

Coupling Socioeconomic Factors into a Global Earth System Model: An Inter-comparison of the Socio-Economic Consequence of the IPCC RCP8.5 and RCP4.5 scenarios

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Abstract

There is growing scientific evidence on the increased likelihood of considerable global warming over the coming century. The United Nations Framework Convention on Climate Change (UNFCCC) advocates measures to stabilize greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system. The full implications of climate change on the environment and society will depend not only on the response of the climate system to changes in greenhouse gas concentrations, but also on the actions that humankind takes to mitigate and adapt to those changes, through the use of technology, economic structures and incentives, lifestyle choices, institutional and policy settings.

To explore the economic implications of moving to a low carbon economy, and the implications of a shifting climate on the global economy we couple the CSIRO version of the Global Trade and Environment Model (GTEM-C) to the Australian Community Climate Earth System Simulator coupled model (ACCESS-CM) via a damage function. GTEM-C is a multi-region, multi-sector dynamic recursive Computable General Equilibrium (CGE) model that has a detailed energy technology bundle. In GTEM-C, we have included detailed accounting of energy and resources flows that are embedded in traded energy goods, along with some additional features, such as a coupling for exporting GHG emissions and other environmental pollutants to ACCESS-CM.

In this modelling exercise, ACCESS-CM and GTEM-C are forced to follow the Inter-Governmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) 8.5 and RCP 4.5 emissions trajectories. The projected surface air temperatures are used to calculate changes in total factor productivity, via a damage function. These climate feedbacks are taken to GTEM-C as exogenous shocks to the socio-economic system, and GTEM-C solves for the set of policy, economic and welfare constraints so that its projected carbon emissions comply with the designated emissions pathways. We then provide a systematic comparison of the regional and global economic outcomes under the RCP8.5 and RCP4.5 scenarios.

Earth System Models (ESMs), such as ACCESS-CM, are a rich source of environmental data, providing detailed information about land cover change, nutrient cycles, and even ice-sheet dynamics. Coupling CGE with ESMs offers the potential to study the effect of long run climate events. ACCESS-CM, for example, has a realistic El Nino Southern Oscillation (ENSO) cycle as well as the ability to reconstruct many observed teleconnections. Such information can be used to construct better climate-economy feedback models to study (say) the impact of more intense and longer El Niño/La Niña events. The coupling of a CGE model to an Earth System Model, shows a potential way of including human decision making directly into ESMs, and could provide a mechanism for creating the next generation of ESMs that could be termed Human-Earth-System Models, where policy, actions, and responses to environmental and global change issues can be modelled in a coupled manner.

1. Introduction

There is growing scientific evidence on the increased likelihood of considerable global warming over the coming century. The United Nations Framework Convention on Climate Change (UNFCCC) advocates measures to stabilize greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system. The full implications of climate change on the environment and society will depend not only on the response of the climate system to changes in greenhouse gas (GHG) concentrations, but also on the actions that humankind takes to mitigate and adapt to those changes, through the use of technology, economic structures and incentives, lifestyle choices, and institutional and policy settings.

In this paper, we examine the global economic impacts of achieving a major emission reduction scenario, namely the Representative Concentration Pathways (RCP) 4.5 relative to RCP 8.5. We discuss the modelling framework in the next section. In section three, we describe our scenario analysis. The results of our scenario analysis are presented in section four. The final section provides some concluding remarks.

2. Modelling framework: A Coupled CGE-Earth System Model Structure

Our modelling framework involves coupling of two models: the CSIRO version of the Global Trade and Environment Model (GTEM-C) and the Australian Community Climate Earth System Simulator coupled model (ACCESS-CM). The coupling is done via a damage function.

