

Temperature Shocks and Economic Growth: Evidence from the Last Half Century[†]

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This paper uses historical fluctuations in temperature within countries to identify its effects on aggregate economic outcomes. We find three primary results. First, higher temperatures substantially reduce economic growth in poor countries. Second, higher temperatures may reduce growth rates, not just the level of output. Third, higher temperatures have wide-ranging effects, reducing agricultural output, industrial output, and political stability. These findings inform debates over climate's role in economic development and suggest the possibility of substantial negative impacts of higher temperatures on poor countries. (JEL E23, O13, Q54, Q56)

At least since Montesquieu's *The Spirit of Laws* (1750), which argued that an “excess of heat” made men “slothful and dispirited,” it has been debated whether temperature is, or is not, central to understanding economic development. In this paper, we use historical fluctuations in temperature within countries to identify its effects on aggregate economic outcomes. We use this approach to inform old debates about the role of temperature in economic development and new debates about the possible impacts of future warming.

The relationship between temperature and aggregate economic activity has traditionally been quantified using two approaches. One approach, emphasized in the growth and development literature, has examined the relationship between average temperature and aggregate economic variables in cross-sections of countries (e.g., Sachs and Warner 1997; Gallup, Sachs, and Mellinger 1999; Nordhaus 2006). In contemporary data, it is well known that hot countries tend to be poor, with national income falling 8.5 percent per degree Celsius in the world cross section (Dell, Jones, and Olken 2009). However, many argue that this correlation is driven by spurious associations of temperature with national characteristics such as institutional quality (e.g., Acemoglu, Johnson, and Robinson 2002; Rodrik, Subramanian, and Trebbi 2004).

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The second approach relies on micro evidence to quantify various climatic effects and then aggregates these to produce a net effect on national income. This approach is embedded within Integrated Assessment Models (IAM), which are utilized extensively in the climate change literature to model climate-economy interactions and form the basis of many policy recommendations regarding greenhouse gas emissions. A fundamental challenge for this approach is complexity. The set of candidate mechanisms through which temperature may influence economic outcomes is large and, even if each mechanism could be enumerated and its operation understood, specifying how they interact and aggregate poses substantial difficulties. The climate literature, at the micro level, suggests a wide array of potential temperature effects, including influences on agricultural productivity, mortality, physical performance, cognitive performance, crime, and social unrest, among other outcomes, many of which do not feature in current implementations of the enumerative models.¹

This paper takes an alternative approach. We first construct temperature and precipitation data for each country and year in the world from 1950 to 2003 and combine this dataset with data on aggregate output. We then examine the historical relationship between changes in a country's temperature and precipitation and changes in its economic performance. Our main identification strategy uses year-to-year fluctuations in temperature and precipitation to identify their effects.^{2,3} By examining aggregate outcomes directly, we avoid relying on a priori assumptions about what mechanisms to include and how they might operate, interact, and aggregate. By utilizing fluctuations in temperature, we isolate its effects from time-invariant country characteristics. Our approach also allows more nuanced insights. Beyond investigating the magnitude and locus of any effects, we can use the panel's distributed lag structure to inform whether temperature impacts national growth rates or simply the level of income.

We find three primary results. First, our estimates show large, negative effects of higher temperatures on growth, *but only in poor countries*. In poorer countries, we estimate that a 1°C rise in temperature in a given year reduced economic growth in that year by about 1.3 percentage points. In rich countries, changes in temperature do not have a robust, discernable effect on growth. Changes in precipitation have

¹On agriculture, see, e.g., Adams et al. (1990); Mendelsohn, Dinar, and Sanghi (2001); Schlenker and Roberts (2006); Deschenes and Greenstone (2007); and Guiteras (2007). On health, see, e.g., Curriero et al. (2002); Deschenes and Moretti (2009); Deschenes and Greenstone (2007); Gallup and Sachs (2001); and Sachs and Malaney (2002). On labor productivity, see, e.g., Huntington (1915), Meese et al. (1982), and Zivin and Neidell (2010). On crime and social unrest, see, e.g., Field (1992); Jacob, Lefgren, and Moretti (2007); and Miguel, Satyanath, and Sergenti (2004). Many other possible climate-economy channels are discussed in the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (IPCC 2007). Main users of IAM models acknowledge that the aggregate estimates require numerous, difficult modeling decisions. For example, the Stern report on the economics of climate change notes: "Making such estimates is a formidable task in many ways ... with the result that such models must make drastic, often heroic, simplifications along all stages of the climate-change chain. What is more, large uncertainties are associated with each element in the cycle. Nevertheless, the IAMs remain the best tool available for estimating aggregate quantitative global costs and risks of climate change" (Stern 2007, 145).

