Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis

Matthew E. Kahn, Kamiar Mohaddes, Ryan N. C. Ng, M. Hashem Pesaran, Mehdi Raissi, and Jui-Chung Yang

Discussion by: Soo Kim and Guillermo Verduzco

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Introduction

- This paper investigates the long-term macroeconomic effects of climate change across 174 countries over the period 1960 to 2014.
- Climate change could affect the level of output (by changing agricultural yields, for example) or an economy's ability to grow in the long-term if the changes in climate variables are persistent, through reduced investment and lower labour productivity.
- The authors focus on the latter and develop a theoretical growth model that links deviations of climate variables (temperature and precipitation) from their historical norms to changes in labour productivity and, hence real output per capita.

Introduction

- In their empirical application, the authors allow for dynamics and feedback effects in the interconnections of climate change and macroeconomic variables.
- Also, by using deviations of climate variables from their respective historical norms, while allowing for nonlinearity, they avoid the econometric pitfalls associated with the use of trended variables, such as temperature, in output growth equations.
- As it is well known, and is also documented in our paper, temperature has been trending upward strongly in almost all countries in the world, and its use as a regressor in a growth regression can lead to spurious estimates.

Contributions

- Firstly, the authors extend the stochastic single-country growth models of previous studies to N countries sharing a common technology but different climate conditions.
- The theoretical model postulates that labour productivity in each country is affected by a common technological factor and country- specific climate variables, which the authors take to be average temperature, $\mathcal{T}_{it}$, and precipitation, $\mathcal{P}_{it}$, in addition to other country-specific idiosyncratic shocks.
- As long as $\mathcal{T}_{it}$ and $\mathcal{P}_{it}$ remain close to their respective historical norms (regarded as technologically neutral), they are not expected to affect labour productivity.
- However, if climate variables deviate from their historical norms, the effects on labour productivity could be positive or negative, depending on the region under consideration.

Contributions

- Secondly, contrary to much of the literature which is mainly concerned with short-term growth effects, the authors explicitly model and test the long-run growth effects of persistent increases in temperature.
- Thirdly, they use the half-panel Jackknife FE (HPJ-FE) estimator proposed in Chudik et al. (2018) to deal with the possible bias and size distortion of the commonly-used FE estimator (given that $\mathcal{T}_{it}$ is weakly exogenous).

Results (spoiler alert)

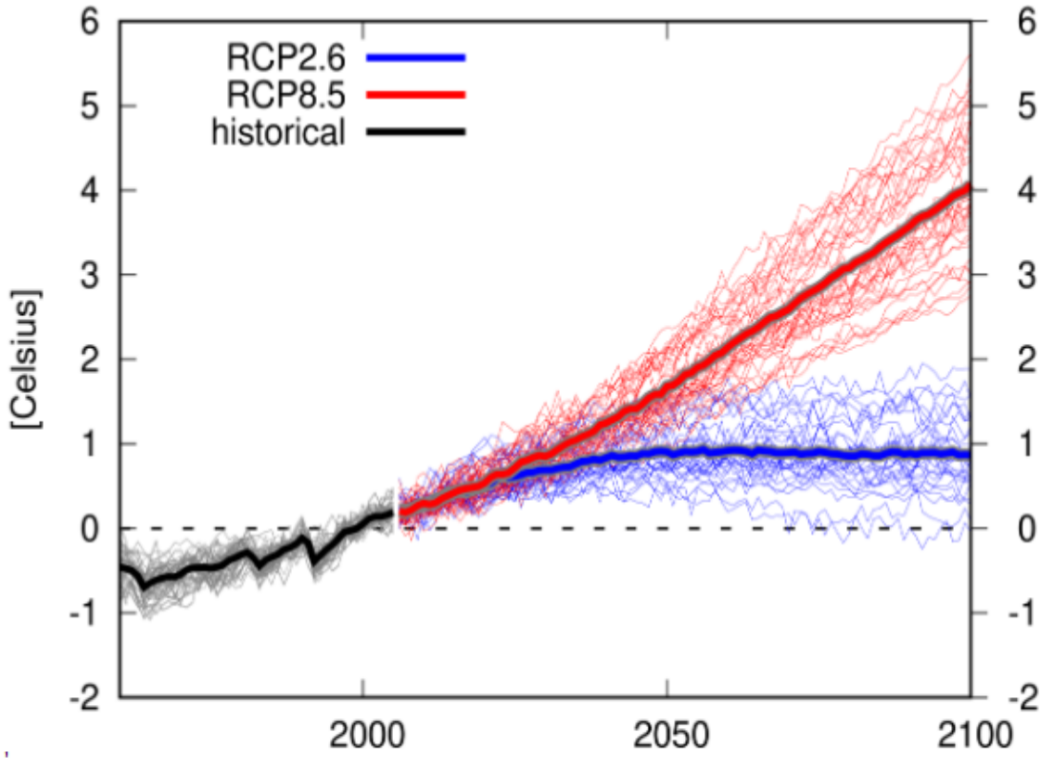
- The authors test the predictions of their theoretical model using cross-country data on per-capita output growth and the deviations of temperature and precipitation from their historical norms over the past fifty five years (1960-2014).
- The results suggest that a persistent change in the climate has a long-term negative effect on per capita GDP growth.
- They could not detect any significant evidence of an asymmetric long-term growth impact from positive and negative deviations of temperature from its norms.
- Furthermore, they show that their empirical findings apply equally to poor or rich, and hot or cold countries.