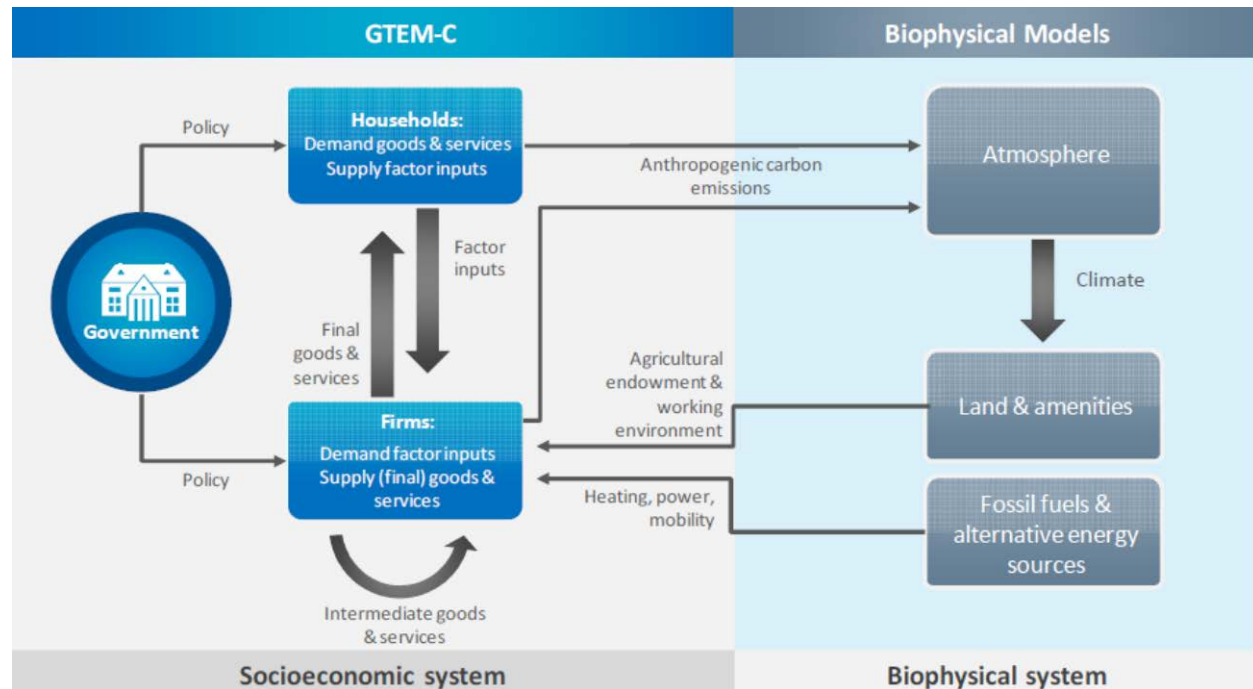
2.1 Overview of GTEM-C

GTEM-C is a multi-region, multi-sector dynamic recursive Computable General Equilibrium (CGE) model that has a detailed energy technology bundle. A detailed description of the GTEM-C is in Cai et al (2015). In GTEM-C, we have included detailed accounting of energy and resources flows that are embedded in traded energy goods, along with some additional features, such as a coupling for exporting GHG emissions and other environmental pollutants to ACCESS-CM.

GTEM-C disaggregates the world economy into a set of autonomous regions. Countries of large economic size are modelled separately, and the rest of the world is disaggregated into regions according to geographical proximity and climate similarity. Each region has a representative household. The representative households play three important roles in the model: (1) they own and supply factor inputs of production, (2) they own the regional income including payments to all factor inputs, tax revenues and international transfers and determine regional savings; and (3) they consume goods and services.

In each of the autonomous regions, local production is divided into multiple commodity sectors/industries. The regions interact with each other through trade and capital flows, and regional households consume both domestic and imported goods. Capital investment takes place across regions, so households can allocate their savings either domestically or internationally. In contrast, other factors of production (land, labour, natural resources) are available only domestically. In GTEM-C, we use the GTAP 8.1 (see Narayanan et al 2012) database which consists of 131 regions and 57 sectors. We aggregate this database into 18 regions and 19 sectors based on their significance to the global economy, as well as, their vulnerability to climate change. A schematic diagram of GTEM-C is presented in Figure 1.

Figure 1: A schematic diagram of GTEM-C



Source: Cai et al (2015)

2.2 Overview of ACCESS-CM

The Australian Community Climate and Earth System Simulator Coupled Model, hereafter ACCESS-CM, is a coupled atmosphere-ocean-sea ice model developed by the Centre for Australian Weather and Climate Research (CAWCR) with contributions from participating Australian Universities. Bi et al. (2013) provides a detailed description of the configuration of ACCESS-CM. Here we use, unless otherwise stated, ACCESS-CM which refers to ACCESS1.0,

where the atmospheric component is the UK Meteorological Office unified model (Davies et al 2005; Martin et al. 2010, 2011), configured to have the HadGEM2 climate configuration. The ocean component of ACCESS-CM is the NOAA/GFDL Modular Ocean Model (MOM4p1) (Griffies 2009), and the sea-ice component is the LANL sea-ice model CICE4.1 (Huinke and Lipscomb 2010). Furthermore, the ACCESS-CM uses MOSES2 land surface model (Rashid et al 2012). ACCESS-CM has been shown to have a medium transient climate response and equilibrium climate sensitivity of 1.89 °C and 3.86 °C respectively (Dix et al. 2013) compared to the assessed ranges of climate models of 1.1–2.5 °C (mean of 1.82 °C) and 2.08–4.67 °C (mean of 3.22 °C), respectively (Forster et al 2013). ACCESS-CM captures regional surface climate patterns (Rashid et al. 2013a), prominent modes of inter-annual variability (Rashid et al 2013b); and present climate (1975–2004) with considerable realism.