²The use of annual variation to estimate the impact of climate change was pioneered by Schlenker and Roberts (2006) and Deschenes and Greenstone (2007), who use annual county-level US data to estimate the impact of weather on US agricultural output. Several authors have also used higher frequency data, focusing on the GDP effect of rainfall in Africa as an instrument for conflict (Miguel, Satyanath, and Sergenti 2004) and to explain the African growth tragedy (Barrios, Bertinelli, and Strobl 2010).

³By convention, an annual realization of temperature and precipitation is termed "weather," while the word "climate" refers to the long-run distribution of temperature and precipitation. This paper thus emphasizes weather variation, although Section IV considers historical variation at longer time scales and along a path where the world is becoming warmer.

relatively mild effects on national growth in both rich and poor countries.⁴ We find broadly consistent results across a wide range of alternative specifications.

Second, to interpret these effects, one can distinguish two potential ways temperature could affect economic activity: influencing the *level* of output, for example, by affecting agricultural yields; or influencing an economy's ability to *grow*, for example, by affecting investments or institutions that influence productivity growth. By looking at multiple lags of temperature, we can examine whether shocks appear to have temporary or persistent impacts on economic output, and thus whether temperature has level or growth effects (or both). Our results provide some suggestive evidence, depending on the specification, that higher temperatures may reduce the growth rate in poor countries, not simply the level of output. Since even small growth effects have large consequences over time, growth effects—if they persist in the medium run—would imply large impacts of warming.

Third, we find evidence that temperature affects numerous dimensions of poor countries' economies, and in ways consistent with possible growth effects. While agricultural output contractions appear to be part of the story, we also find adverse effects of hot years on industrial output. Moreover, higher temperatures lead to political instability in poor countries, as evidenced by irregular changes in national leaders, and this political instability could plausibly reduce growth rates.⁵ These effects sit outside the primarily agricultural focus of much economic research on climate change and underscore the challenges in building aggregate estimates of climate impacts from a narrow set of channels. They are consistent with other recent work that suggests that temperature can have broad impacts outside of agriculture (Hsiang 2010). These effects may also help explain how temperature might affect growth rates in poor countries, not simply the level of output.

These results are identified using short-run fluctuations in temperature and precipitation, whereas the long-run effects of climate may be different. For example, in the long run, countries may adapt to a particular temperature, mitigating the short-run economic impacts that we observe. This type of adaptation may explain why our estimates of short-run economic impacts of temperature shocks are larger than what the overall cross-sectional relationship between temperature and income across the world would imply (see Section V). Alternatively, sustained climatic changes may have additional long-run effects on dimensions, such as water tables, soil quality, and health, producing larger impacts (e.g., Meehl, Tebaldi, and Nychka 2004).⁶

Although our approach cannot fully overcome these challenges, we can make some headway in exploring potential impacts of shifts in climate by examining medium-term temperature shifts within countries. Mean global land temperatures have risen nearly 1°C since 1970 (Brohan et al. 2006), but countries have not warmed equally. We therefore examine whether those countries that experienced

⁴Precipitation does show positive effects on agricultural output in poor countries, as discussed in Section III.

⁵The idea that climate shocks can affect political institutions is consistent with Brückner and Ciccone (2011), which shows that negative rainfall shocks lead to an increased probability of democratization in sub-Saharan Africa. Burke and Leigh (2010) also find that output contractions associated with weather shocks affect the timing of democratic change.