Counterfactuals

- The authors perform a number of counterfactual exercises where we investigate the cumulative income effects of annual increases in temperatures over the period 2015-2100 (when compared to a baseline scenario under which temperature in each country increases according to its historical trend of 1960-2014).
- They show that an increase in average global temperature of 0.04°C per year reduces world's real GDP per capita by 7.22 percent by 2100.
- Limiting the increase to 0.01°C per annum, which corresponds to the December 2015 Paris Agreement, reduces the output loss substantially to 1.07 percent, only.

Counterfactuals

Figure 1: Global Temperature Projections (Deviations from 1984-2014)



Counterfactuals

- In contrast with the previous literature, the counterfactual estimates in this paper suggest that all regions (cold or hot, and rich or poor) would experience a relatively large fall in GDP per capita by 2100 in the absence of climate change policies (i.e., the RCP 8.5 scenario).
- However, the size of these income effects varies across countries depending on the projected paths of temperatures.
- Finally, the authors examine the climate change-growth relationship in a within-country context and also focus on the channels of impact (labour productivity, employment, and output growth in various sectors of the economy).

Historical patterns

This section examines how global temperature has evolved over the past half century (1960-2014). Allowing for the significant heterogeneity that exists across countries with respect to changes in temperature over time, wthe authors estimate country-specific regressions

$$\mathcal{T}_{it} = \alpha_{\mathcal{T}i} + b_{\mathcal{T}i}t + v_{\mathcal{T}i,t}, \quad \text{for } i = 1, 2, 3, ..., N = 174$$

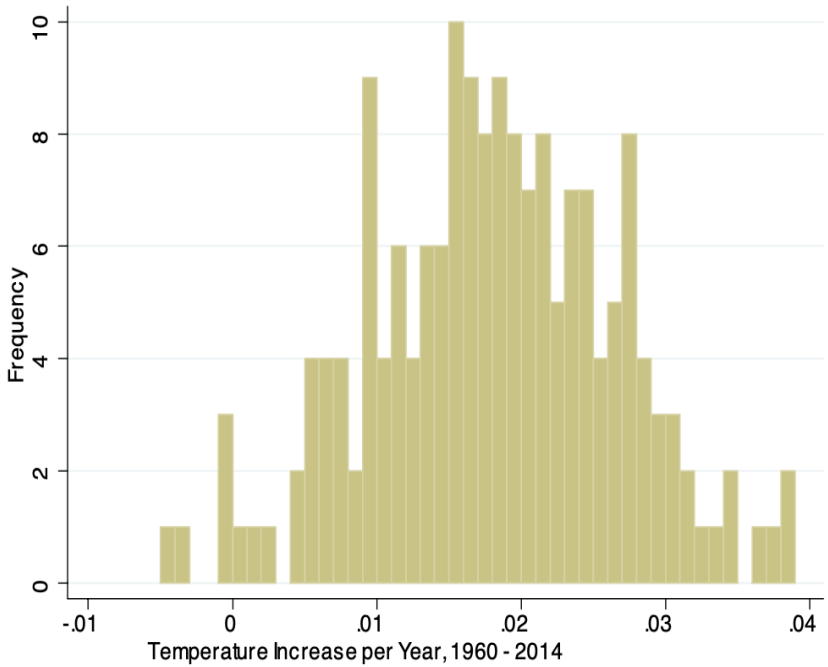
where $\mathcal{T}_{it}$ denotes the population-weighted average temperature of country i at year t. The per annum average increase in land temperature for country i is given by $b_{\mathcal{T}i}$.

