Climate Change Around the World

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Abstract

The economic effects of climate change vary across both time and space. To study these effects, this paper builds a global economy-climate model featuring a high degree of geographic resolution. Carbon emissions from the use of energy in production increase the Earth's (average) temperature and local, or regional, temperatures respond more or less sensitively to this increase. Each of the approximately 19,000 regions makes optimal consumption-savings and energy-use decisions as its climate (or regional temperature) and, consequently, its productivity change over time. The relationship between regional temperature and regional productivity has an inverted U-shape, calibrated so that the high-resolution model replicates estimates of aggregate global damages from global warming. At the global level, then, the high-resolution model nests standard one-region economy-climate models, while at the same time it features realistic spatial variation in climate and economic activity. The central result is that the effects of climate change vary dramatically across space—with many regions gaining while others lose—and the global average effects, while negative, are dwarfed quantitatively by the differences across space. A tax on carbon increases average (global) welfare, but there is a large disparity of views on it across regions, with both winners and losers. Climate change also leads to large increases in global inequality, across both regions and countries. These findings vary little as capital markets range from closed (autarky) to open (free capital mobility).

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> [C]limate change is going to affect different nations to different degrees and in different ways. Unfashionable though these terms may be, there will be "winners" as well as "losers."[1]

1 Introduction

That human greenhouse gas emissions cause global warming is no longer questioned in the science community. Still, much uncertainty remains regarding how much warming there will be under different emission scenarios; the IPCC reports have, since their first version, narrowed their intervals of estimated warming but not by very significant amounts. In addition, how a given amount of warming will affect human welfare is also subject to much—if anything, to more—uncertainty. For these reasons, views differ substantially among commentators on the extent to which emissions need to be curbed. However, an arguably more important reason why they, and policymakers around the world, display quite dispersed attitudes toward climate action is that different parts of the world are expected to be affected very differently by global warming, as well as by the proposed measures to mitigate it. Here, we believe that economic research can be of great, if not indispensable, help.

The present paper is motivated by a need to understand better the heterogeneous costs and benefits involved in combating climate change. With a framework that allows a systematic account of heterogeneous effects, different policy options can then be assessed, including region/country-specific compensation schemes. We view our framework as a natural next modeling step in Nordhaus's agenda: the core is his neoclassical growth model augmented with carbon-cycle and climate blocks but, in addition, now featuring rich regional heterogeneity both in economic and climate outcomes. Another important difference with Nordhaus's work is that we study market settings explicitly: for the population, preferences, and technology given, we define a dynamic general equilibrium and can therefore expose our global economy to a range of policy interventions, such as taxes on carbon emissions.[2] Another point of reference is the macroeconomic literature—notably Aiyagari (1994)'s framework—focusing on consumer inequality, which materializes here across regions. In emphasizing dynamics of inequality, as climate change by nature is a transitional phenomenon, our setting is also related to our own previous work in Krusell & Smith (1998) and Krusell & Smith (1997).[3]

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[1] See p. 6 in Pumphrey (2008).

[2] If one studies planning problems, it is straightforward to derive what an optimal carbon tax would look like, but it is not possible to study various forms of sub-optimal policy.

[3] Our model here does not feature stochastic fluctuations in regional or aggregate temperatures, but it is feasible to include them by adapting the methods developed in Krusell & Smith (1998), as outlined in Technical Appendix E; we have implemented these methods successfully in earlier versions of this work.

A starting point for our work is that the physical and economic effects of climate change are nowhere near uniform across the globe. As the Earth warms, some regions of the globe, such as those in northern latitudes, actually warm more rapidly than others. At the same time, some regions, particularly cold ones, become more productive for economic activity as they warm, while hot regions, becoming even hotter, become less so. These spatially heterogeneous changes in productivity, in turn, induce economic resources to move across space. To study these effects, we thus build a dynamic, general-equilibrium, global model of economy-climate interactions featuring a high degree of geographic resolution. At the global level, the model nests standard one-region economy-climate models, such as the canonical DICE (Dynamic Integrated Climate Economy) model.[4] At the regional level, by contrast, it features realistic spatial variation in climate and economic activity. The model therefore permits the quantitative evaluation of how climate change and policies designed to combat it affect different regions in the world in different ways. Put differently, the model serves as a laboratory in which we can quantify not just the aggregate (or average) effects of climate change and climate policy, but also their distributional effects across space. As the global warms, for example, which regions gain and which lose, and by how much? If one set of regions imposes a tax on carbon emissions, do some regions gain while others lose?

