

THE POSSIBILITY AND PLAUSIBILITY OF LARGE MACROECONOMIC IMPACTS FROM CLIMATE CHANGE

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Implications of Climate Change and
Ecosystem Services Degradation for
Macroeconomic and Financial Stability

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Does climate change represent a serious or even catastrophic threat to future lives and livelihoods, or is it more likely to be a relatively modest annoyance that most of the world will be able to straightforwardly deal with? Proponents of both views are commonly found in both academic literature and broader popular and policy debates. Surveys of academic experts have found very wide variation in expectations of potential economic damage from future climate change, with some expecting negligible economic impacts and others foreseeing substantial possible declines in future economic output from a warming climate.¹ Early economic analysis using integrated assessment models suggested that climate change might reduce economic output by only a few percentage points by 2100²—or roughly one to two years of economic growth, hardly an economic catastrophe. However, more recent microeconomic and sector-specific work suggests the possibility of much more substantial economic damage

1. See Pindyck (2019).

2. See Revesz and others (2014).

Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability, edited by Maximilian Auffhammer, Elías Albagli, Sofia Bauducco, and Gonzalo García-Trujillo, Santiago, Chile. © 2025 Central Bank of Chile.

when impacts are summed across sectors.³ Perhaps consistent with these findings, a growing body of empirical work using national and subnational macroeconomic data also suggests the possibility of much larger aggregate future damages from climate change.⁴ Reconciling these disagreements on the potential magnitude of the effects of climate change on the economy and related outcomes is important for scaling mitigation ambition and anticipating adaptation needs.

Here we revisit and expand on recent analyses that use country-level data on climate and output to estimate the future economic impacts of climate change. We use an updated panel dataset on country-level rates of growth in per capita GDP paired with data on temperature and precipitation⁵ to study whether contemporaneous and lagged temperature shocks affect GDP growth rates. Our approach uses within-country variation over time in temperature and GDP growth and controlling flexibly for a host of time-invariant and time-varying factors that could be correlated with both GDP growth and temperature. We then combine these estimated historical relationships between temperature and GDP growth with output from an ensemble of global climate models that project future changes in temperature under different emissions scenarios. This allows us to project potential impacts on country and global economic output, under the assumption that the economic impacts of a given amount of future warming are similar to the impacts of the same amount of historical temperature variation. We project impacts of warming on future growth rates, relative to a counterfactual world where temperatures are fixed at recent values, and integrate over time to estimate aggregate impacts on output at both the country and global level, accounting for uncertainty in both the historical econometric estimates as well as in the climate model estimates of future warming.

From this exercise, we estimate large possible impacts of future warming. Under a more conservative approach where temperature is not allowed to have lagged effects on growth rates, we find that global economic output could be 10 percent lower in 2100 relative to a world that did not warm beyond today's temperatures. Under a model that allows lagged temperature shocks to affect contemporaneous growth—a model that appears more consistent with the data—we

3. See Rennert and others (2022), U.S. EPA (2022).

4. See Dell and others (2012), Burke and others (2015), Kalkuhl and Wenz (2020), Burke and Tanutama (2019), Nath and others (2023), Bilal and Kanzig (2024).

5. See Burke and others (2023).

estimate that global economic output could be 30 percent lower by 2100 relative to a no-warming scenario. We thus conclude that large macroeconomic impacts of climate change are indeed possible.

However, are such impacts plausible? Or do they require making claims about future growth rates that are wholly inconsistent with observed historical behavior of growth rates? As one way of assessing plausibility, we compare our projected impacts of climate on growth rates to observed historical variation in growth rates and to a recent Bayesian econometric model of international growth dynamics that was trained on historical data and used to project plausible future growth rates, absent climate change, over the next century and beyond.⁶ This comparison cannot tell us whether climate change can or will have impacts as large as we suggest but allows us to ask whether the finding of large impacts requires assumptions on future growth impacts that push growth rates well outside their historical bounds. This is a somewhat conservative test, given that there is no reason, in principle, to believe that climate change could not generate ahistoric outcomes for which historical experience is a poor guide. However, we find that for most countries, the projected difference between growth rates under climate change and in a counterfactual world without climate change is within both historical variation as well as projected ranges in future growth rates by Müller and others (2022). We thus conclude that for most countries, growth impacts are historically plausible. In the hottest countries where we project future growth impacts to be largest, such as some countries in the African Sahel and Middle East, our projected impacts do appear to push growth rates outside of their historical range. We discuss whether such impacts could be consistent with other impact mechanisms identified in the existing climate literature.