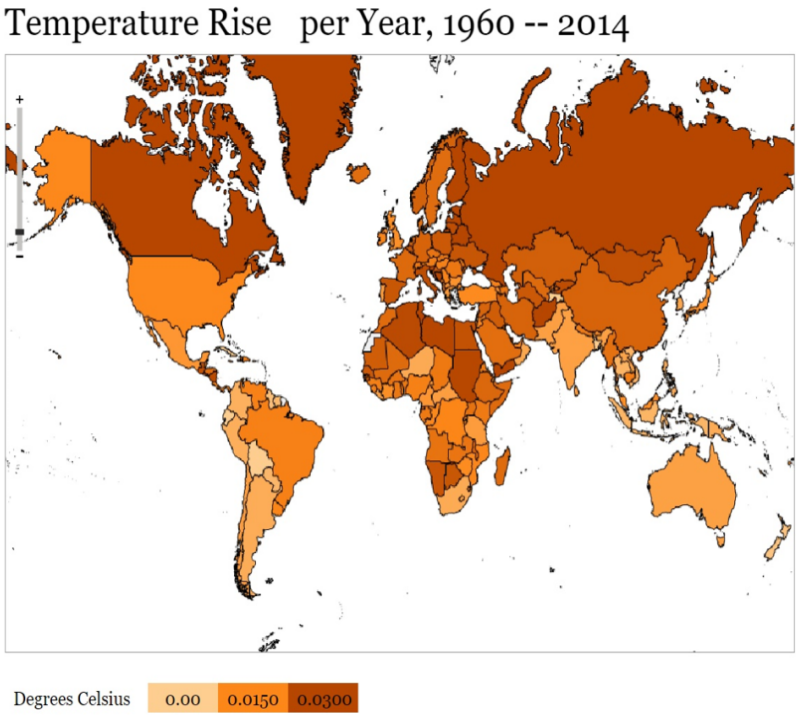
Historical patterns

- Estimates range from -0.0044 (Samoa) to 0.0390 (Afghanistan).
- For 169 countries (97.1% of cases), these estimates are positive; out of which, the estimates in 161 countries (95.3% of cases) are statistically significant at the 5% level.
- There are only five countries for which the estimate, $b_{\mathcal{T}i}$, is not positive: Bangladesh, Bolivia, Cuba, Ecuador and Samoa, but none of these estimates are statistically significant at the 5% level.
- Temperature has been rising for pretty much all of the countries in our sample, indicating that $\mathcal{T}_{it}$ is trended.

Historical patterns

Figure 4: Temperature Increase per year for the 174 Countries, 1960–2014





Long-Term Impact of Climate Change on Economic Growth

The authors examine the long-term impact of climate change on per capita output growth across countries. To this end, they estimate the following panel ARDL model:

$$\Delta y_{it} = a_i + \sum_{\ell=1}^{p} \varphi_\ell \Delta y_{i,t-\ell} + \sum_{\ell=0}^{p} \boldsymbol{\beta}_\ell' \Delta \mathbf{x}_{i,t-\ell} + \varepsilon_{it}, \tag{17}$$

where y_{it} is the log of real GDP per capita of country i in year t, a_i is the country-specific fixed effect, $\mathbf{x}_{it} = [(\mathcal{C}_{it} - \mathcal{C}^*_{i,t-1})^+, (\mathcal{C}_{it} - \mathcal{C}^*_{i,t-1})^-]'$, $\mathcal{C}_{it} = (\mathcal{T}_{it}, \mathcal{P}_{it})'$, $\mathcal{C}^*_{i,t-1} = (\mathcal{T}^*_{i,t-1}, \mathcal{P}^*_{i,t-1})'$, $\mathcal{T}_{it}$ and $\mathcal{P}_{it}$ are the population-weighted average temperature and precipitation of country i in year t, respectively, and $\mathcal{T}^*_{i,t-1}$ and $\mathcal{P}^*_{i,t-1}$ are the historical norms of climate variables.