⁶In the context of future global climate change, other factors, such as changing sea levels, increasing frequency of natural disasters, and issues of biodiversity, may create additional costs not captured here (IPCC 2007; Nicholls and Leatherman 1995).

the largest climatic shifts between early and late periods in our sample had the largest shifts in their growth rates. Though this approach has less statistical power than using annual variation, the estimated effects of increased temperature over 10- or 15-year time horizons are similar to our annual panel estimates, showing substantial negative effects in poor countries. The decline in statistical precision with these medium-term results means that they should be interpreted with more caution than the annual panel data results, but the fact that they appear consistent is suggestive that the effects may persist at least over the medium term.

Our evidence suggests specific directions in which IAMs could be modified to better match the historical evidence. The two key distinctions between our evidence and the assumptions in most IAM models are that our estimates show striking differences between rich and poor countries; and our estimates explicitly allow growth effects of higher temperatures (for example, on TFP growth), not just level effects. Incorporating these effects in aggregate climate-economy models would help them predict long-run output paths that are consistent with the evidence in the short and medium run.

Our results also inform the older debate over temperature's role in economic development. Climatic theories of development have a long history, with prominent examples dating to Huntington (1915), Montesquieu (1750), and even to Ibn Khaldun's 14th Century *Muqaddimah* (Gates 1967). Yet, even with contemporary analysis, there remains substantial debate over temperature's aggregate effects (e.g., Acemoglu, Johnson, and Robinson 2002; Sachs 2003). Our estimates identify a substantial, contemporary causal effect of temperature on the development process, providing explicit evidence that temperature affects not only numerous subcomponents in an economy, but aggregates into substantial impacts on national output.

The remainder of the paper is organized as follows. Section I introduces the data and provides descriptive statistics. Section II describes the estimation strategy, presents the main results, and considers a number of robustness checks. Section III considers channels that may link temperature change to national output. Section IV estimates the effects of longer run temperature shifts. Section V relates the historical panel estimates to the cross-sectional relationship between temperature and income, and discusses some implications of the results for understanding potential economic effects of climate change. Section VI concludes.

I. Data and Descriptive Statistics

A. Data

The historical weather data are taken from the *Terrestrial Air Temperature and Precipitation: 1900–2006 Gridded Monthly Time Series, Version 1.01* (Matsuura and Willmott 2007). This dataset provides worldwide (terrestrial) monthly mean temperature and precipitation data at 0.5×0.5 degree resolution (approximately $56\text{km} \times 56\text{km}$ at the equator). Values are interpolated for each grid node from an average of 20 different weather stations, with corrections for elevation.

We use geospatial software to aggregate the weather data to the country-year level. Our main specifications use population-weighted average temperature and

precipitation, where the weights are constructed from 1990 population data at 30 arc second resolution (approximately 1km at the equator) from the *Global Rural-Urban Mapping Project* (Balk et al. 2004). We also consider averaging based on geographic area, which produces broadly similar weather variables for most countries.⁷ Online Appendix I presents additional details about the temperature and precipitation data.

For economic data, we primarily use the *World Development Indicators* (World Bank 2007). We focus on the panel of 125 countries with at least 20 years of GDP data in the *World Development Indicators*, and consider other samples as robustness checks. We also consider economic growth data from the *Penn World Tables Version 6.2* (Heston, Summers, and Aten 2006) as a robustness check and find very similar results. We use the *World Development Indicators* as our primary dataset given recent concerns with high frequency PWT data (Johnson et al. 2009).

B. Descriptive Statistics

Figure 1 summarizes temperature (panel A) and precipitation (panel B) data for each country in the sample, plotted against log per capita GDP in the year 2000. For each country, the circle symbols represent the mean levels of temperature and precipitation in the first decade of our sample (1950–1959), the plus symbols represent the mean levels in the last decade of our sample (1996–2005), and the gray lines indicate the range of annual mean levels we observe for that country. On average, our data show that the world has become about 1°C warmer between the early and late parts of our sample. The warming trend, which is concentrated since the 1970s, is well-documented (e.g., Brohan et al. 2006).

