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The impact of climate change on developed economies

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HIGHLIGHTS

- We use sub-national data to examine the temperature–growth relationship.
- We study both the United States and the European Union.
- We find that the optimal temperature is at about 6 °C.
- IPCC projected warming has significantly negative impact on economic growth.
- Our results suggest more proactive climate policy.

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ABSTRACT

We use sub-national data to examine the relationship between temperature and growth within the United States and the European Union. Different from previous studies based on national data, we find that the optimal temperature is much lower. Because most of production takes place in areas with temperatures above the optimal temperature, projected temperature increases have significantly negative impact on the economic growth of the United States and the European Union. Our results suggest more proactive climate policy.

1. Introduction

A consensus from the research based on *national data* is that climate change does not negatively affect developed economies. For instance, Burke et al. (forthcoming) find: "Europe could benefit from increased average temperatures" (p. 3). The common explanation is that developed economies are better able to adapt to climate change.[3] However, recent research based on *sub-national* data challenges this consensus. For instance, Deryugina and Hsiang (2014) (DH) find that increases in daily temperature above 15 °C significantly reduce personal income at the county level in the United States (US). Colacito et al. (2016) (CHP) show that an increase in the average summer temperature is associated with lower annual growth rate of US state-level output.

In this paper, we extend DH and CHP. First, to understand if adaptation over long run makes developed countries not negatively affected by climate change, we focus on five-year average temperatures, not daily or annual temperatures as in DH and CHP. Second, to understand if it is the US or developed economies in general that are not negatively affected by climate change, we study the US as well as the European Union (EU). Empirically, we utilize a unique dataset, the geophysically-scaled economic dataset (GEcon) developed by Nordhaus (2006), which provides consistent economic and geography data across the global at the sub-national level. With the GEcon data, we find a significantly nonlinear relationship between temperature and growth within the US and the EU, with the optimal temperature much lower than previously thought. Because most of production takes place in areas

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3 See Dell et al. (2014) for an excellent review.

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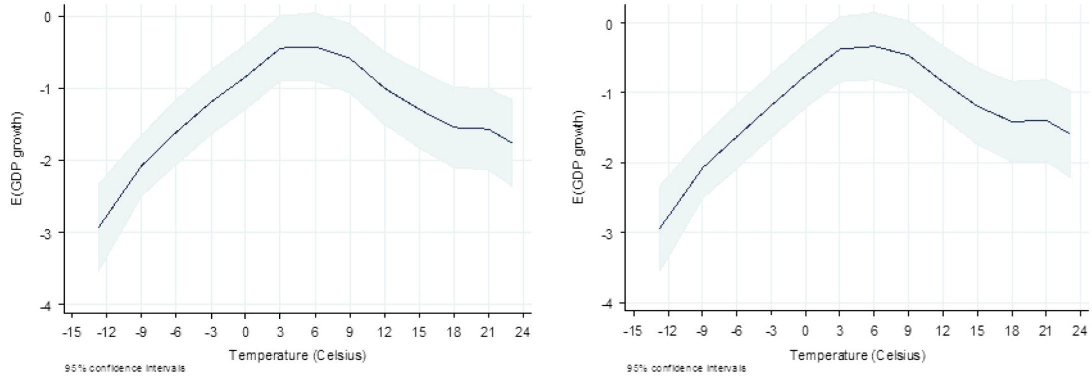


(a) Model (1). (b) Model (2).

Fig. 1. Temperature and growth in the US. Figs. 1 reports the mean impact of temperature on the US economic growth (i.e., $f(T_{it}) = \sum_m \tau^m T_{it}^m$).

with temperatures above the optimal temperature, projected temperature increases have significantly negative impact on the economic growth of the US and the EU. Our results therefore suggest more proactive climate policy.

2. Data

There are two potential issues with using national data. First, as Nordhaus (2006) points out, "for many countries, averages of most geographic variables (such as temperature or distance from seacoast) cover such a huge area that they are virtually meaningless" (p. 3511). Second, if there is a nonlinear relationship between temperature and growth within a country, the impact at the average national temperature will be a biased estimate of the average impact across the country, due to Jensen's inequality. We therefore follow Nordhaus (2006) and use the GEcon data, which covers not only the US but also the EU. GEcon estimates *real* gross output at a 1-degree longitude by 1-degree latitude resolution at a global scale. The conceptual basis of gross cell product (GCP) is the same as that of gross domestic product (GDP) as developed in the national income accounts, except that the geographic unit of the latitude–longitude grid cell is used instead of the political boundaries. See Internet Appendix for more details about our data (see Appendix A).