1. DATA AND EMPIRICAL APPROACH

To estimate the relationship between variation in temperature and economic output, we follow earlier work⁷ and use panel fixed effects regression to isolate the contribution of annual temperature fluctuations to variation in growth in real per capita GDP, by using national accounts data on country-level GDP from 1961 to 2019. Specifically, we estimate distributed lag panel fixed effects models of the form:

6. See Müller and others (2022).

7. See Dell and others (2012), Burke and others (2015, 2023).

$$g_{it} = \sum_{k=0}^n f(T_{i,t-k}, P_{i,t-k}) + \alpha_i + \mu_t + \theta_i \cdot t + \theta_i \cdot t^2 + \varepsilon_{it} \quad (1)$$

where g_{it} is the first difference of the natural log of real per capita GDP in country i and year t , using data in World Bank (2022). α_i is a vector of country fixed effects that account for any time-invariant differences between countries; μ_t is a vector of year fixed effects that account for any shocks or trends in either temperature or growth that are common across countries, such as macroeconomic shocks; $\theta_i \cdot t$ and $\theta_i \cdot t^2$ are country-specific quadratic time trends that additionally flexibly control for locally-trending variables that could be correlated with both temperature and growth. To estimate the function $f()$, we again follow earlier work⁸ and use a parsimonious quadratic function to allow growth to respond nonlinearly to temperature and precipitation:

$$f(T_{i,t-k}, P_{i,t-k}) = \beta_{1,k} T_{i,t-k} + \beta_{2,k} T_{i,t-k}^2 + \lambda_{1,k} P_{i,t-k} + \lambda_{2,k} P_{i,t-k}^2 \quad (2)$$

This specification allows the effect of warming to depend on temperature levels, which can be seen by taking the derivative of equation (2) with respect to temperature. Prior work has shown that the temperature-growth relationship is well approximated with a concave quadratic function and that this relationship is in turn consistent with a host of microeconometric estimates of temperature impacts in various sectors of the economy.⁹ We use data on annual country-average temperature and precipitation data from ERA5-Land,¹⁰ a global monthly 0.1-degree gridded dataset with temperature, precipitation, and other climate variables. We compute country-year average temperature T_{it} by aggregating the native 0.1-degree data to the country-year level by taking the population-weighted mean over grid cells and months, using population data from the Gridded Population of the World dataset.¹¹

To understand whether the data are consistent with “level effects”, in which output returns to its previous trajectory in the years following a temperature shock, or “growth effects”, in which output is permanently lower following a temperature shock, we again follow earlier work¹² and estimate distributed lag models where we

8. See Burke and others (2015, 2023).

9. See Burke and others (2015).

10. See Muñoz-Sabater and others (2021).

11. See CIESIN (2018).

12. See Dell and others (2012), Burke and others (2015).

model growth as a function of contemporaneous and multiple lagged values of temperature and precipitation. The sum of contemporaneous and lagged effects provides evidence into whether the effects of a temperature shock on output are persistent or transitory in nature: contemporaneous and lagged effects that sum to zero indicate level effects, whereas effects that do not sum to zero are consistent with growth effects. Given that we are estimating a nonlinear temperature response function, we test for level versus growth effects by evaluating the sum of marginal effects (current and lagged) at each point in the temperature distribution. In this analysis, we estimate distributed lag functions out to five lags. In the work on which this paper builds, functions are estimated out to ten lags and also compared to local projections approaches to estimating the impacts of shocks.¹³

To project climate damages, growth in each country in each future year is calculated as $g_{it} = \eta_{it} + \delta_{it}$, where η_{it} is the assumed baseline secular rate of growth absent climate change, and δ_{it} is the growth impact of warming, calculated as:

$$\delta_{it} = f(T_{it}) - f(\bar{T}_i) \quad (3)$$

using the estimated zero-lag or five-lag response functions estimated by equation (1). Here, $\bar{T}_i$ represents the baseline (2010–2020) average temperature in country i , and T_{it} the projected future temperature in year t in that country. We calculate T_{it} using a set of 30 global climate models run under the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), which together ran the same set of prescribed emissions experiments. In each future year, we calculate the projected temperature in each country from each model and then take the median across models to get the median projected temperature change in that year. To avoid level biases in climate model output, we follow the customary approach and “de-bias” climate model projections by computing differences between model predicted temperature in year t and predicted temperature in the base years (2010–2020), and then applying these temperature differences to the observed baseline temperature to compute the time series of future temperatures in each country. This time series is then used in equation (3) to compute growth decrements at the country-year level.