Panel A of Figure 1 shows the tremendous temperature variation across countries. The hottest country in the world is Mauritania, with an average population-weighted temperature of 28.4°C, and the coldest is Mongolia, with an average population-weighted temperature of –1.77°C. Figure 1 also shows the strong relationship between temperature and per capita income, with hot countries tending to be poor and cold countries rich. This relationship has been known since at least the eighteenth century (Montesquieu 1750) and has been further established using sub-national data (Nordhaus 2006). The exceptions to this rule fall into two main groups: oil states of the Middle East, such as Qatar and Kuwait, which are hot and wealthy; and Communist/post-Communist states, such as Mongolia and North Korea, which are cold and poor. On average, a simple cross-section regression in the year 2000 shows that a 1°C increase in average temperature predicts a fall in per capita income by 0.085 log points (i.e., about 8 percent).

Looking at variability within countries, we see fluctuations in annual mean temperatures, with the difference between the maximum and minimum annual mean temperature within a country averaging 2.2°C in our baseline sample.⁸ Thus, the

⁷Countries where the weighting scheme makes a substantial difference are those with large, sparsely populated areas with unusual climates: Russia (Siberia), Canada (the Arctic and sub-Arctic areas), the United States (Alaska), and Australia (central Australia).

⁸This max-min difference in annual means within countries ranges between 1.3°C and 3.4°C for 95 percent of countries in our baseline sample.

