU in 2030 for all three types of labour. Nevertheless, agriculture and labour productivity initial impacts see an increase in employment with respect to BaU in 2030. The climate change impacts result in the largest decline in low skilled wages relative to high skilled wages except for the health impact. This is likely caused by a change in the demand for skilled labour.

We have contributed to the literature by analysing the secondary impacts of climate change on the Irish economy. Considering secondary impacts are important because the market adjusts based on the initial impacts with demand for certain goods and services becoming higher or lower. In comparison with the initial impacts, coastal and riverine flooding have larger secondary impacts. The secondary health impacts are positive in contrast to the initial negative impacts, this is likely because improving health expenditure benefits other people. Whilst, for agriculture, in 2030 the secondary benefits are negative but in 2040 they are positive whilst the initial benefits are positive.

Our sectoral analysis found that the service sector had the most impacts relative to other sectors. We also find that the extent of the impacts differs depending on the year and the climate change scenario with the impacts increasing according to the RCP scenario in 2040.

From a policy perspective, our results have a clear message that the composition of impacts matter as they drive the secondary impacts. In some cases secondary impacts can be much higher than initial impacts. Secondary impacts can be positive reducing the initial impacts or negative increasing the initial impacts.

This paper considered only five types of climate change impacts, a complete analysis should include more impacts such as storms, extreme events, biodiversity and non-yield agricultural impacts. Our analysis does not consider adaptation explicitly, though includes market adaptation implicitly through the CGE framework. The inclusion of adaptation options and their associated costs would be extremely useful. Furthermore, the shocks implemented could be further refined, such as capital losses to specific sectors based on their location. Future work should focus on including adaptation, implementing more types of impacts and specific shocks such as changes in particular types of capital.

6 REFERENCES

Bergin, A., Conroy, N., Rodriguez, A. G., Holland, D., McInerney, N., Morgenroth, E. L. W., & Smith, D. (2017). *COSMO: A new COre Structural MOdel for Ireland*.

Boere, E., Valin, H., Bodrisky, B. B., Balkovic, J., Batka, M., Folberth, C., Wang, X., Weindl, I., Havlik, P., Karstens, C., Kindermann, G., Krasovskii, A., Leclere, D., & Lotze-Campen, H. (2019). *D2.2 Impacts on agriculture including forestry & fishery*.

Bosello, F., Nicholls, R. J., Richards, J., Roson, R., & Tol, R. S. J. (2012). Economic impacts of climate change in Europe: sea-level rise. *Climatic Change*, *112*(1), 63–81. https://doi.org/10.1007/s10584-011-0340-1

Ciscar, J.-C., Iglesias, A., Feyen, L., Szabó, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O. B., Dankers, R., Garrote, L., Goodess, C. M., Hunt, A., Moreno, A., Richards, J., & Soria, A. (2011). Physical and economic consequences of climate change in Europe. *Proceedings of the National Academy of Sciences*, *108*(7), 2678–2683. https://doi.org/10.1073/pnas.1011612108

Cronin, D., & McQuinn, K. (2018). The Cyclicality of Irish Fiscal Policy Ex-Ante and Ex-Post. *The Economic and Social Review*, *49*(1), 1–16.

Dasgupta, S., van Maanen, N., Gosling, S. N., Piontek, F., Otto, C., & Schleussner, C. F. (2021). Effects of climate change on combined labour productivity and supply: an empirical, multi-model study. *The Lancet Planetary Health*, *5*(7), e455–e465. https://doi.org/10.1016/S2542-5196(21)00170-4

de Bruin, K. C., & Yakut, A. M. (2021a). *Construction of the Energy Social Accounting Matrix for Ireland, v2.0* (Issue 78). https://doi.org/https://doi.org/10.26504/sustat108

de Bruin, K. C., & Yakut, M. (2021b). *Technical Documentation of the I3E Model, v4.0*. https://doi.org/10.26504/sustat109

de Bruin, K., Kweku Kyei, C., & Henry, L. (2024). *Climate Change Impacts and Associated Economic Costs in Ireland* (Working Paper No. 788). Economic and Social Research Institute.