13. See Burke and others (2023).

GDP per capita in each future country-year through 2100 is then calculated as:

$$GDPcap_{it} = GDPcap_{it-1}(1 + \eta_{it} + \delta_{it}) \quad (4)$$

with GDP/cap initialized in the base year using observed recent values. Aggregate damages are then computed by running this computation twice, once as above and once where δ_{it} is set to zero in a no climate-change scenario. The annual difference in per capita incomes between these two scenarios is then multiplied by projected population totals to get total climate-change impacts on GDP, is summed across years to get country-level impacts, and is then summed across countries to get global impacts. More details on this basic approach are provided in Burke and others (2023).

2. RESULTS

2.1 Empirical Relationships between Temperature and Growth

The left panels of Figure 1 show the results of estimating equation (1) with either zero or five lags. In the zero-lag model, in which growth in year t can only be shaped by temperature in year t , the marginal effect of warming (the derivative of the response function) is positive for countries with average temperatures below about 13°C and negative for countries with temperatures above that. This finding is consistent with earlier published evidence.¹⁴ In the five-lag model—i.e., the model where the growth rate in year t can be affected by temperature shocks in years $t-5$ to t —we find a flattening of benefits at the cold end of the temperature distribution and an amplification of negative impacts at the hotter end of the distribution. These findings suggest that positive temperature shocks yield immediate benefits in cold places that then dissipate within a few years and yield persistent negative shocks to growth for most other countries in the world that grow over time, with cumulative impacts getting more negative the hotter the country was to start with. As shown in Burke and others (2023), the marginal effects from the five-lag model are significant and negative for all countries with average temperature above about 15°C. Also shown in that paper

14. See Burke and others (2015).

is the fact that these response functions are robust to a range of other controls, fixed effects, and datasets, and that they appear to be fairly stable over the last 60 years, implying limited adaptation to date.

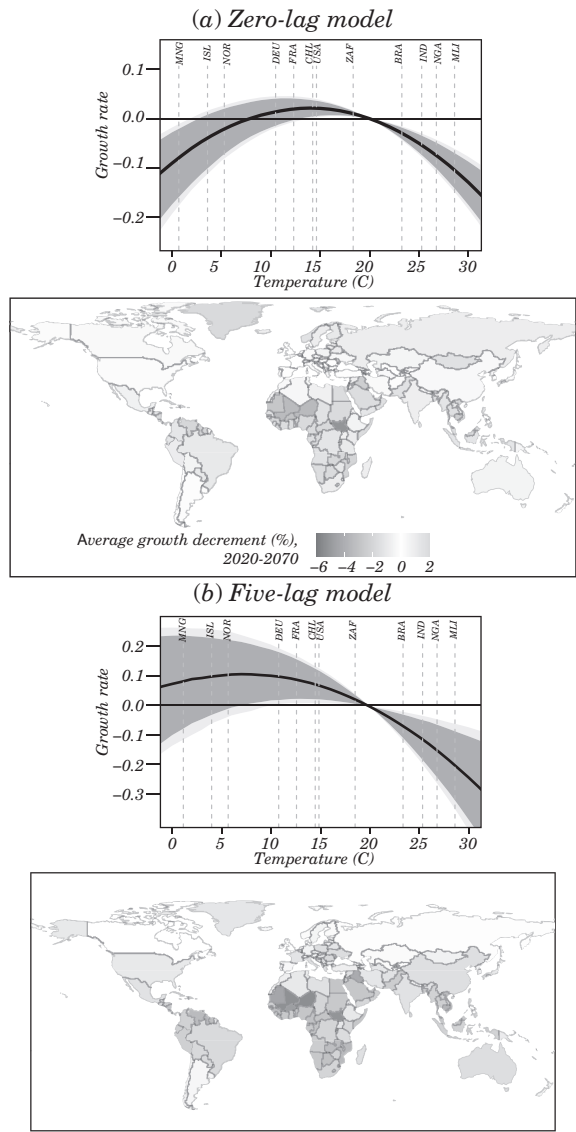
2.2 Effects on Future Growth and Output

We combine these historical econometric estimates with output from an ensemble of global climate models to project future impacts on growth rates at the country level and future impacts on the level of output by 2100. The right panels of Figure 1 show estimated impacts of warming on future growth rates at the country level, using the SSP3-7.0 warming scenario (a middle-to-high warming scenario), where calculated as the average decline in growth rates due to warming over the next 50 years (2020–2070)—i.e., the average value of δ_{it} from equation (3). Projected impacts are more negative in the tropics, which are hot to begin with, and are more negative in the five-lag model as compared to the zero-lag model. In the zero-lag model, we estimate that growth would slow by a modest 0.1–0.3 percentage points in many large economies (U.S., China) and could increase by that amount in colder parts of the European Union. In the hottest parts of the tropics, the zero-lag model predicts that growth could slow by 2–3 percentage points annually.