Long-Term Impact of Climate Change on Economic Growth

- The fixed estimated coefficients of the precipitation variables are not statistically significant.
- However, long-run economic growth is adversely affected when temperature deviates from its historical norm persistently.
- The fixed effects estimates suggest that a 0.01°C annual increase in the temperature above its historical norm reduces real GDP per capita growth by 0.0577 percentage points per year and a 0.01°C annual decrease in the temperature below its historical norm reduces real GDP per capita growth by 0.0505 percentage points per year.

Long-Term Impact of Climate Change on Economic Growth

Given the heterogenous sample of 174 countries, a follow-up question is whether the estimated adverse long-run growth effects are driven by poor countries.

The authors, therefore, follow Dell et al. (2012) and Burke et al. (2015) and augment their specification with an interactive term to capture any possible differential effects of temperature increases (decreases) above (below) the norm for the rich and poor countries:

$$\Delta y_{it} = a_i + \sum_{\ell=1}^{p} \varphi_\ell \Delta y_{i,t-\ell} + \sum_{\ell=0}^{p} \boldsymbol{\beta}_\ell' \Delta \mathbf{x}_{i,t-\ell} + \sum_{\ell=0}^{p} \boldsymbol{\zeta}_\ell' \Delta \mathbf{x}_{i,t-\ell} \times \mathbb{I}\left(\text{country } i \text{ is poor}\right) + \varepsilon_{it},$$

Long-Term Impact of Climate Change on Economic Growth

Moreover, to investigate whether temperature increases affect hotter countries more than colder ones, they estimated the following panel data model:

$$\Delta y_{it} = a_i + \sum_{\ell=1}^{p} \varphi_\ell \Delta y_{i,t-\ell} + \sum_{\ell=0}^{p} \boldsymbol{\beta}_\ell' \Delta \mathbf{x}_{i,t-\ell} + \sum_{\ell=0}^{p} \boldsymbol{\xi}_\ell' \Delta \mathbf{x}_{i,t-\ell} \times \mathbb{I}\left(\text{country } i \text{ is hot}\right) + \varepsilon_{it},$$

where a country is defined as cold (hot) if its historical average temperature is below (above) the global median.

Long-Term Impact of Climate Change on Economic Growth

- The estimated coefficients of the interactive terms are not statistically significant.
- Therefore, we cannot reject the hypothesis that there are no differential effects of climate change on poor versus rich nations or hot versus cold countries.
- Therefore, the first specification is the preferred model and will be used in the counterfactual analysis.
- The results across all four specifications suggest that climate change, defined as persistent deviations of temperature from its historical norm, affects long-run income growth negatively (the estimates range from -0.0352 to -0.0692).

Long-Term Impact of Climate Change on Economic Growth

- In contrast with the literature, these results show that an increase in temperature above its historical norm is associated with lower economic growth in the long run.
- This suggests that the welfare effects of climate change are significantly underestimated in the literature.
- Therefore, these findings call for a more forceful policy response to climate change.

Counterfactual Analysis: ARDL Model

$$\Delta y_{it} = \alpha_i + \sum_{l=1}^{p} \varphi_l \Delta y_{i,t-l} + \sum_{l=0}^{p} \beta_l' \Delta x_{i,t-l} + \epsilon_{it}$$

$$\Rightarrow \varphi(L)\Delta y_{it} = \alpha_i + \sum_{l=0}^{p} \beta_l' \Delta x_{i,t-l} + \epsilon_{it}$$

$$\Rightarrow \Delta y_{it} = \varphi(L)^{-1}\alpha_i + \sum_{l=0}^{p} \varphi(L)^{-1}\beta_l' \Delta x_{i,t-l} + \varphi(L)^{-1}\epsilon_{it}$$

- The authors perform a counterfactual exercise to measure the cumulative output per capital effects of persistent increases in annual temperatures above their norms over the period 2015-2100.

Counterfactual Analysis: ARDL Model

- The counterfactual output then can be written as:

$$\begin{aligned}\xi_{i,T+h} &= \mathbb{E}(y_{i,T+h}|\text{Expected Change}) - \mathbb{E}(y_{i,T+h}|\text{No Change}) \\ &= \sum_{j=1}^{h} \psi_{h-j}(x_{i,T+j}^{\text{Change}} - x_{i,T+j}^{\text{No Change}})\end{aligned}$$

- Note that the impact of climage change clearly depends on the magnitude of $x_{i,T+j}^{\text{Change}} - x_{i,T+j}^{\text{No Change}}$.

