Differentiated Carbon Pricing to 2050: Insights from KPMG-IAM[a]

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Draft – April 2023

Abstract

Climate change is a major source of structural breaks and uncertainty affecting businesses around the world. The economic literature suggests that the principal policy instrument to curb emissions and limit earth's average temperature increase relative to preindustrial levels below 2°C should be carbon pricing. In addition, few economic studies have analysed the impacts of worldwide net-zero emissions by mid-century. This paper introduces KPMG-IAM, a GTAP-MAGICC-based integrated assessment model, and examines the economic impacts of achieving net-zero emissions by 2050 through either a uniform or differentiated carbon price.

At the global level the size of the carbon tax under both carbon pricing specifications are quite similar, they reach around $510 and $600 in 2050, for the 2°C and 1.5°C scenarios, respectively. At the regional level and under the differentiated carbon price mechanism, the carbon tax trajectory of the different regions is shaped by the countries' initial NDC commitments to 2030, which leads to a wider regional difference in carbon tax in 2030, but then we observe a regional convergence in carbon taxes to the above values.

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[a] This paper has been prepared for presentation at the 26th Annual Conference on Global Economic Analysis in June 2023, Bordeaux. The views expressed in this paper are the authors' alone and do not necessarily reflect the views or policies of KPMG.

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1 Introduction

Integrated Assessment Models (IAMs) have become the standard tool for climate policy analysis as they combine both human behaviour and earth system into a single framework. Complex IAMs include detailed representation of energy technologies, energy use choices, land-use changes, and socioeconomic trends alongside simply but meaningful specifications of climate and environmental systems. The increasing numbers of commodities, industries, technologies, and regions become however too large to allow their modelling in a single mathematical system. The decomposition of an IAM into linked sub-systems allows reducing dimensionality and hence making them computationally easier to solve. KPMG-IAM links mathematical representations of human and earth systems to capture cause-effect chains. It integrates into a single framework a top-down economic equilibrium model, a reduced complexity climate model and a simple econometric ecosystem model.

2 KPMG-IAM

The top-down macroeconomic equilibrium model is a global trade computable general equilibrium (CGE) model of the world economy. It is built on the latest version of the core GTAP model (Corong, et al. 2017). It combines the recursive dynamic version (Aguiar, Corong and van der Mensbrugghe 2019) with a detailed treatment of the energy-economy-environment linkages (Peters 2016). In addition, it introduces technology-specific capital in renewable and nuclear electricity generation to allow realistic penetration processes in the electricity sector over time.

The climate model uses the latest version of MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change) and employs a configuration consistent with the IPCC Sixth Assessment Report (Meinshausen, Raper and Wigley 2011). It is a reduced complexity climate model but extremely powerful as it is calibrated against the best Earth System Models (ESM). Based on a three-part main carbon cycle, a one-pool atmosphere, land, and ocean, it translates anthropogenic greenhouse gas emissions into atmospheric concentrations, radiative forcing, and global-mean temperature change. In addition, it is computationally efficient enough to encapsulate the uncertainties along the whole cause-effect chain from emissions to global-mean temperature and sea level rise.

The ecosystem model is a set of damage functions, which translate shift in global-mean temperature into physical impacts of climate change that can be mapped onto economic variables within each country. Readily available damage functions are related to chronic risks and include rising sea levels, variation in crop yields, heat-induced impacts on labour productivity, changes in the occurrence of diseases, changes in tourism, and changes in household energy demand (Roson and Sartori 2016). We focus on the first four chronic risks (Fernando, Liu and McKibbin 2021), which affect various economic sectors' productivity for the first two while the last two risks affect labour supply.

KPMG-IAM represents the causal chain through which economic activities generate emissions (economic model), which leads to change in global-mean temperature (climate model) and ultimately feeds back to the economy as physical impacts (ecosystem model). The three sub-systems as well as their respective interactions are implemented in different computer languages and the whole KPMG-IAM is fully automated. The economic model is formulated as a system of linearized equalities derived from a highly nonlinear system of equations and is solved using the GEMPACK economic modelling software (Harrison and Pearson 1996). Emissions are passed to the climate model via Python-embedded code in GAMS that calls an API for running the MAGICC model on Climate Resource server and retrieving temperature shift. Calculations of physical impacts within the ecosystem model are executed in GAMS, as well as the feedback to the economic model. For reporting purposes, a GAMS routine merges all climate, physical and economic results as well as combines KPMG-IAM output with other IAMs output on a dedicated dashboard in Power BI.

3 Simulation

Uncertainty is a common challenge to any long-term policy decisions. One way to manage uncertainty is to identify policy-relevant scenarios that cover a reasonable range of future states, both unfavourable and favourable. For the former, we consider a scenario that leads to an increase in global mean temperature of 4°C above pre-industrial levels in 2100, whereas for the latter, we think about scenarios that project global mean temperature below 2°C above pre-industrial levels in 2100.

The 4°C scenario represents a situation of the world where no additional climate policies have been introduced other than those already in place in 2020. Nevertheless, global society, demographics and economics might change over this century resulting in different pathways about future socioeconomic developments. Among the five Shared Socioeconomic Pathways (SSPs) that have been developed in the literature, SSP2 is defined as the Middle of the Road scenario as both challenges to mitigation and adaptation are lessen. Our scenarios are based on SSP2, which is characterized by moderate global population growth and GDP growth in line with historical trends.