In the five-lag model, we estimate that growth could slow by 1–1.5 percentage points across many large economies and cooler regions (U.S., China, much of the EU, Chile) on average over the next 50 years, and that growth could slow by as much as 3–4 percentage points in much of the tropics including Latin America, Africa, the Middle East, and parts of South and Southeast Asia, and above 5 percentage points in the very hottest regions. In the zero-lag model, many higher-latitude countries experience modest benefits from warming. In the five-lag model that allows for delayed impacts, these benefits dissipate in all but the very coldest countries (e.g., Mongolia).

Based on these growth rate impacts, we project global aggregate impacts on GDP, expressed as the percentage difference in global GDP in a world that did not warm beyond 2020 versus a world that warmed at different rates, as projected by different emissions scenarios used by the IPCC. We propagate uncertainty in projected global damages by combining uncertainty in both the econometrically estimated relationship between temperature and warming from historical data as well as the cross-model uncertainty in future warming (given emissions), as revealed by the ensemble of global climate models that we use.

Figure 1. The Impact of Temperature on Country-Level Growth Rates



Source: Authors' calculations.

Notes: Left plots show the estimated relationship between country annual temperature and country growth rates, using historical data from 1961–2019. Top panel shows the zero-lag model and bottom panel, the five-lag model. Vertical dotted lines indicate today's average temperatures for selected countries. Maps show predicted growth rate impacts under future climate change, averaged over the next 50 years, using either the zero-lag (top) or five-lag model (bottom) to project impacts. Estimates represent the difference in annual growth in GDP/capita in a world with climate change versus a world without climate change, averaged over the years 2020–2070.

Estimated impacts are shown in Figure 2 using both the zero-lag and five-lag response functions and computing damages across emissions scenarios that range from highly ambitious and perhaps currently implausible (e.g., SSP1-1.9 and SSP1-2.6 that both limit warming to below about 1.5°C by 2100) to fairly ambitious (SSP2-4.5, which limits warming to between about 2–2.5°C) to more pessimistic (SSP3-7.0, which results in about 3°C of global warming). Updated estimates suggest that, given recent emissions trends and policy commitments, the world is on track for 2–3°C of warming by 2100.¹⁵ We find that damages grow roughly linearly with projected warming, with damages reaching roughly 10 percent of global GDP in 2100 under SSP3-7.0 using the zero-lag model and reaching 30 percent of global GDP under the same scenario using the five-lag model.

These estimates contrast with headline estimates from earlier published work¹⁶ in two ways. First, point estimates of impacts, particularly for the zero-lag model, are somewhat smaller, a result of progress on emissions mitigation and thus lower projected warming by 2100 as compared to a decade ago. Second, unlike previous work, confidence intervals on projected impacts do not contain zero—a result of substantially less econometric uncertainty in temperature growth relationships using updated data. This is particularly true for the five-lag model, which is substantially less noisy using updated data and implies much more negative (and statistically significant) impacts.

Companion work¹⁷ calculates the social cost of carbon (SCC) implied by these aggregate damages by using a range of assumptions about discounting, secular growth rates, and time horizons over which damages are allowed to accumulate. Using the zero-lag model, Ramsey discounting calibrated to near-term rates and an impact horizon that ends in 2100, the SCC is found to be around USD 200. Using the five-lag model under the same assumptions, SCC estimates are substantially higher—roughly USD 1400 per ton. Higher discount rates yield lower SCC estimates—for instance, USD 125 for a 3 percent discount rate under the zero-lag model. Lower discount rates or longer impact time horizons (e.g., through 2300 instead of 2100) can yield substantially higher rates, with the highest estimates coming when growth effects are assumed to cumulate through 2300—the time horizon used in recent U.S. regulatory analyses.¹⁸

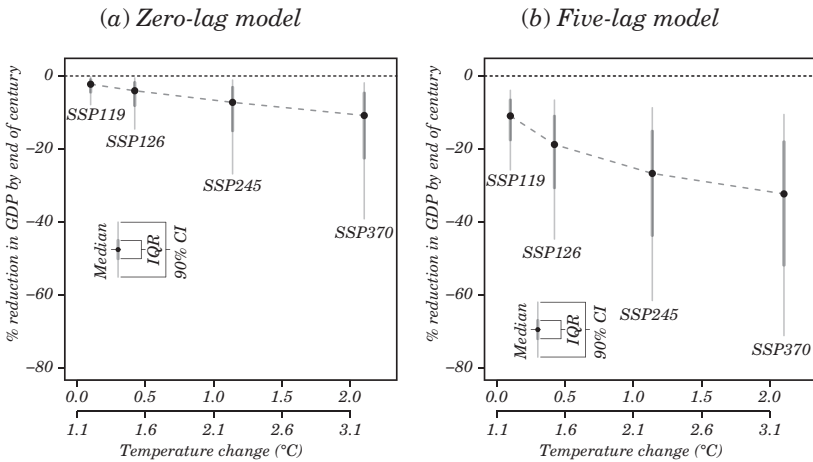
15. See van de Ven and others (2023).