3. Empirical methodology

Our base linear spline model is derived from a Cobb–Douglas type production function:

$$\text{Model (1)}: y_{it} = \mu_i + \theta_t + \sum_m \tau^m T_{it}^m + \sum_m \rho^m P_{it}^m + \gamma l_{it} + \eta_{it} \quad (1a)$$

where y_{it} is the five-year growth rate in GCP in cell i, μ and θ are cell and time fixed effects, T_{it}^m's are the linear spline of the five-year average temperature, P_{it}^m's are the linear spline of the five-year average precipitation, and l_{it} is the five-year growth rate in population. For robustness, we also estimate the following model:

$$\text{Model (2)}: ypc_{it} = \mu_i + \theta_t + \sum_m \tau^m T_{it}^m + \sum_m \rho^m P_{it}^m + \eta_{it} \quad (1b)$$

where ypc_{it} is the five-year growth rate in GCP per capita in cell i. We follow DH and use 3 °C-wide temperature bins. Thus, for the US sample, m is set to 12, and the knots are −9, −6, −3, 0, 3, 6, 9, 12, 15, 18, and 21 (i.e., the first temperature bin is $T < -9$ °C, the second one is $-9 \leq T < -6$, and so on). For the EU sample, m is set to 7, and the knots are 0, 3, 6, 9, 12, and 15 (because few cells have average temperatures below −3). The mean impact of temperature on economic growth is then $f(T_{it}) = \sum_m \tau^m T_{it}^m$. See Internet Appendix for more details about our empirical framework (see Appendix A).

With the parameter estimates based on our linear spline regression models, we conduct a thought experiment to gauge the impact of temperature increases on economic growth. Essentially, we compare the economic growth under two scenarios. One is the "no warming" scenario in which temperatures are assumed to stay at their 1995 levels ("counterfactual"), and the other is the "warming" scenario in which temperatures increase. See Internet Appendix for more details about how we estimate the impact of climate change (see Appendix A).

4. Empirical results

4.1. Nonlinear relationship between temperature and economic growth

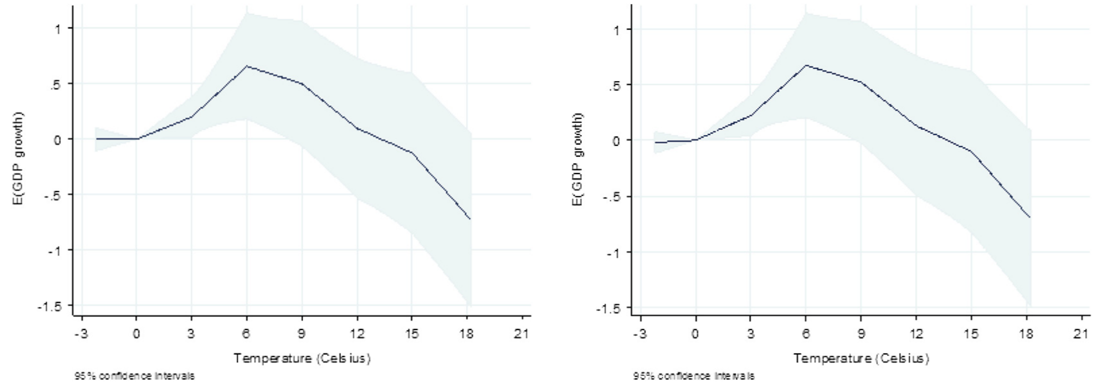
We estimate Model (1) for the US sample, and report the mean impact of temperature on economic growth (i.e., $f(T_{it}) = \sum_m \tau^m T_{it}^m$) in Fig. 1(a). As we can see, economic growth increases with temperature, but only until 6 °C, well below the optimal temperature based on national data (e.g., 13 °C in Burke et al., forthcoming). What explains the difference in the optimal temperatures between national- and cell-level regressions? First, as Nordhaus (2006) points out, for large economies such as the US, national average temperatures are "virtually meaningless". Second, if there is a nonlinear relationship between temperature and growth within an economy, the impact at the national average temperature will be a biased estimate of the average impact across the country, due to Jensen's inequality. The results based on Model (2) are depicted in Fig. 1(b), and are consistent.

Are the US results unique? To answer this question, we repeat the same analysis for the EU and plot the mean impact of temperature on economic growth based on Model (1) in Fig. 2(a) and that based on Model (2) in Fig. 2(b). Again, economic growth increases as temperature increases, but only until 6 °C. Thus, the nonlinear relationship between temperature and economic growth with the optimal temperature at about 6 °C is not unique to the US sample.