2.3 Climate-Economy Feedbacks

As has been discussed in detail in Cai et al (2015), GTEM-C is capable of projecting future GHG emissions. The carbon pathway can be analysed by global climate models, such as the ACCESS-CM version 1.0 (ACCESS 1.0). The simulation results of global climate models are used to quantify the climate-economy interactions through a set of empirical and econometric sub-models. These climate feedbacks are taken to GTEM-C as exogenous shocks to the socioeconomic system, and GTEM-C solves for the set of policy constraints so that its projected carbon pathway is consistent with the one that is analysed by the global climate models.

The channel of climate-economy interactions currently considered in the GIAM-C framework is the degree of climate change represented by the surface air temperature which affects regional total factor input productivities. We use the quadratic damage function as per Nordhaus (2008), such that climate change damages enter GTEM-C as a (negative) input-augmenting productivity shock to the factor-composite in industrial production (see Cai et al 2015 for more details of the climate change damage treatment in GTEM-C)

3. Scenario analysis

3.1 Background

The current generation of long range emissions scenarios, namely the Representative Concentration Pathways (RCPs), form a set of greenhouse gas concentration and emissions pathways designed to support research on impacts of potential policy responses to climate change (Moss et al. 2010).

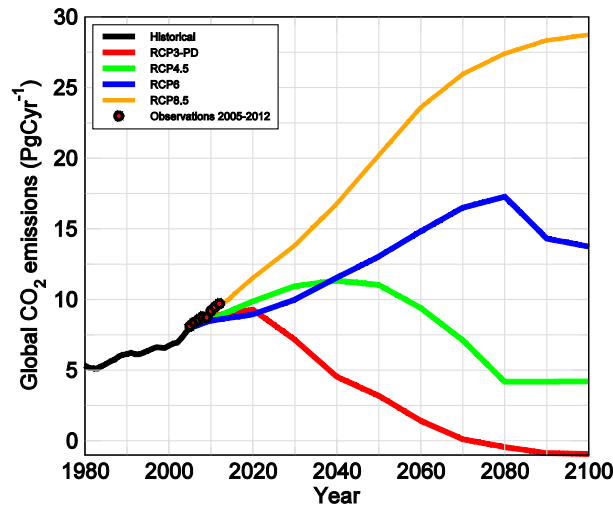
As a set, the RCPs cover the range of forcing levels associated with emissions scenarios published in the literatures. Figure 2 shows the four core emissions pathways selected by the

IPCC to use as the basis for the Fifth Assessment Report. For the four core emissions scenarios, ACCESS-CM modelled the earth system response to two of these: RCP4.5 and RCP8.5.

Briefly these RCPs can be described as:

- RCP 8.5 which is a high greenhouse gas emission pathway that forms a business as usual “baseline” scenario that does not include any climate mitigation targets leading to a radiative forcing of 8.5 Wm^{-2} at the end of the century, but is continuing to rise thereafter; and
- RCP4.5 (Thompson et al. 2011) which is characterised by steady growth in emissions during the first half of the century, then a decline in emissions leading to a radiative forcing that stabilizes —without overshoot— at 4.5 Wm^{-2} in 2100.

Figure 2: The Four Core Representative Concentration Pathway Scenarios.



3.2 Scenarios

Our baseline or reference case scenario is RCP 8.5. We use two versions of this reference case: RCP 8.5 without climate change damages; and with climate change damages.

Our counterfactual scenario is a GHG mitigation scenario represented by RCP 4.5. Again, we use two versions of RCP4.5: RCP 4.5 without climate change damages; and with climate change damages.