16. See Burke and others (2015).

17. See Burke and others (2023).

18. See U.S. EPA (2022).

Figure 2. Projected Impact of Future Warming on Global GDP by 2100, under Different Emissions Scenarios and Two Econometric Models



Source: Authors' calculations.

Notes: Left panel: projected impacts using the zero-lag model, under four different emission scenarios. Predicted changes in global temperature from each scenario are shown on the x-axis and estimated changes in global output (relative to a world that did not experience warming) on the y-axis. Confidence intervals account for both econometric and climate model uncertainty. Right panel: as in left panel but for five-lag model.

There is no question that all of these estimates are large. Given current global annual CO₂ equivalent emissions of 50 billion tons, the lower estimates would imply that current annual emissions generate USD 10 trillion in discounted damages every year, or about 10 percent of current global GDP. The higher SCC estimates imply annual discounted damages from annual emissions exceeding 50 percent of current GDP.

2.3 Are These Impacts Plausible?

2.3.1 Comparison to Existing Damage Estimates

We assess the plausibility of our impact projections in three ways. The first compares our estimates of projected climate impacts to recent independent impact projections. One simple point of comparison is the estimates of the SCC. Our zero-lag estimate of an SCC of around USD 200 is very similar to multiple recent “bottom-up” econometric

estimates of the SCC that informed recent U.S. policymaking¹⁹ and are near the median of an earlier expert elicitation of the SCC.²⁰ Our much higher estimates from the five-lag model are only slightly larger than those found in recent a global econometric exercise²¹ and are also consistent in magnitude with bottom-up estimates that use equity weights to account for differential impacts in low-income countries.²² These comparisons do not indicate our estimates are correct, but they suggest that our results are no longer the empirical outlier that earlier versions of our estimates²³ were deemed to be. Put simply, others have recently arrived at similar damage estimates, albeit through different pathways.

2.3.2 Comparison to Variation in Historical Growth

Our second approach to assessing plausibility examines whether the impacts of future climate change on growth rates that we predict are small or large relative to the historical variation in long-run growth rates that has been observed. Given the large number of non-climatic factors that are important in economic growth, a prediction that climate change alone might push growth rates outside their historical distribution could appear implausible, even if not impossible. As an example, if a country had grown at a real annual rate between 1–3 percent for over a century, or based on historical data is projected to grow at something close to that rate in the future and then we predicted that climate change would reduce annual growth in that country below 0 percent, then the implicit argument is that climate change is substantially more important than all other factors in future growth—an assumption that many might view as implausible for advanced economies in particular, even if in principle it cannot be ruled out.

Figure 3 uses World Bank data on real per capita growth rates to characterize variation in long-run growth rates around the world since 1960. The data show substantial variation in average long-run growth rates across countries, with some countries shrinking on average over the period and others growing by over 5 percent per annum.

19. See Rennert and others (2022), U.S. EPA (2022).

20. See Pindyck (2019).

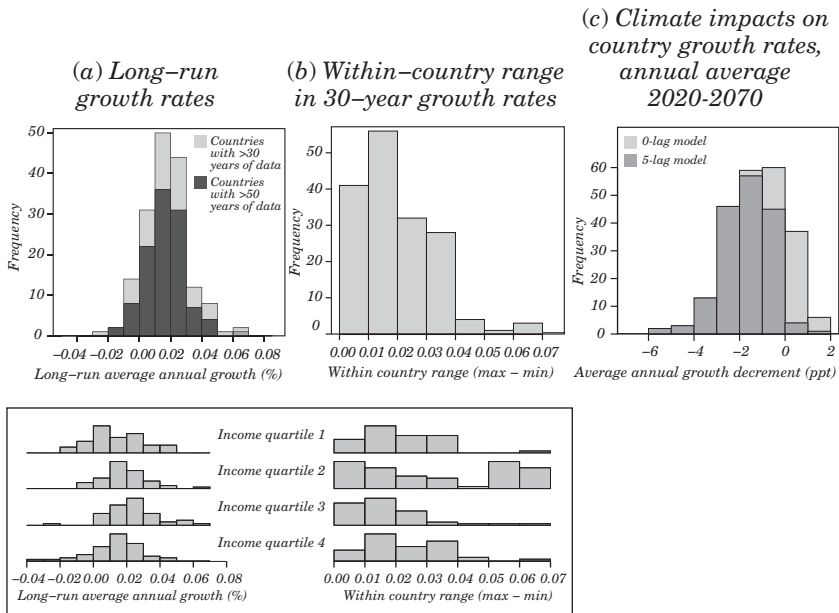
21. See Bilal and Kanzig (2024).