4.2. Impact of climate change on the US and the EU

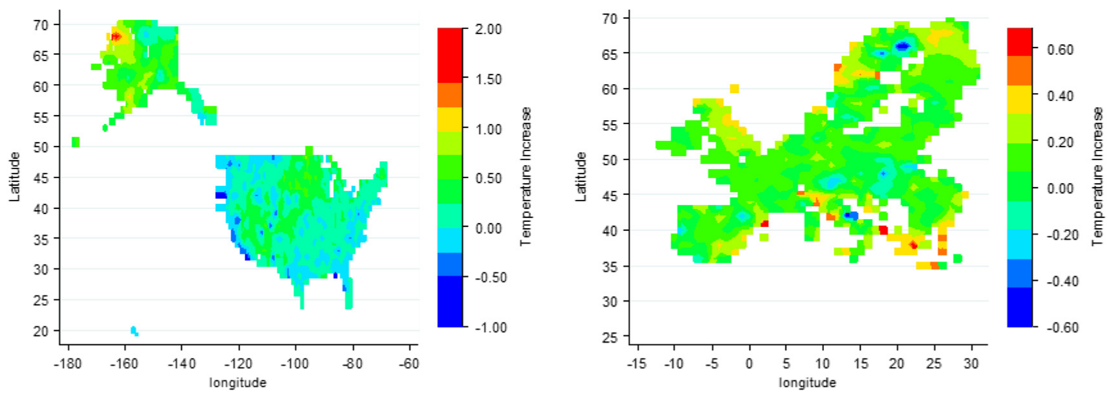
4.2.1. Heterogeneous temperature increases across cells

We first examine if warming is homogeneous across cells. Figs. 3(a) and (b) show the temperature increases in the US and the EU from 1995 to 2005, respectively. As we can see, warming is not homogeneous. Thus, we would mis-estimate the impact of climate



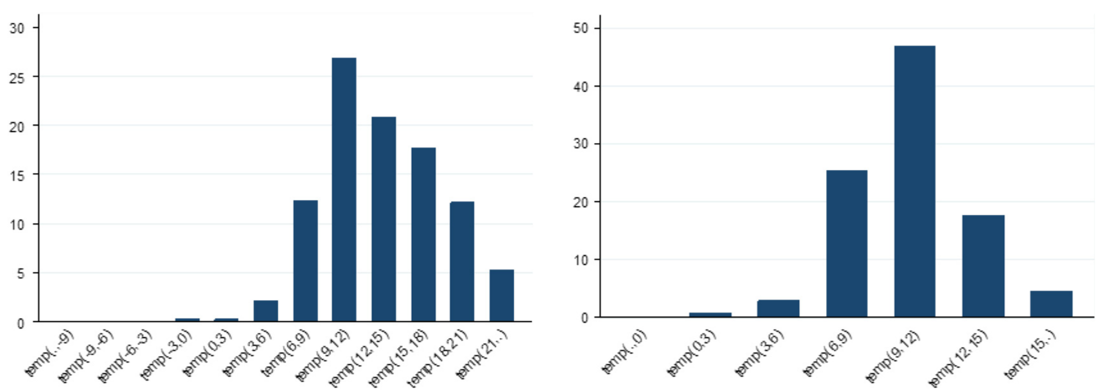
(a) Model (1). (b) Model (2).

Fig. 2. Temperature and growth in the EU. Figs. 2 reports the mean impact of temperature on the EU growth (i.e., $f(T_{it}) = \sum_m \tau^m T_{it}^m$).



(a) United States. (b) European Union.

Fig. 3. Heterogeneous temperature increases across cells. Fig. 3 depicts the temperature increases in the US and the EU from 1995 to 2005, respectively.



(a) United States. (b) European Union.

Fig. 4. Heterogeneous distribution of production. Fig. 4 shows the distribution of production in the US and the EU.

change on economic growth if we used national-level temperature projections.

The above observation motivates us to use the grid-level temperature projections downscaled from CMIP5 (IPCC, 2014) by Hijmans et al. (2005).[4] More specifically, we focus on the climate projections for 2050, which consist of a total of 63 projections and are derived from 19 Global Climate Models (GCM) combined with four Representative Concentration Pathways (RCP). In addition to monthly minimum/maximum temperatures and precipitation, each projection also consists of a set of bioclimatic variables among which the annual mean temperature is used in this study. Each projection is a GeoTIFF raster (which enables geographic locations of values), and can be visualized with Geographic Information Systems tools. Projections are available with 10-min spatial resolution which is about 18.5 km at the equator. Since this study adopts a 1-degree resolution, an ArcGIS tool Aggregate is called in a Python script to aggregate each annual mean temperature raster to 1-degree resolution. Finally, annual mean temperature values are retrieved from 63 1-degree resolution rasters for further analysis.