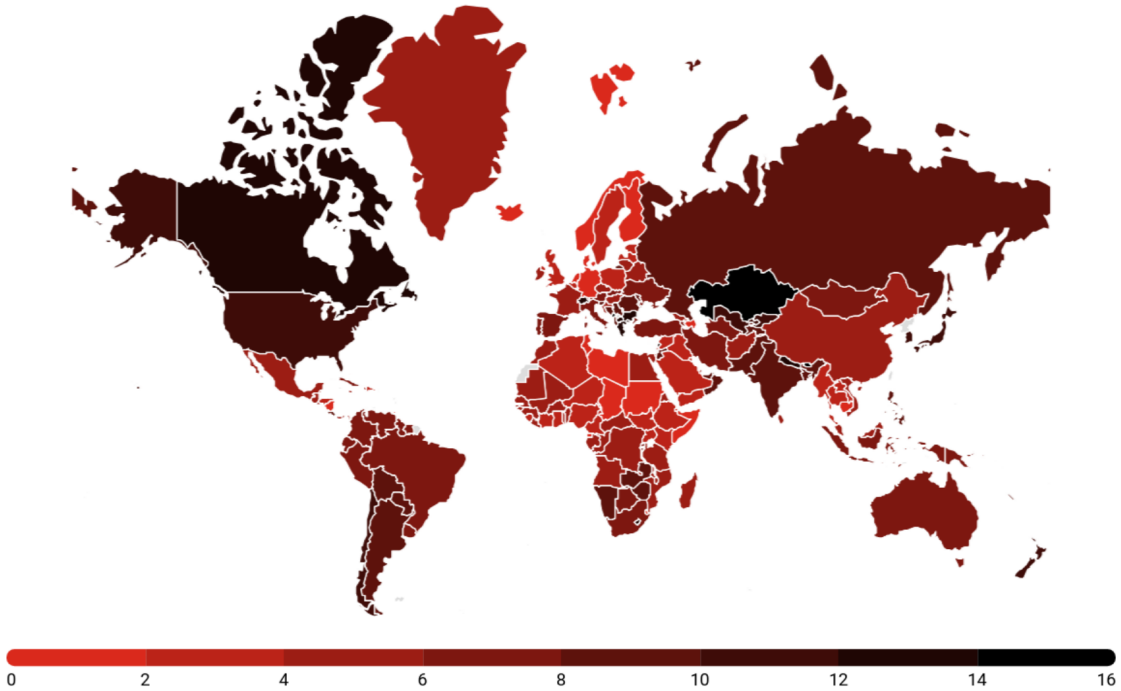
- $x_t^{(*)} = (T_{it}, P_{it})'$ (Temperature and precipitation)

Counterfactual Analysis: ARDL Model

- The authors considered output effects between the historical trend of 1960-2014 and:
  - RCP 8.5: Increase in average global temperature of 0.04 C per year (Uncontrolled)
  - RCP 2.6: Increase in average global temperature of 0.01 C per year (2015 Paris Agreement)

Counterfactual Analysis: Results

Figure 6: Percent Loss in GDP per capita by 2100 in the Absence of Climate Change Policies (RCP 8.5 Scenario)