Our scenario analysis involved two sets of comparisons:

- RCP 8.5 without climate change damages with RCP 4.5 without climate change damages

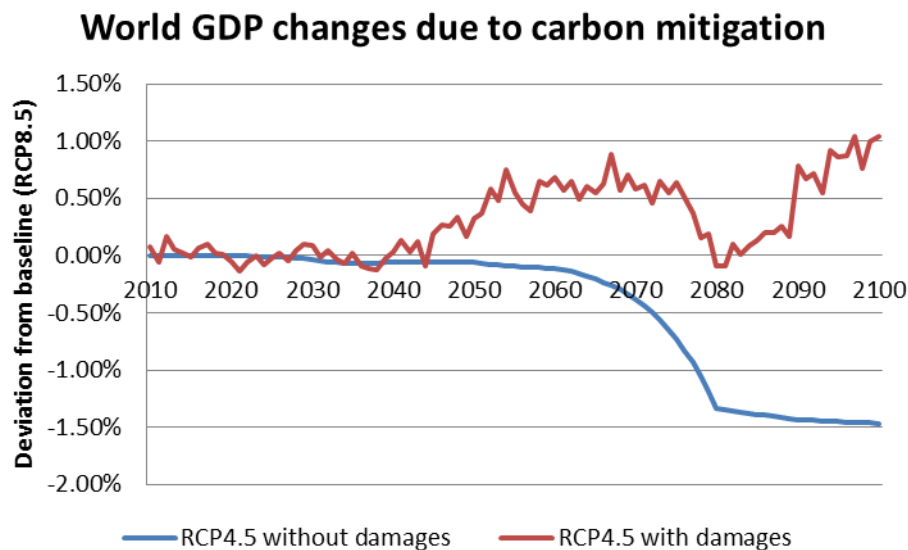
- RCP 8.5 with climate change damages with RCP 4.5 with climate change damages

The pathway from RCP 8.5 to 4.5 is implemented by the use of a global carbon price, which stimulates the adoption of new and cleaner energy technologies.

One of the key reasons for undertaking these two sets of scenario comparisons is to provide some insights into the importance of explicitly taking account of climate change damages in GHG mitigation analysis.

4 Results and discussion

Figure 3: Comparison of global GDP pathways



The key results from our scenario analysis are presented in Figure 3.

As shown in Figure 3, under the ‘without climate damage’s scenarios, i.e. when the impacts of climate change on the global economy is not explicitly taken into account, there is a reduction in global GDP under RCP 4.5 relative to 8.5. This reduction in global GDP is quite considerable since 2040s. Here the use of a global carbon price to reduce GHG emissions from RCP8.5 to 4.5 is resulting in a reduction in global GDP.

On the other hand, when a similar GHG reduction is undertaken with climate change damages explicitly taken into account in the analysis, the economic outcomes are substantially different. Reduced GHG emissions and hence lower climate change damages under RCP 4.5 (with explicit climate change damages) scenario relative to RCP 8.5 (with explicit climate change damages)

scenario leads to a favourable outcome on global GDP pathway over time. This is particularly evident after 2040 – when the GHG emissions pathway under RCP 4.5 (with explicit climate change damages) scenario and RCP 8.5 (with explicit climate change damages) scenario diverge further (see Figure 2). This is an important and noteworthy projection in our current analysis. In other words, any negative impacts of carbon tax on global GDP growth are outweighed by the positive impacts of reduced emissions and hence the flow-on reduction in climate change damages in the global economy under RCP 4.5 (with explicit climate change damages) scenario relative to RCP 8.5 (with explicit climate change damages) scenario. Due to the tightening of GHG emissions from the middle of the 2060's, however, the GDP gains from mitigation lessen before picking up again in 2080.

5 Concluding remarks

In this paper, we demonstrate the application of a coupled the ACCESS1.0 Earth System model to the CSRIO version of the Global Trade and Environment Model via a damage function. Our analysis shows that global warming poses increasingly severe environmental limitations on economic activity. The imposition of a global uniform carbon price also reduces economic activity. However the impact of a carbon price required to move from RCP 8.5 to RCP 4.5 is outweighed by the economic implications of reduced environmental damages, once the impacts of climate change damages are explicitly taken into account in our analysis.

This study has also shown several other important factors. First, it has shown the development of an Earth System model and, the first step in the move towards a Human-Earth System Model. Second, it has demonstrated the systematic and tractable approach for developing socio-economic pathways at the global aggregate scale. Third, our analysis reflects the benefits of technological advancements particularly in the energy sector which could result in less pressure on the climate system per unit of economic output. Fourth, it also shows that it is possible to have sustained economic growth and well-being without a conflict with the preservation of the environment including the climate system. Finally our analytical framework is instructive for scenario development in general, as it made a number of assumptions that are part of the processes more obvious.

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