The fundamental unit of analysis in the model is a $1^\circ \times 1^\circ$ cell, or region, containing land, with regions straddling more than one country subdivided to preserve national boundaries for a total of approximately 19,000 regions. Output (i.e., gross domestic product, or GDP) in each region is produced using physical capital, labor, and energy. In each period each region decides how much to consume and how much to save, either locally or abroad, as well as how much energy to use. Labor supply is exogenous but its productivity varies over time as a region's climate changes. Energy use emits carbon into the atmosphere, which warms the globe but not in a uniform fashion: some regions warm faster than others. The sensitivity of each regions's temperature to the global temperature is calibrated using output from geophysical models of the Earth's climate.

The productivity of labor in each region is the product of two components. The first component does not depend on a region's climate (or average temperature): its initial value in each region is calibrated to replicate the global distribution of regional output in 1990 in the G-Econ (Geographically based Economic data) database and thereafter it grows at a constant annual rate. The second component, by contrast, varies with regional temperature according to an inverse U-shape normalized to have a maximum of one and a minimum of zero. This U-shape is calibrated so that the high-resolution economy-climate model constructed in this paper generates aggregate (global) damages from global warming that match those in standard representative-consumer economy-climate models. The predictions of the high-resolution climate-economy model for global aggregates, then, align with those delivered by the DICE model or its modern macroeconomic

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[4] For an exposition of this model, see, for example, Nordhaus (2007).

counterpart in Golosov et al. (2014).

At the regional level, the optimal annual average temperature (at which the calibrated inverse U-shape governing how labor productivity varies with temperature reaches its peak) is approximately 12 degrees Celsius ($^{\circ}C$); an increase of regional temperature from 10 $^{\circ}C$ to 12 $^{\circ}C$ increases a region's total factor productivity (TFP) by about 1%, while a further increase in annual average temperature from 12 $^{\circ}C$ to 14 $^{\circ}C$ reduces its TFP by about 2%.[5]

The main quantitative finding is that climate change affects regions very differently: output (GDP) grows dramatically in some regions (relative to trend), while it shrinks sharply in others; these regional variations in GDP growth, moreover, are much, much larger (in absolute value) than the changes in growth of global output wrought by climate change. Consequently, from a regional perspective, there are large disagreements about the welfare effects of carbon taxes: when a uniform carbon tax is imposed across all regions, with revenues redistributed locally as a lump sum so that there are no interregional transfers, some regions gain and others lose, often by large amounts that swamp the globally-averaged benefits of carbon taxes.

In the framework built here labor is assumed to be immobile and therefore does not migrate across regions in response to climate change. Nonetheless, there is significant adaptation to climate change. This adaptation occurs both across time—through intertemporal smoothing of consumption streams within a region—and across space—through movements of capital across regions. The framework therefore also permits leakage—movements of resources across space in response to differences in carbon taxes across regions. A key methodological finding is that shutting down capital markets has little effect on the quantitative results: in autarky, optimal saving behavior within regions comes close to equalizing the marginal product of capital (net of taxes) across regions, as would obtain under free capital mobility. The case of free capital mobility, moreover, lends itself relatively easily to numerical characterization thanks to an aggregation result that we show obtains in our framework.

Our main contribution is to offer a quantitative framework with regional heterogeneity at a high level of resolution. Since the first version of our work in 2014, a number of studies have developed settings that also feature regional heterogeneity. The most notable of these is arguably a set of economic geography papers: Desmet & Rossi-Hansberg (2015), Conte et al. (2021), Cruz & Rossi-Hansberg (2021), Desmet et al. (2021), Rudik et al. (2021), and Cruz & Rossi-Hansberg (2022). These frameworks (Cruz & Rossi-Hansberg (2021) in particular is a very rich model) focus precisely on the mobility of people; we document and quantify migration pressures in our framework (below, we document how much is gained from moving, on purely economic grounds, with and without climate change), but do not allow migration. Some of these alternative settings also have other

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[5] The non-linearity in the estimated relationship between temperature and TFP is significant; an increase of 4 $^{\circ}C$ from the peak reduces TFP by about 6%, while an increase of 4 $^{\circ}C$ to the peak increases it by about 5%.