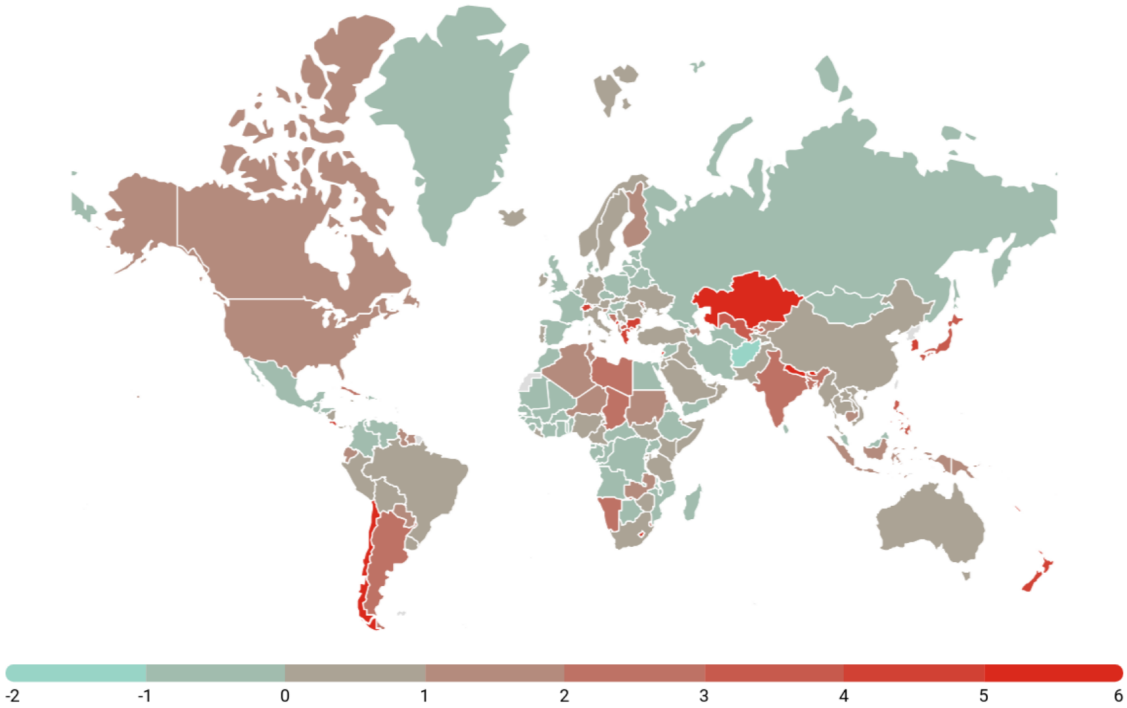
Counterfactual Analysis: Results

In the absence of climate change policy:

- The percentage loss in per-capita income by 2100 are sizable, regardless of whether a country is rich or poor, and hot or cold.
- The losses vary significantly across countries depending on the country-specific projected paths of temperatures.
- On average, per-capita output losses are 7.22%.
- Rich and cold countries suffer from larger output losses than poor and hot countries.

Counterfactual Analysis: Results

Figure 7: Percent Loss in GDP per capita by 2100 Abiding by the Paris Agreement (RCP 2.6 Scenario)



Counterfactual Analysis: Results

Under the Paris Agreement:

- The percentage loss in per-capita income by 2100 are substantially mitigated.
- The world could benefit from the mitigation policies in 2030, limiting losses of climate change to 1.07% on average.
- Rich and cold countries suffer from larger output losses than poor and hot countries.
- It is unlikely that we offset the effect of climate change entirely.

Evidence from the United States: Overview

- The authors then conduct a similar analysis using the data of 48 contiguous US states, an advanced economy with a high level of development, from 1963 to 2016.
- Main robustness check:
  - A universal long-run relationship between climate change and economic growth?
  - If the US economy were adapting to climate change, should we not expect the negative impact of deviations of temperature and precipitation from their historical norms to be shrinking over time?