de Bruin, K. C., Dellink, R. B., & Tol, R. S. J. (2009). AD-DICE: an implementation of adaptation in the DICE model. *Climatic Change*, *95*(1–2), 63–81. https://doi.org/10.1007/s10584-008-9535-5

Dellink, R., Lanzi, E., & Chateau, J. (2019). The Sectoral and Regional Economic Consequences of Climate Change to 2060. *Environmental and Resource Economics*, *72*(2), 309–363. https://doi.org/10.1007/s10640-017-0197-5

Diao, X., Roe, T. L., & Yeldan, A. E. (1999). How Fiscal Mismanagement May Impede Trade Reform: Lessons From An Intertemporal, Multi-Sector General Equilibrium Model For Turkey. *The Developing Economies*, *37*(1), 59–88. https://doi.org/10.1111/j.1746-1049.1999.tb00865.x

Diaz, D. B. (2016). Estimating global damages from sea level rise with the Coastal Impact and Adaptation Model (CIAM). *Climatic Change*, *137*(1), 143–156.

Doorley, K., Callan, T., & Savage, M. (2021). What drove income inequality in EU crisis countries during the Great Recession? *Fiscal Studies*, *42*(2), 319–343. https://doi.org/10.1111/1475-5890.12250

Duffy, K., de Bruin, K., Henry, L., Kweku-Kyei, C., Nolan, A., & Walsh, B. (2024). *Health Impacts of Climate Change and Mitigation Policies in Ireland*.

Eboli, F., Parrado, R., & Roson, R. (2010). Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. *Environment and Development Economics*, *15*(5), 515–533. https://doi.org/10.1017/S1355770X10000252

Goulder, L. H. (1995). Effects of Carbon Taxes in an Economy with Prior Tax Distortions: An Intertemporal General Equilibrium Analysis. *Journal of Environmental Economics and Management*, *29*(3), 271–297. https://doi.org/10.1006/jeem.1995.1047

Goulder, L. H., & Hafstead, M. A. C. (2013). Tax reform and environmental policy: Options for recycling revenue from a tax on carbon dioxide. *Resources for the Future DP*, 13–31.

Graff Zivin, J. G., & Neidell, M. (2014). *Temperature and the Allocation of Time: Implications for Climate Change*.

Havlík, P., Valin, H., Herrero, M., Obersteiner, M., Schmid, E., Rufino, M. C., Mosnier, A., Thornton, P. K., Böttcher, H., Conant, R. T., & others. (2014). Climate change mitigation through livestock system transitions. *Proceedings of the National Academy of Sciences*, *111*(10), 3709–3714.

Hayashi, F. (1982). Tobin's Marginal q and Average q: A Neoclassical Interpretation. *Econometrica*, *50*(1), 213–224.

Hinkel, J., Lincke, D., Vafeidis, A. T., Perrette, M., Nicholls, R. J., Tol, R. S. J., Marzeion, B., Fettweis, X., Ionescu, C., & Levermann, A. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences*, *111*(9), 3292–3297.

Hinkel, J., van Vuuren, D. P., Nicholls, R. J., & Klein, R. J. T. (2013). The effects of adaptation and mitigation on coastal flood impacts during the 21st century. An application of the DIVA and IMAGE models. *Climatic Change*, *117*, 783–794.

Holmøy, E., & Strøm, B. (2013). Computable General Equilibrium Assessments of Fiscal Sustainability in Norway. In P. B. Dixon & D. W. Jorgenson (Eds.), *Handbook of Computable General Equilibrium Modeling* (Vol. 1, pp. 105–158). Elsevier. https://doi.org/10.1016/B978-0-444-59568-3.00003-1

IPCC. (2013). Summary for Policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, R. K. Pachauri, & L. A. Meyer, Eds.). IPCC.