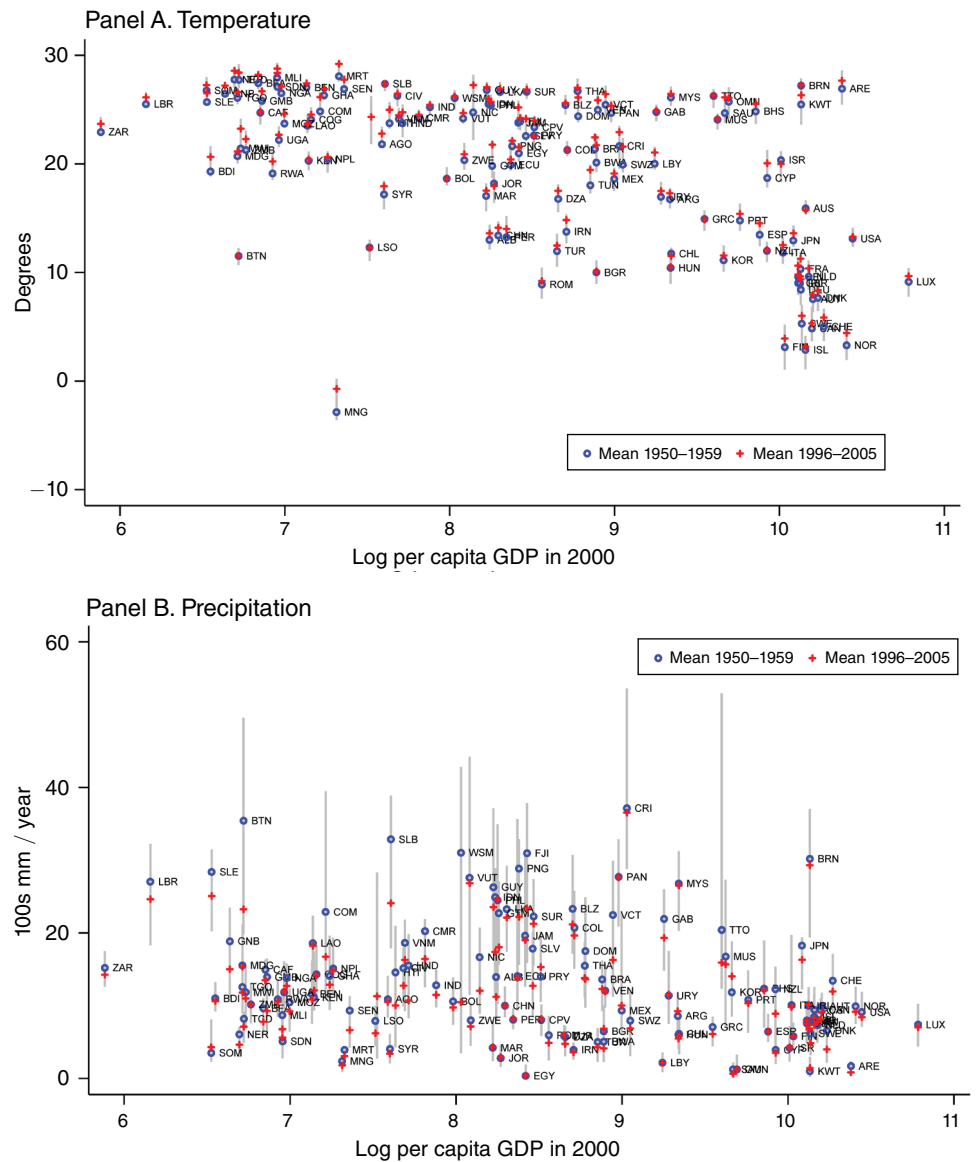


FIGURE 1. CHANGES AND VARIABILITY IN TEMPERATURE AND PRECIPITATION

Notes: These graphs present data on each country’s temperature (panel A) and precipitation (panel B), plotted against per capita GDP from the World Development Indicators (WDI) in the year 2000. For each country, the circle symbols represent the mean level of temperature/precipitation in the first decade of our sample (1950–1959), the plus symbols represent the mean level of temperature/precipitation in the last decade of our sample (1996–2005), and the gray lines indicate the range of annual temperature/precipitation levels we observe for that country during our sample period. Country averages are calculated using population weights, as discussed in the text.

max-min variation within countries is more than twice the average increase in temperature observed over the period and reasonably similar to estimated global temperature increases expected to occur over the next century. Figure 1 further shows that, while there tend to be larger temperature fluctuations in cooler countries,

TABLE 1—OBSERVED TEMPERATURE AND PRECIPITATION VARIATION, 1950–2003

	Proportion of country-years with temperature [...] degrees above/below country mean					
	0.25	0.50	0.75	1.00	1.25	1.50
Raw data	0.573	0.299	0.144	0.064	0.028	0.011
After removing worldwide year fixed effects	0.511	0.215	0.085	0.032	0.013	0.005
After removing region \times year and poor \times year fixed effects	0.448	0.153	0.051	0.018	0.008	0.002

	Proportion of country-years with precipitation [...] 100 mm units above/below country mean					
	1	2	3	4	5	6
Raw data	0.480	0.229	0.121	0.070	0.042	0.027
After removing worldwide year fixed effects	0.494	0.221	0.113	0.062	0.038	0.024
After removing region \times year and poor \times year fixed effects	0.462	0.213	0.106	0.058	0.032	0.021

the upward trend in temperature has occurred globally with similar magnitude in both hot and cold countries.

Examining the data on precipitation in panel B of Figure 1 shows substantial annual variability in precipitation in all but the very driest countries. However, there is no clear relationship between the level of precipitation and the level of per capita income in 2000.

To examine the variability further, Table 1 documents the extent of temperature and precipitation fluctuations within countries. While the average difference (across all countries) between the hottest and coldest year is 2.2°C (Figure 1), a country's temperature deviates more than 1°C from the country mean approximately once every 15 years. Precipitation is more volatile, with deviations from mean rainfall of about 400–500 millimeters (mm) appearing once every 15 years. When common global or region-specific year fixed effects are removed, these deviations become somewhat more modest.

II. The Effect of Temperature Fluctuations on Economic Activity

In this section, we develop the empirical framework for the analysis of temperature shocks, present our main results, and consider a variety of robustness checks.

A. Empirical Framework

Our empirical framework follows the derivation in Bond, Leblebicioglu, and Schiantarelli (2010). To fix ideas, consider the following simple economy:⁹

$$(1) \quad Y_{it} = e^{\beta T_{it}} A_{it} L_{it}$$

⁹Here, we focus on this simple production model. Online Appendix II extends the reasoning developed here to more general dynamic panel models that incorporate richer lag structures and lagged dependent variables.

$$(2) \quad \Delta A_{it}/A_{it} = g_i + \gamma T_{it},$$

where Y is aggregate output, L measures population, A measures labor productivity, and T measures weather. Equation (1) captures the *level effect* of weather on production, e.g., the effect of current temperature on crop yields. Equation (2) captures the *growth effect* of weather, e.g., the effect of temperature on features, such as institutions that influence productivity growth.