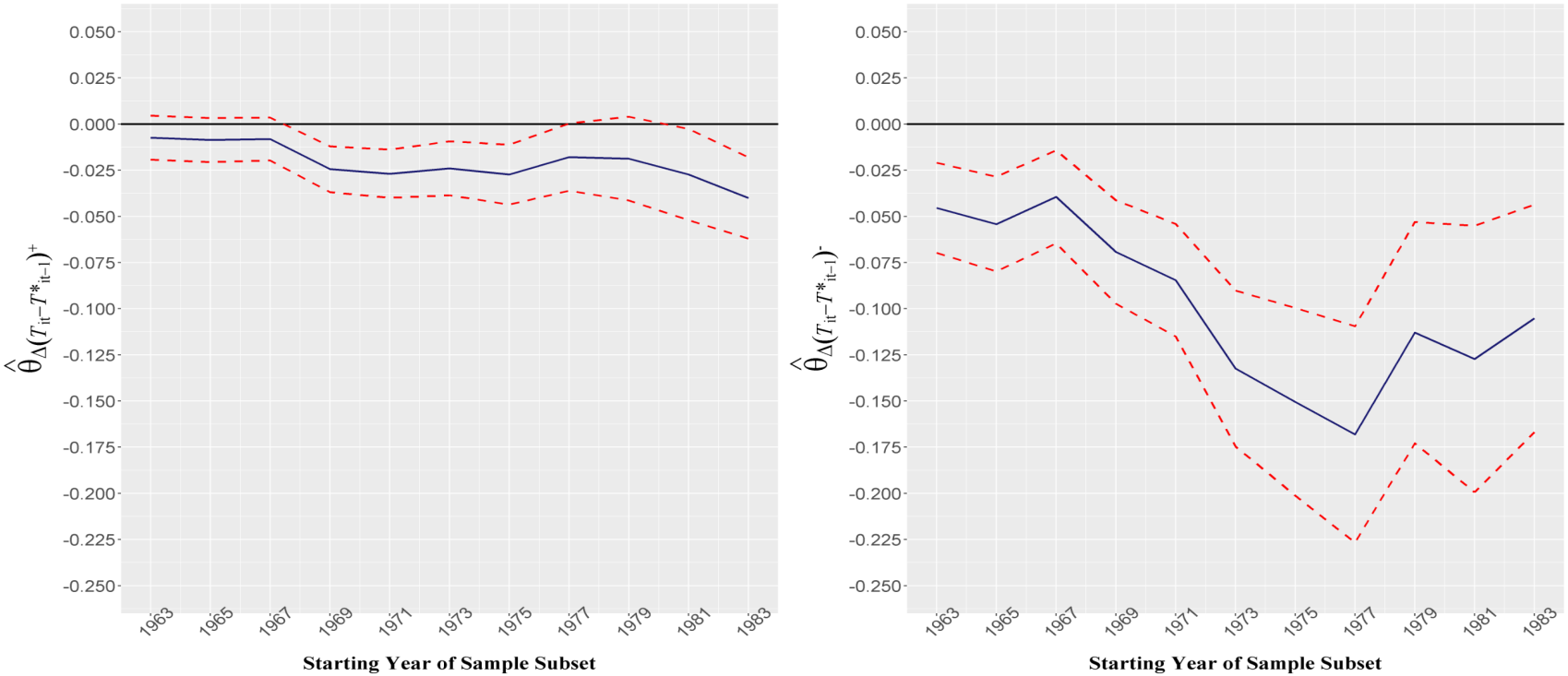
Evidence from the United States: Results

Summary of the Results

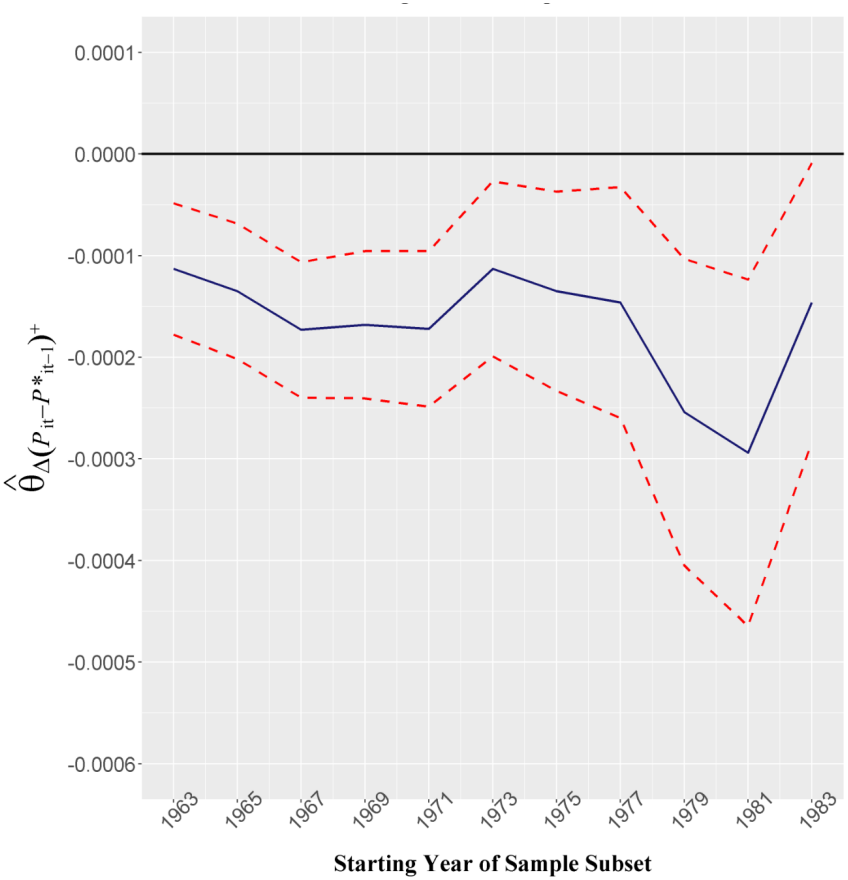
- Climate change affects the U.S. ecosystem not only through increases in average temperatures, but also through changes in the extremes— more intense droughts; heavier snow and rainfall; as well as extreme cold.
- Estimated LR coefficient are negatively correlated with real GSP and employment.
- Size of the estimates for LR coefficients are smaller in absolute value than the cross-country average. (Higher degree of adaptation in the United States)