22. See Nath and others (2022).

23. See, for example, Burke and others (2015).

The distribution looks similar if we restrict the sample to countries that report data for at least 50 years since 1960. Distributions remain wide even if we look within quartiles of the income distribution. The data clearly show that different countries can grow at very different rates over long periods.

Figure 3. Between- and Within-Country Variation in Long-Run Growth since 1960, and Projected Climate Impacts on Growth Rates



Source: Authors' calculations.

Notes: Left column of plots show variation in long-run country-average annual growth rates, computed as the average annual growth rate of real per capita GDP in each country over all available data in that country, restricting to countries with at least 30 years of data (grey) or 50 years of data (dark grey) since 1960. Histograms at bottom show the same data but by quartiles of per capita income. Center column of plots show within-country variation in 30-year-average growth rates, estimated by computing, for each country, a 30-year rolling mean of per capita growth rates in that country and then taking the range by country. For instance, a value of 0.02 would indicate that in a given country, the max 30-year growth rate was 2 percentage points higher than the min 30-year growth rate. Bottom histograms again show distributions by quartile of the per capita income distribution. Right panel shows distribution of predicted climate impacts on annual growth rates from our analysis, averaged over the next 50 years (2020–2070), for the zero-lag and five-lag models. For instance, a value of -2 indicates a predicted growth rate that is 2 percentage points lower under climate change than under no climate change, averaged over 50 years.

To complement these between-country comparisons, we then look at within-country variation in long-run growth rates. We first compute, for each country, a 30-year rolling mean of average per capita growth rates over all available data for each country and then compute the within-country range in these 30-year means. As shown in the right panels in Figure 3, we find substantial within-country variation in long-run (30-year) growth rates, and large variation is observed across all countries as a whole as well as when looking at income-quantile groupings. The average range in within-country 30-year growth rates is about 1.9 percentage points, the median is 1.8 percentage points, and the 25th and 75th percentiles are 1 percentage point and 2.7 percentage points. This implies that since 1960, a large majority of countries have experienced one 30-year period where growth was at least 1 percentage point higher per year than another 30-year period, and about half of all countries have experienced differences twice that large. Our conclusions from this simple descriptive analysis are consistent with a very large literature on cross-country growth:²⁴ countries can grow at very different rates for long periods of time within their own history, and two different countries (even with similar initial incomes) can grow at very different rates for very long periods.

How large are our predicted future growth decrements from climate relative to the within- or between-country range in observed growth rates over the last half century? The right panel of Figure 3 shows the distribution of predicted impacts of climate change on country growth rates across countries—essentially, a histogram of the rates plotted in the maps in Figure 1. For the zero-lag model, the median annual growth decrement from climate change over the next 50 years is 0.7 percentage points, and the 25th percentile is -1.4 percentage points. For the five-lag model, the median is -1.6 percentage points and the 25th percentile is -2.3 percentage points. These numbers imply that, for instance, if the set of countries had grown at 2 percent with no climate change, we would predict that the median country would instead grow at an average rate of 1.3 percent over the next 50 years with the zero-lag model, and 0.4 percent under the five-lag model. These decrements are no doubt large, but the resulting values are well within both the observed between-country variation in long-run growth rates, as well as the observed within-country variation over the last 60 years.

24. See, for example, the recent review by Johnson and Papageorgiou (2020).

2.3.3 Comparison to Müller, Stock, and Watson Estimates

In much more sophisticated recent work, Müller, Stock, and Watson (2022) (hereafter MSW) build an econometric model of historical growth dynamics, discipline the model on a range of historical data and use this model to project the range of future growth rates possible at both a global and country level. Although climate is not an explicit factor in the model (the model is purposely agnostic on the sources of growth), to the extent that an already-warming climate has influenced historical growth rates, the modeling exercise can perhaps be construed as implicitly subsuming the historical influence of climate on growth and then holding that influence fixed. Consistent with the simplistic analysis of historical data above, MSW find that countries can grow at different rates for very long times (decades or centuries) and that they can experience prolonged periods of faster growth and prolonged periods of growth collapse.