Taking logs in the production function and differencing with respect to time, we have the dynamic growth equation

$$(3) \quad g_{it} = g_i + (\beta + \gamma)T_{it} - \beta T_{it-1},$$

where g_{it} is the growth rate of per-capita output. The “level effects” of weather shocks on output, which come from equation (1), appear through β . The “growth effects” of weather shocks, which come from equation (2), appear through γ .¹⁰

The growth equation in (3) allows separate identification of level effects and growth effects through the examination of transitory weather shocks. In particular, both effects influence the growth rate in the initial period of the shock. The difference is that the level effect eventually reverses itself as the weather returns to its prior state. For example, a temperature shock may reduce agricultural yields, but once temperature returns to its average value, agricultural yields bounce back. By contrast, the growth effect appears during the weather shock and is not reversed. A failure to innovate in one period leaves the country permanently further behind. The growth effect is identified in (3) as the summation of the temperature effects over time.

The above reasoning extends to models where temperature effects play out more slowly.¹¹ With more general lag structures in (1) and (2), the growth effect is still identified by summing the lagged effects of the weather fluctuation. This standard distributed-lag result is demonstrated formally in online Appendix II.

To estimate these effects, we run panel regressions of the form

$$(4) \quad g_{it} = \theta_i + \theta_{it} + \sum_{j=0}^L \rho_j T_{it-j} + \varepsilon_{it},$$

where θ_i are country fixed effects, θ_{it} are time fixed effects (interacted separately with region dummies and a poor country dummy in our main specifications), ε_{it} is an

¹⁰ Rather than first-differencing (1), one could integrate (2), producing a fully specified equation in the log level of output. However, as Bond, Leblebicioglu, and Schiantarelli (2010) note, this creates nonstationarity in both output levels (on the left-hand side) and accumulable factors (on the right-hand side). To avoid relying on cointegration assumptions for identification, Bond, Leblebicioglu, and Schiantarelli (2010) recommend first-differencing. Online Appendix II presents Monte Carlo results, which show that the first-differencing approach is very effective at correctly identifying both level effects (β) and growth effects (γ), whereas the integrated model with the log level of output as the dependent variable correctly identifies level effects (β) but does a poor job identifying growth effects (γ). Given these results, we focus on the model with growth as the dependent variable as in equation (3).

¹¹ For example, low temperatures in the latter part of one year could affect harvests the next year, which would generate a lagged level effect. Alternatively, a permanent shock to productivity could influence subsequent capital accumulation as the capital stock adjusted to its new steady state, which would generate a lagged growth effect. The key distinction is that, as in equation (3), level effects eventually generate equal and opposite responses through further lags, whereas growth effects do not. See online Appendix II.

error term clustered simultaneously by country and region-year (following the two-way clustering of Cameron, Gelbach, and Miller 2011), and T_{it} is a vector of annual average temperature and precipitation with up to L lags included.¹² In addition, we also consider variations of (4) that include interactions between weather variables and country characteristics. We have verified using Monte Carlo analysis that the specification in (4) produces unbiased estimates of both growth and level effects given the properties of our data. (See online Appendix II for more details.)

We begin by estimating (4) with no lags, focusing on the null hypothesis that temperature does not affect growth:

$$H_0(L = 0) : \rho_0 = 0.$$

A failure to reject this hypothesis would indicate an absence of both level and growth effects. In subsequent regressions with lags, following the conventions in the distributed-lag literature (see Greene 2000), we separately test the immediate effect of temperature,

$$H_0^1(L > 0) : \rho_0 = 0,$$

and the cumulated effect of temperature,

$$H_0^2(L > 0) : \sum_{j=0}^L \rho_j = 0.$$

The summation of the lag coefficients corresponds to the parameter γ , the growth effect, in the simple model above, as well as a more general concept of growth effects in models with longer lag structures, as demonstrated in online Appendix II. Online Appendix II also discusses generalizations of the empirical model and tests following Bond, Leblebicioglu, and Schiantarelli (2010) that allow for more general short-run dynamics. As discussed in the online Appendix, the results from the extended dynamic model are very similar to the results from the simpler model developed here.

