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On the spatial economic impact of global warming ☆

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ABSTRACT

We propose a dynamic spatial theory to analyze the geographic impact of climate change. Agricultural and manufacturing firms locate on a hemisphere. Trade is costly, firms innovate, and technology diffuses over space. Emissions from energy used in production contribute to the atmospheric stock of carbon, which increases temperature. Warming differs across latitudes and its effect on productivity varies across sectors. We calibrate the model to analyze how climate change affects the spatial distribution of economic activity, trade, migration, growth, and welfare. We assess quantitatively the impact of migration and trade restrictions, energy taxes, and innovation subsidies.

1. Introduction

The potential negative economic effects of anthropogenic temperature increases are the result of frictions that prevent the free movement of goods and people in space. The logic and evidence behind this claim is straightforward. Temperature varies by parallel from 0° Celsius in the North Pole to 28° Celsius in the Equator (during the growing season). This range is much larger than the estimates of temperature increases in extreme scenarios, that reach at most 6–8° Celsius over the next 200 years. Hence, over this time period, the increase in temperature will induce more moderate temperatures at high latitudes, thereby increasing productivity in those regions. Of course, under these same scenarios, global warming will also create large deserts in regions closer to the Equator where no agricultural or manufacturing production will be feasible. Combine these observations with the fact that most land in the world is essentially economically unused and empty. According to G-Econ 4.0, in 2005 at market exchange rates 91% of production occupied only 10% of land. The number is 85% in PPP terms and 75% if we focus on population. The extreme concentration of production and population implies that if we expect large economic losses from global warming, those cannot come just from the direct effect of temperature increases on the productivity of land. Since most of land is unused, making a fraction of it unfit for production would not by itself lead to large losses in output. Instead, any substantial cost of climate change must be associated with the frictions involved in moving production and people from their current sites to the regions that will be suitable for production in the future. Understanding how these frictions affect the impact of global warming is the primary goal of this paper.

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Global warming has had an important effect on the geography of economic activity already in the past. During the Medieval Warm Period, roughly between the ninth and fourteenth centuries, the world experienced temperature rises of up to 2° Celsius that, according to Fagan (2008), "...brought bounty to some areas, but to others, prolonged droughts that shook established societies to their foundations".[1] Northern Europeans and Inuits benefitted enormously, while Mongols, native Americans, and other Mesoamerican societies suffered losses that went from limiting their expansion to bringing them to the brink of extinction. The world as we know it today was shaped by these changes, not because warming led to less available land or resources in the world as a whole, but because of the changes in the location of the suitable areas for production and growth. As we emphasize here for the case of future anthropogenic global warming, during the Medieval Warm Period Fagan (2008) concludes that "The only protection against such disasters was movement".[2] Moving goods and people is restricted and costly, and the economic effect of temperature change will depend crucially on the magnitude of these frictions.

Understanding the spatial implications of global warming requires a framework with geography as well as dynamics. The economic models that have been proposed to study the economic implications of temperature change are in general dynamic, but have not incorporated geographically ordered space. Some frameworks, such as Krusell and Smith (2009) and Nordhaus (2010), do include many regions, but these regions are not linked to each other through trade costs and technology diffusion. Hence, it is impossible to use them to understand changes in geographic specialization and trade patterns, as well as the geography of innovation and migration.

Incorporating a rich set of spatially ordered locations in a dynamic model is in general intractable. In Desmet and Rossi-Hansberg (2014) we develop a framework with both a spatial and a time dimension that can be solved forward due to local competition for land and technological diffusion. With the proposed structure, innovations yield profits for the firm today, but only increases in land values, not in profits, in the future. This property of the model implies that a firm's dynamic optimization problem can be solved as a sequence of static problems. Hence, the equilibrium of the model is just a sequence of static spatial equilibria with state variables that follow laws of motion determined contemporaneously. This structure of the model makes the framework computable and suitable for the problem at hand.