IPCC. (2023). *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press. https://doi.org/10.1017/9781009325844

Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. J. (2009). The direct impact of climate change on regional labor productivity. *Archives of Environmental & Occupational Health*, *64*(4), 217–227.

Kompas, T., Pham, V. H., & Che, T. N. (2018). The Effects of Climate Change on GDP by Country and the Global Economic Gains From Complying With the Paris Climate Accord. *Earth's Future*, *6*(8), 1153–1173. https://doi.org/10.1029/2018EF000922

Liu, J., Varghese, B. M., Hansen, A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A., & Bi, P. (2022). Heat exposure and cardiovascular health outcomes: a systematic review and meta-analysis. *The Lancet Planetary Health*, *6*(6), e484–e495.

Met Office. (2018). *UKCP18 Guidance: Representative Concentration Pathways*. https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf

Piontek, F., Drouet, L., Emmerling, J., Kompas, T., Méjean, A., Otto, C., Rising, J., Soergel, B., Taconet, N., & Tavoni, M. (2021). Integrated perspective on translating biophysical to economic impacts of climate change. *Nature Climate Change*, *11*(7), 563–572. https://doi.org/10.1038/s41558-021-01065-y

Rausch, S., Metcalf, G. E., & Reilly, J. M. (2011). Distributional Impacts of Carbon Pricing: A General Equilibrium Approach with Micro-data for Households. *Energy Economics*, *33*(S1), 20–33. https://doi.org/10.1016/j.eneco.2011.07.0

Roson, R., & Mensbrugghe, D. Van der. (2012). Climate change and economic growth: impacts and interactions. *International Journal of Sustainable Economy*, *4*(3), 270. https://doi.org/10.1504/IJSE.2012.047933

Roson, R., & Sartori, M. (2016). Estimation of Climate Change Damage Functions for 140 Regions in the GTAP 9 Database. *Journal of Global Economic Analysis*, *1*(2), 78–115. https://doi.org/10.21642/JGEA.010202AF

Sahu, S., Sett, M., & Kjellstrom, T. (2013). Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future. *Industrial Health*, *51*(4), 424–431.

Somanathan, E., Somanathan, R., Sudarshan, A., & Tewari, M. (2021). The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing. *Journal of Political Economy*, *129*(6), 1797–1827.

Sue Wing, I., & Lanzi, E. (2014a). Integrated Assessment of Climate Change Impacts: Conceptual Frameworks, Modelling Approaches and Research Needs. In *OECD Environment Working Papers* (Issue 66). https://doi.org/10.1787/5jz2qcjsrvzx-en

Sue Wing, I., & Lanzi, E. (2014b). *Integrated Assessment of Climate Change Impacts: Conceptual Frameworks, Modelling Approaches and Research Needs*. https://doi.org/https://doi.org/10.1787/19970900

Watkiss, P., & Ebi, K. L. (2022). A lack of climate finance is harming population health. *BMJ*, o313. https://doi.org/10.1136/bmj.o313

Winsemius, H. C., Van Beek, L. P. H., Jongman, B., Ward, P. J., & Bouwman, A. (2013). A framework for global river flood risk assessments. *Hydrology and Earth System Sciences*, *17*(5), 1871–1892.

Woodland, L., Ratwatte, P., Phalkey, R., & Gillingham, E. L. (2023). Investigating the health impacts of climate change among people with pre-existing mental health problems: a scoping review. *International Journal of Environmental Research and Public Health*, *20*(8), 5563.

Yakut, A. M., & de Bruin, K. C. (2023). The importance of having a more realistic welfare transfer determination rule: A CGE analysis for Ireland. *Economic Analysis and Policy*, *80*, 1310–1325. https://doi.org/10.1016/j.eap.2023.10.021