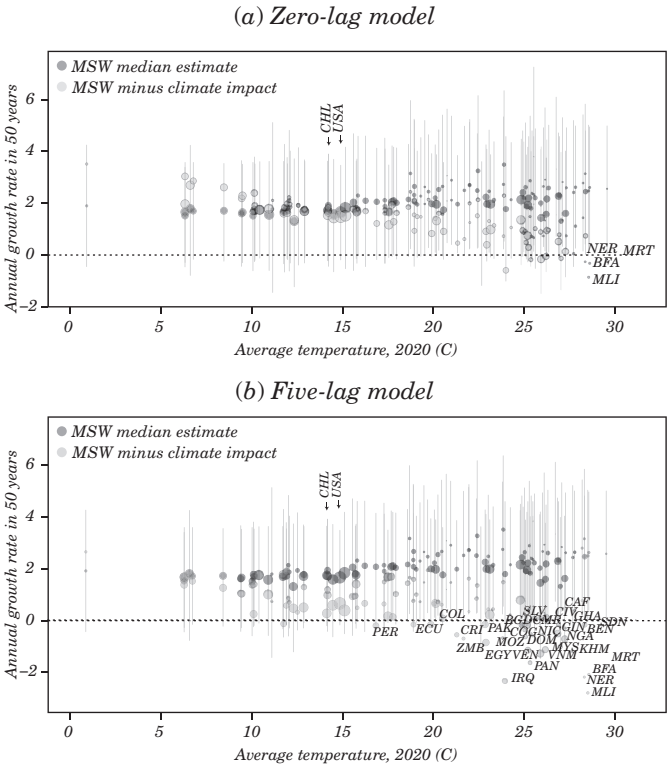
The range of projected future growth rates from MSW allows another check on whether our predicted decrements to growth from climate change are far outside the bounds of possible variation in growth rates from non-climatic factors. In Figure 4, we compare MSW's projected country-average growth rates over the next 50 years to our projected growth rates over the same period if we had taken the MSW median as our estimated secular rate and then adjusted these rates up or down as a result of climate change. We plot our climate-impacted average growth rates on top of MSW median and 5th to 95th percentile estimates of country growth rates. Data are available for 111 countries in the MSW data.

In the zero-lag model, growth rates are amplified under climate change for a small set of countries on the cold end of the temperature distribution, but all climate-adjusted growth rates are well within MSW's uncertainty bounds on secular growth rates. For hotter countries, growth decrements are negative and increasingly large and fall outside MSW bounds for four of the hottest countries in our dataset, all of which are in the African Sahel. Thus in this model, about 4 percent of countries have climate-impacted growth rates outside MSW's secular bounds on what growth rates could be.

In the five-lag model, very few countries are projected to benefit from warming. Nearly all countries are harmed, and some very substantially. Under this model, we find that 31 countries now fall outside the MSW bounds (or 28 percent of countries in the MSW data), including Sub-Saharan African, Asian, and Latin American

countries across the tropics, as well as a handful of very hot countries in the Middle East. Most large economies, and all economies in more temperate latitudes, remain inside the secular uncertainty bounds.

Figure 3. Between- and Within-Country Variation in Long-Run Growth since 1960, and Projected Climate Impacts on Growth Rates



Source: Authors' calculations.
Notes: MSW projected median (black dot) and range (whiskers) of country-level growth rates over the next 50 years, with countries sorted horizontally by average temperature today. Orange dots (top panel) or red dots (bottom panel) are predicted growth rates under climate change, calculated by adjusting the MSW median estimates by predicted growth impacts of climate change using either the zero-lag (light grey) or the five-lag (dark grey) model. Countries are labeled if their projected growth rate under climate change is outside the range of MSW estimated secular growth rates. Chile and the U.S. are also labeled. Dots are scaled relative to the total GDP of the country.

What does this tell us about the plausibility of our estimates? While there is no clear reason why it would be impossible for climate change to push countries completely outside their secular growth experiences or trajectories, doing so would require climate to be the dominant factor in growth—a proposition that many might find implausible. However, we find that our estimates for climate-impacted growth rates for the large majority of countries—and all large economies that account for the lion's share of global GDP impacts we measure—fall inside MSW's data-driven estimates of their secular bounds. This perhaps suggests our estimates are plausible: MSW's numbers suggest these countries could experience similar growth rates even without climate change.

What about the few dozen tropical and largely lower-income countries that fall outside projected secular bounds? Is there a plausible story that would link future changes in climate to growth collapses in those countries? The literature identifies a few possibilities. One well-studied effect relevant for agriculturally dependent economies is the highly nonlinear relationship between temperature and productivity of key crops. Multiple careful econometric studies suggest that warming in this century, which would push exposure to “killing degree days” well outside the historical distribution of exposures, could reduce the productivity of these crops by over 50 percent.²⁵ A second and perhaps related channel is the observed link between warmer temperatures and various types of human conflict.²⁶ In this work, small increases in temperature are observed to generate very large increases in the risk of civil conflict in the tropics. Other work has shown that such conflict can be incredibly and persistently damaging to economic output.²⁷ Finally, Dell and others (2012) show how hot temperatures can destabilize political institutions in low-income countries and use that fact to help explain the large impact of temperature on growth they find in these countries. Ongoing and protracted low-growth episodes or growth collapses are readily observed around the world in conflict-prone and climate-vulnerable countries, including Somalia, Haiti, South Sudan, Afghanistan, Yemen, Libya, Syria, Chad, and the Central African Republic. These mechanisms and examples thus offer three possible stories for how future unprecedented changes in climate could dominate growth trajectories in agriculturally dependent or conflict-prone countries, although their realization is by no means preordained.