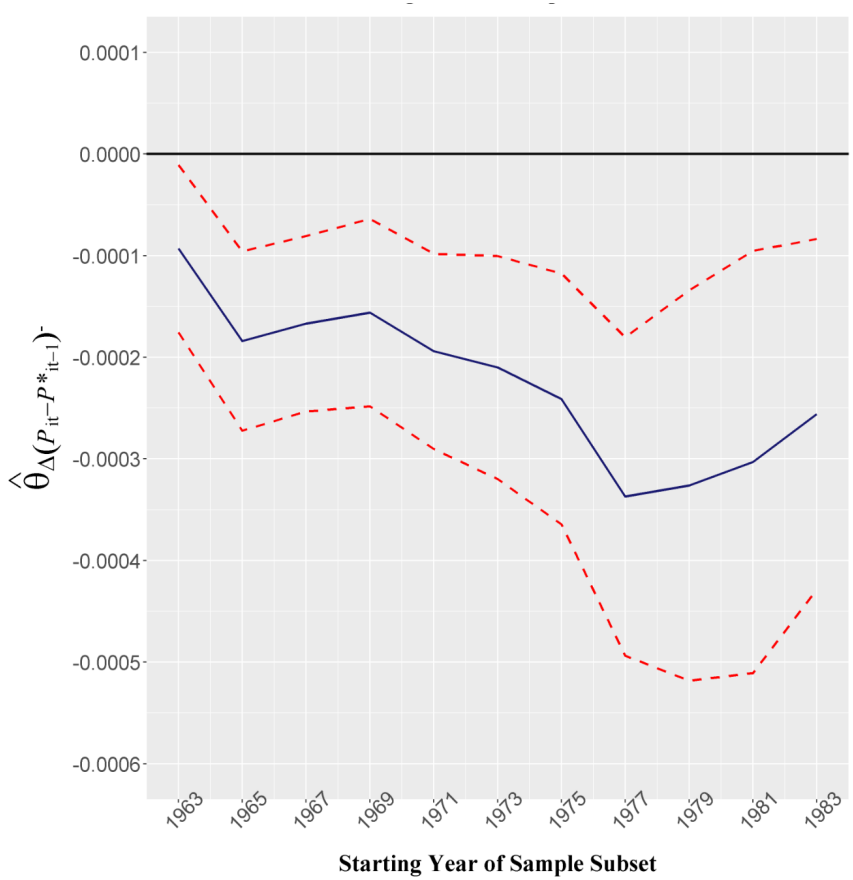
Evidence from the United States: Results

Figure 8: Long-Run Effects of Climate Change on per capita Real GSP Growth in the United States, 1963–2016



Evidence from the United States: Results





Evidence from the United States: Results

Results from dropping the first few years:

- Estimated LR coefficients becoming larger in absolute value over time. $\Rightarrow$ Efficacy of adaptation effort of the U.S.?
- Possible Explanation
  - Adaptation efforts might be concentrated in cetain sectors.
  - Global temperature rises at an unprecedented pace.
  - Firms might underestimated the likelihood or severity of future weather events.

Conclusion

- Data: 174 countries, 1960-2014.
- Methodology: differentiating between short-run and long-run effects, accounting for bi-directional feedbacks and temperature feedbacks.
- Findings:
  - Persistent changes in climate has LR negative effects on economic growth.
  - These effects are universal across rich and poor, hot and cold countries.
  - Climate change policies are effective in limiting economic losses from climate change across almost all countries, larger than conventionally expected.