The economic model is calibrated using a 27-sector 20-region aggregation of the GTAP Power 10a dataset with base year 2014 (Aguiar, Chepeliev, et al. 2019; Chepeliev 2020). Baseline construction involves assumptions about 1) the development of key model variables until 2050, and 2) mechanisms in the model which accommodate the development of these key variables. The first step requires the definition of key model variables and the identification of credible sources for external forecasts of these variables. We distinguish between macroeconomic variables and energy-related supply and demand developments. For the infilling of relevant emissions by MAGICC (IPCC category non 1A), we use the specification SSP3-RCP7.0 as current scientific understanding suggests that it results in a best-estimate 2100 warming of approximately 4°C.

Macroeconomic projections come from the GTAP-based SSP database that has been developed by the GTAP Center. It uses projections for population and labour force growth (Samir and Lutz 2017) as well as GDP projections at market exchange rates (Dellink, et al. 2017). Regarding energy-related assumptions, we capture technological developments both in terms of the supply and final consumption of energy using information from a bottom-up energy model (Delzeit, et al. 2020). Bottom-up models combine detailed technological assumptions and physical constraints of technologies with macro-economic assumptions on growth. We use the reference scenario from the Global Energy and Climate Outlook (GECO) 2019 from the Joint Research Centre (JRC) of the European Commission (Keramidas, et al. 2020).

The second step involves accommodating this additional information in the baseline. GDP projections are targeted by endogenizing regional total factor productivity that are differentiated between agriculture, manufacturing, and service sectors depending on their expected contribution to total growth rate (Britz and Roson 2019). Energy-related technological information is captured in our top-down framework by calibrating the relevant cost and input shares found in the bottom-up analysis along the baseline.

Below 2°C scenarios achieve the temperature goal set out in the Paris Agreement, which means global emissions trajectories up to 2050 consistent with either 2°C or 1.5°C global warming in 2100. The policy instrument to target emission trajectories in these two scenarios is carbon emissions pricing applied to CO2 emissions from fuel combustion (CO2|1A emissions). We devise two alternative specifications for emissions trading. The first one assumes a global emissions trading scheme (ETS), which leads to a uniform global emissions price. The second specification considers only current ETS with no additional regional ETS in the future, which implies differentiated emissions prices across regions.

In terms of regional emission trajectories, we specify quantitative emission targets for 2030 based on pledges in countries' Nationally Determined Contributions (NDCs) to the UNFCCC under the Paris Agreement. For the period 2030-2050, we assume that CO2 prices converge within a range of $50 per tCO2. The idea behind the convergence assumption is that improved coordination of climate targets and policies is a precondition for a 2°C (1.5°C) world (van Soest, et al. 2021; Kriegler, et al. 2018). For the infilling procedure in MAGICC, we use specification SSP1-RCP2.6 for the 2°C scenario and SSP2-RCP1.9 for the 1.5°C scenario. Additional assumptions are increase in substitution elasticities in the power sector over time to mimic technological developments (Landis, Fredriksson and Rausch 2021) and exogenous carbon dioxide removals on the global level (Jaumotte, Liu and McKibbin 2021; Fuss, et al. 2018).

4 Results

Preliminary results of KPMG-IAM are without any feedback effects of physical impacts on the economy. They show that global CO2 emissions in the baseline scenario increase at an annual average growth rate of 0.9%, reaching around 40.1 Gt CO2 in 2050. The implementation of global emissions trajectories consistent with either 2°C or 1.5°C global warming requires a reduction of global CO2 emissions by 68% and 80% compared to the baseline in 2050, respectively. While at the global level CO2 emission reduction pathways are similar under the uniform and differentiated carbon tax specifications, substantial differences are observed at the regional level. As a global uniform carbon tax achieves emission reduction targets at the lowest economic cost, emission reductions are larger in developing regions where emission reductions are cheaper than in developed regions. Thus, higher mitigation efforts are expected in China, India, the Former Soviet Union, and the Middle East under the global uniform carbon tax compared to the differentiated carbon tax. In contrast, a uniform carbon tax is particularly beneficial to developed countries with expensive emission reduction costs, such as the US, Japan, Canada, and other high-income European countries. However, these emission reduction savings in developed countries are less significant under the 1.5°C scenario, which implies more stringent emission reduction targets at the global level.

At the global level the size of the carbon tax under both carbon pricing specifications are quite similar, they reach around $510 and $600 in 2050, for the 2°C and 1.5°C scenarios, respectively. At the regional level and under the differentiated carbon price mechanism, the carbon tax trajectory of the different regions is shaped by the countries' initial NDC commitments to 2030, which leads to a wider regional difference in carbon tax in 2030, but then we observe a regional convergence in carbon taxes to the above values.

The pace of economic growth is affected by climate change mitigation. In the short-term (2014-2030 period) climate change mitigation has a limited effect in economic growth. However, in the long-term (2014-2050 period), the global annual growth rates in the 2°C and 1.5°C scenarios are around 0.16 and 0.20 percentage points lower compared to the baseline (2.7% annual growth rate), respectively. At the regional level, GDP impacts are quite mixed. Depending on the assumed carbon tax mechanism and temperature target, GDP might increase in some regions to around 2% and decrease in others to around 19%. The particular outcome for a specific region will depend on several factors, mainly on the amount and speed of emission reductions, the level of the carbon tax, the baseline energy mix, the future deployment of renewable energy and costs, the level of economic dependency on fossil fuels (at the macro and micro level), the speed of the industrial decarbonisation and the induced changes in competitiveness caused by the above decarbonisation actions.

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