4 The data are available at http://worldclim.org/.

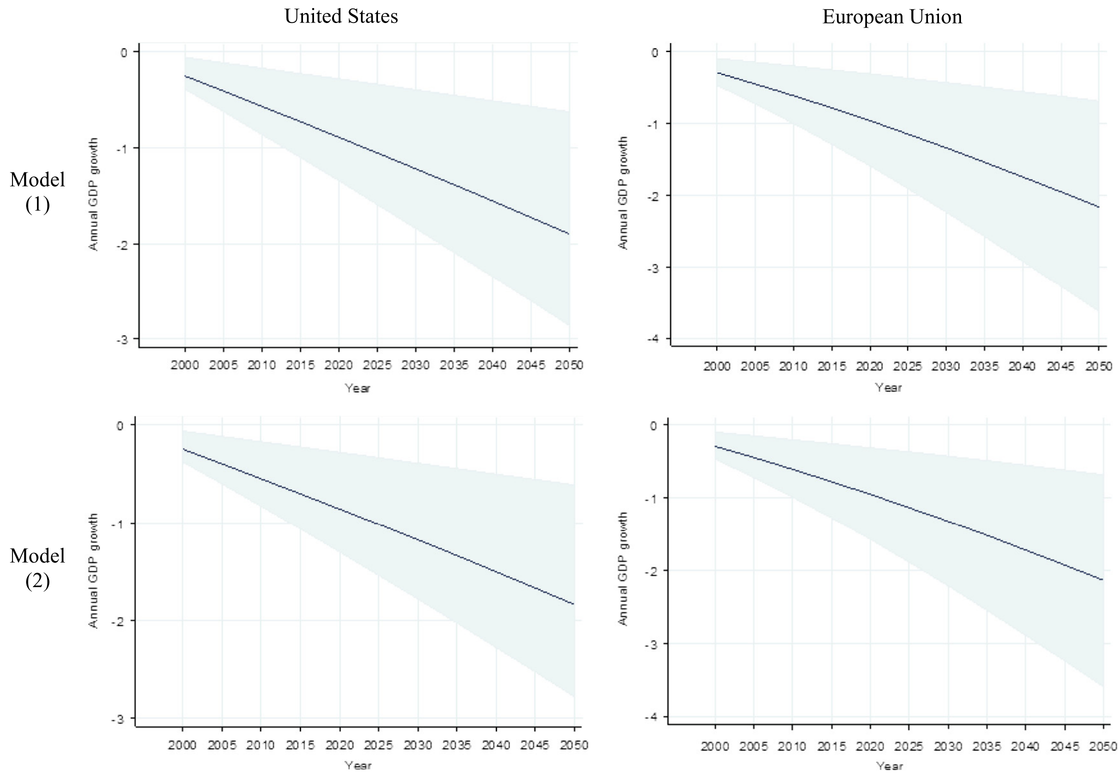


Fig. 5. Impacts of climate change on economic growth. Fig. 5 presents the impact of climate change. While the solid line depicts the median projection across all 63 climate models, the range between 5th and 95th percentiles is plotted as shaded area.

4.2.2. Heterogeneous distribution of production

The impact of climate change on economic growth also depends on the distribution of production. For instance, if most of production occurs in areas with temperatures below the optimal temperature, climate change helps increase economic growth. We therefore examine the distribution of production in Figs. 4(a) and (b). For both the US and the EU, production occurs mainly in cells with temperatures above the optimal temperature, suggesting that temperature increases projected by IPCC (2014) could have significantly negative impact on economic growth.

4.2.3. Impact of climate change

We estimate the impact of climate change on economic growth based on the parameter estimates from Section 4.1 and the IPCC temperature projections. The results are presented in Fig. 5. While the solid line depicts the median projection across all 63 climate models, the range between 5th and 95th percentiles is plotted as shaded area. As we can see, based on the cell-level temperature–growth relationship, projected temperature increases have significantly negative impact on the economic growth of the US and the EU. By 2050, with IPCC projected warming, the annual economic growth in the US would be 1.90%/1.84% lower relative to the counterfactual case in which temperatures stay at their 1995 levels, based on Model (1)/Model (2). The significant impact is due to that most of production in the US takes place in areas with temperatures above the optimal temperature of 6 °C. The EU results are consistent with the US results. By 2050, with the IPCC projected temperature increases, the annual economic growth in the EU would be 2.17%/2.14% lower relative to the counterfactual case in which temperatures stay at their 1995 levels, based on Model (1)/Model (2).

5. Conclusions

In this paper, we extend Deryugina and Hsiang (2014) and Colacito et al. (2016), and find that long-run temperature increases significantly negatively affect the US and the European Union. Our results suggest that mitigation over long run does not make developed economies not negatively affected by climate change. Therefore, our results suggest more proactive climate policy.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.econlet.2017.01.017.

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