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Spatial climate-economic models in the design of optimal climate policies across locations

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ABSTRACT

We couple a one-dimensional energy balance climate model with heat transportation across latitudes, with an economic growth model. We derive temperature and damage distributions across locations and optimal taxes on fossil fuels which, in contrast to zero-dimensional Integrated Assessment Models, account for cross latitude externalities. We analyze the impact of welfare weights on the spatial structure of optimal carbon taxes and identify conditions under which these taxes are spatially nonhomogeneous and are lower in latitudes with relatively lower per capita income populations. We show the way that heat transportation affects local economic variables and taxes, and locate sufficient conditions for optimal mitigation policies to have rapid ramp-up initially and then decrease over time.

1. Introduction

The impact of climate change is expected to vary profoundly among geographical locations in terms of temperature and damage differentials.[1] The spatial dimension of damages can be associated with two main factors: (i) natural mechanisms which produce a spatially *non-uniform* distribution of the surface temperature across the globe; and (ii) economic-related forces which determine the damages that a regional (or local) economy is expected to suffer from a given increase in the local temperature. These damages depend primarily on the production characteristics (e.g. agriculture vs services) or local natural characteristics (e.g. proximity to the sea and elevation). The interactions between the spatially non-uniform temperature distribution and the spatially non-uniform economic characteristics will ultimately shape the spatial distribution of damages.

Existing literature and in particular the RICE model (e.g. Nordhaus, 2007a, 2007b, 2010, 2011) provides a spatial distribution of damages in which the relatively higher damages from climate change are concentrated in the zones around the equator.[2] However, this model as well as other Integrated Assessment Models (IAMs) does not account for the first factor, the natural mechanism generating temperature distribution across the globe.

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[1] See "Climate observations, projections and impacts" at http://www.metoffice.gov.uk/climate-change/policy-relevant/obs-projections-impacts.

[2] Recent papers by Hassler and Krusell (2012) and Desmet and Rossi-Hansberg (2012) also introduce space and regional issues into models of climate change.

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In climate science terminology, IAMs with a carbon cycle and no spatial dimension are zero-dimensional models which do not include spatial effects due to heat transportation across space. In contrast, the one- or two-dimensional energy balance climate models (EBCMs) model heat transport across latitudes or across latitudes and longitudes (e.g. Budyko, 1969; Sellers, 1969, 1976; North, 1975a,b; North et al., 1981; Kim and North, 1992; Wu and North, 2007). Since prediction of climate at various spatial scales plays an important role in policy analysis, approaches other than EBCMs have been developed for approximating temperature fields. These are based on more complex and computationally costly models, such as pattern scaling (Lopez et al., 2012) or emulation theory (e.g. Challenor et al., 2006). However, because the purpose of this paper is to construct the simplest coupled climate economy model with a climate feedback response mechanism in space that responds to changes in the spatiotemporal structure of taxes on fossil fuels, and which is still analytically tractable, we considered the EBCMs framework as most appropriate.[3] It should be noted, however, that for a comprehensive analysis of regional climate change and prediction of future regional climates, one must turn to the large literature that deals with just that. An approach such as the MAGICC/SCENGEN model, for example, could be considered a very sophisticated combination of an energy-balance model plus pattern scaling, although this is far too simple a description of this kind of work (see Meinshausen et al., 2011). We stress that the purpose of our own work is more modest. We seek a framework simple enough for a pencil and paper analysis to expose, for example, potentially important forces that shape Pareto optimal carbon tax schedules in the face of different possibilities for international transfers. Our framework has not yet been developed to the point where it can deal with important dynamics of the actual climate system, e.g. the time-response of ocean heat uptake, which is needed for a more detailed analysis of economic impacts on the climate system. We hope that this kind of exercise will prove useful for economists who are used to working with simple analytical models, but also wish to include more features of the dynamic spatial climate system than is usual in these kinds of models.

One-dimensional EBCMs predict a concave temperature distribution across latitudes with the maximum temperature at the equator. In this paper we study the economics of climate change by coupling a one-dimensional EBCM with heat transport and albedo differentiation across latitudes, with an economic growth model. This approach integrates solution methods for one-dimensional spatial climate models, which may be new to economics, with methods of solving economic models. It may therefore provide new insights regarding issues such as the spatiotemporal structure of optimal policies and the spatial distribution of damages, relative to the zero-dimensional IAMs with carbon cycle, which ignore cross latitude externalities due to heat transport.

The literature on climate and economy is so large that a complete literature review is beyond the scope of this paper. Many scholars besides Nordhaus have written extensively on coupled economy and climate models.[4] However, to our knowledge, there has been no analysis of the shape of socially optimal tax structures in models that have a spatial heat transport mechanism that shapes the dynamics of the temperature field, as we attempt to do. Thus the main contribution of our paper is to couple spatial climate models with economic models, and then use these spatial climate models to achieve three objectives.

The first objective is to show the role of heat transport across latitudes in the prediction of the spatial distribution and the corresponding temporal evolution of temperature and damages. Our results show that heat transport explicitly affects the spatial distribution of temperature and damages, thus its omission from zero-dimensional models which rely on mean global temperature may introduce a bias. As far as we know, this is the first time that the spatial distribution of surface temperature and damages, and their temporal evolutions, have been determined endogenously by accounting for the interactions between local temperature and regional damages. We therefore believe this to be a contribution of our paper relative to the traditional IAMs with regional disaggregation but without the natural mechanism of heat transport across locations.

The second objective is to provide insights into the optimal spatial and temporal profile for current and future mitigation, when thermal transport across latitudes is taken into account. Regarding the spatial profile of fossil fuel taxes, our results suggest higher tax rates for wealthier geographical zones due to the practical inability of implementing without cost the international transfers needed to implement a competitive equilibrium associated with the Pareto optimum, or when Negishi welfare weights are not used. Our one-dimensional model allows us to study how heat transport across geographical zones impacts the degree of spatial differentiation of fossil fuel taxes between poor and wealthy regions. The result that, in the absence of international transfers, a spatially uniform optimal mitigation is not possible was first noted by Chichilnisky and Heal (1994). Our results provide new insights into this issue by characterizing the spatial distribution of fossil fuel taxes and linking the degree of spatial differentiation of optimal fossil fuel taxes to heat transport.

With regard to the temporal profile of optimal mitigation, the debate among economists dealing with climate change on the mitigation side appears to have basically settled on whether to increase mitigation efforts (that is, carbon taxes) gradually (e.g. Nordhaus, 2007a, 2010, 2011) or rapidly (e.g. Stern, 2006; Weitzman, 2009a,b). In this paper we locate sufficient conditions for profit taxes on fossil fuel firms to be decreasing over time and for unit taxes on fossil fuels to grow

[3] Furthermore, models such as pattern scaling may not be suitable when there are strong nonlinear feedbacks present, such as "snow-albedo feedback at high latitudes" (Challenor et al., 2006). Since we want to allow these nonlinear types of feedbacks, which can be modeled using EBCMs, we did not use pattern scaling.

[4] See Nordhaus' (2011) review for coverage of some of this work.