To study the impact of global warming on spatial and aggregate outcomes we model the Northern Hemisphere. So space is half a sphere with the diameter of the Earth. We study symmetric spatial equilibria where prices and allocations are identical for all locations at a given latitude. This is natural since we assume that all regions in a given latitude have the same temperature.[3] The model features two industries, agriculture and manufacturing, whose productivity depends on both temperature and the local technology in the sector. The local technology is the result of technological innovations in the region as well as technological diffusion over space. In that sense, our model is a spatial endogenous growth model. Goods can be traded across locations subject to iceberg transport costs that depend on distance. Since space is continuous, incomplete specialization can happen only in a set of measure zero, and so it does not represent a problem to our focus on symmetric equilibria.

Agriculture and manufacturing firms produce using labor, land, and energy as inputs. Energy use generates a global stock of pollution (or CO_2 in the atmosphere), which in turn leads to temperature change. The increases in temperature that result from a larger stock of CO_2 in the atmosphere are not uniform across locations. As documented by the Intergovernmental Panel on Climate Change (IPCC, 2007), locations in latitudes closer to the North Pole increase their temperature more than those close to the Equator, although never enough to compensate for the larger temperatures close to the Equator. Obviously, since emissions are local but lead to a global stock of pollution, which in turn changes local temperatures, global warming is affected by an externality in energy use. Absent policy, local producers do not internalize the effect of their emissions on temperature change.

Temperature change has two main effects on spatial production patterns. First, the gradual increase in average temperatures makes the ideal location to produce in both industries move to the north over time. The literature suggests that the impact of temperature on productivity is more pronounced in agriculture than in manufacturing. Nevertheless, general equilibrium effects imply that the specialization areas in manufacturing change as well. These changes in specialization lead to changes in technology innovation in the different locations, thus amplifying the effects. The second implication of temperature change is that locations closer to the North Pole experience larger changes in temperatures, which enhances their comparative advantage in agriculture. Hence, temperature changes tend to favor specialization of the north in agriculture and the south in manufacturing. This is balanced by the fact that technologies in manufacturing are initially better in the northern latitudes, which leads to more innovation in the north. In calibrated examples, we observe that when the effect of pollution on temperature is small, the south specializes in agriculture and the north in manufacturing, as is roughly the case in the world today. In contrast, when the effect of CO_2 on temperature is large, the south increasingly specializes in manufacturing and produces in this sector using backward technologies with low total factor productivity. Eventually, if the effect is very large or if we study a very long period, locations closer to the North Pole end up specializing in agriculture.

The effects outlined above lead to large migrations of agents across locations, and so the consequences of global warming are mediated by the ability of agents and goods to move across space. To get a better sense of the role of moving frictions, we analyze three scenarios for labor mobility: one where labor is freely mobile across locations and therefore welfare in the world is equalized; another where labor is freely mobile within a southern region and within a northern region (modeled as intervals of latitudes) but not across them; and a third where labor cannot move at all. Three results stand out from our analysis of these different scenarios. First, when comparing the average welfare effect of global warming, we find virtually no impact under free mobility, but a very substantial negative impact if people cannot move. Second, mobility frictions do not only affect average welfare, they also lead to spatial inequities. In the scenario with no migration between south and north, we find substantial welfare gains in the north, with corresponding losses in the south. Third, the impact of migration restrictions becomes more pronounced when temperature is more sensitive to pollution. Overall, these quantitative exercises show that global warming is particularly problematic in the presence of moving frictions. Migration policy should therefore become an integral part of the debate on how to limit the negative economic impact of climate change.

The framework can also be used to evaluate a variety of environmental, industrial, regional, and migration policies. Since we model the local decision to use energy in the production process, we can introduce either carbon taxes or cap-and-trade type

[1] See page 129 in Fagan (2008).

[2] See page 80 in Fagan (2008).

[3] This is a reasonable approximation. Using spatial data from G-Econ 4.0 on average temperature between 1980 and 2008, we find that the average within-latitude variance in temperature as a share of the overall variance in temperature is 0.05. That is, a mere 5% of the variance in temperature occurs within latitudes.