25. See Hultgren and others (2022), Schlenker and Lobell (2010).

26. See Hsiang and others (2013).

27. See Cerra and Saxena (2008).

2.3.4 Do Our Estimates Violate Convergence?

A voluminous literature in economics has argued about whether countries converge to similar growth rates or to similar levels of income over the long run.²⁸ MSW suggest that convergence is observed, but for many countries happens on multi-decadal or century-long time scales, and that countries can grow at different rates for very long periods of time. A large body of related work—summarized in Johnson and Papageorgiou (2020)—finds that if convergence is happening, it is likely happening in “convergence clubs”, or within countries that grow at similar rates or converge to similar income levels. The idea is that even if there is no clear evidence of a global force that keeps all country incomes moving together, there are both theoretical and empirical reasons to think that certain sets of countries might move similarly. Because nothing in our impact projections forces country growth rates or income levels to move together or converge, either globally or in groups, a concern might be that our climate-change projections could generate a divergence in incomes that is inconsistent with theoretical or empirical notions of convergence. This concern has been raised by Nath and others (2023).

To assess this concern, we examine the “OECD club”, a set of advanced economies estimated to exhibit conditional convergence in MSW, which currently accounts for over half of global output. Figure 5 characterizes the evolution of per capita incomes in OECD countries over the next 50 years, comparing a world without climate change (in which countries grow at the median projected rate by MSW) to a world in which that rate is adjusted downward annually due to the impact of climate change, as estimated by our five-lag model. As shown in the Figure, incomes in the climate-affected world are lower than in the non-climate-affected world, as expected, but we find that both the range and variance of incomes after 50 years are *smaller* in the climate-affected world than in the non-climate-affected world. For instance, the standard deviation of per capita incomes is USD 39,000 in the non-climate-affected world and USD 37,000 in the climate-affected world, and the difference between highest and lowest incomes is 25 percent higher in the non-climate-affected world. As another comparison, we estimate that the standard deviation of 50-year-average historical growth rates across our OECD sample is 0.8 percentage points, whereas it is 0.4 and 0.5 percentage points

28. See Johnson and Papageorgiou (2020).

over the next 50 years among the same countries in our zero-lag and five-lag estimates, respectively.

While these are just a few possible lenses through which convergence can be assessed, and other tests could yield different insights, we provisionally conclude that our projections are no less consistent with convergence in income growth and levels than state-of-the-art projections of future income levels absent climate change or recent observed variation in long-run income growth among OECD countries.

3. CONCLUDING REMARKS

We combine historical data on temperature and growth from the last 60 years with projections of future climate change from an ensemble of climate models and estimate large potential impacts of climate change on global economic output. Our estimated damages are large relative to earlier estimates from integrated assessment models²⁹ but are more similar to recent empirical approaches that use a variety of data and empirical strategies to estimate damages.³⁰

We assess the plausibility of our estimates in a number of ways, including by comparing them to these recent independent estimates, as well as by comparing them to historical and projected future variation in growth rates absent climate change. This allows for a heuristic test of whether, in order to generate the magnitude of impacts we predict, climate change would have to generate either variation in growth rates that is unobserved in historical data or variation that is outside the bounds of likely variation in growth predicted by a sophisticated growth model disciplined by historical data. For most countries in the world, we find that our predicted growth impacts from climate change are within the “secular bounds” of non-climate growth experience—that is, variation as large or larger than what we predict is routinely observed. For countries where predictions fall outside these bounds, we point to existing evidence and historical examples that could lend plausibility to growth collapses.

Does this analysis mean we can be certain that climate change will have as large an impact on global output as we suggest? No. Does it suggest that the growth rate impacts we estimate should be considered implausible because they clearly diverge from patterns

29. See Revesz and others (2014).

30. See Rennert and others (2022), U.S. EPA (2022), Bilal and Känzig (2024).

or variations in growth rates that have been observed historically? Also no. Our calculations, and those done by others, suggest that very large macroeconomic impacts from climate change are possible. Our analysis here suggests that the growth effects that generate these large impacts are historically plausible.

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