B. Panel Results

Table 2 examines the null hypothesis that temperature does not affect growth, either through level effects or growth effects. It presents results from estimating equation (4) with no lags (i.e., imposing $\rho_j = 0$ for all $j > 0$; models with lags are examined in the next subsection). Column 1 of Table 2 shows a negative but statistically insignificant relationship between temperature fluctuations and growth on average across all countries. In column 2, we interact temperature with a dummy for a country being “poor,” defined as having below-median PPP-adjusted per capita GDP in the first year the country enters the dataset. The coefficient on the interaction

¹²The regions are Middle East/North Africa, sub-Saharan Africa, Latin America and Caribbean, Western Europe and offshoots, Eastern Europe and Central Asia, and Asia and Pacific Islands. See the online Appendix for a full list of countries.

TABLE 2—MAIN PANEL RESULTS

Dependent variable is the annual growth rate	(1)	(2)	(3)	(4)	(5)
Temperature	−0.325 (0.285)	0.261 (0.312)	0.262 (0.311)	0.172 (0.294)	0.561* (0.319)
<i>Temperature interacted with...</i>					
Poor country dummy		−1.655*** (0.485)	−1.610*** (0.485)	−1.645*** (0.483)	−1.806*** (0.456)
Hot country dummy				0.237 (0.568)	
Agricultural country dummy					−0.371 (0.409)
Precipitation			−0.083* (0.050)	−0.228*** (0.074)	−0.105** (0.053)
<i>Precipitation interacted with...</i>					
Poor country dummy			0.153* (0.078)	0.160** (0.075)	0.145* (0.087)
Hot country dummy				0.185** (0.078)	
Agricultural country dummy					0.010 (0.085)
Observations	4,924	4,924	4,924	4,924	4,577
Within R^2	0.00	0.00	0.00	0.01	0.01
R^2	0.22	0.22	0.22	0.22	0.24
Temperature effect in poor countries		−1.394*** (0.408)	−1.347*** (0.408)	−1.473*** (0.440)	−1.245*** (0.463)
Precipitation effect in poor countries			0.069 (0.058)	−0.0677 (0.073)	0.0401 (0.089)

Notes: All specifications use WDI data and include country FE, region \times year FE, and poor \times year FE. Robust standard errors are in parentheses, adjusted for clustering at parent-country level. Sample includes all countries with at least 20 years of growth observations. Poor is defined as a dummy for a country having below median PPP GDP per capita in its first year in the data. Hot is defined as a dummy for a country having above median average temperature in the 1950s. Agricultural is defined as a dummy for a country having above median share of GDP in agriculture in 1995. Temperature is in degrees Celsius and precipitation is in units of 100 mm per year.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

between the “poor” dummy and temperature is negative and statistically significant, indicating substantial heterogeneity between poor and rich countries.¹³ As shown in the last row of the table (which reports the sum of the main effect of temperature and its interaction with the poor dummy), the net effect of a 1°C rise in temperature is to decrease growth rates in poor countries by −1.39 percentage points. Put another way, since the standard deviation of annual temperature once country fixed effects, region \times year, and poor country \times year fixed effects are removed is 0.50 degrees,

¹³ We have also considered quintiles of initial per capita income rather than a binary distinction. We find the largest negative effects of temperature on the bottom two quintiles of temperature, and especially on the lowest income quintile. Using an interaction with a linear initial log per capita income variable produces similar results, although the linear specification implies positive effects of temperature in rich countries, which do not appear with either the rich/poor dummy or using quintiles. (See online Appendix.)

the estimates in Table 2 imply that a one standard deviation increase in annual temperature is associated with a reduction in growth of about 0.69 percentage points.

The next column of Table 2 adds precipitation as a control variable, and shows that controlling for precipitation does not substantively affect the temperature estimates. Average annual precipitation itself shows relatively mild effects. An extra 100 mm of annual precipitation is associated with a 0.08 percentage point lower growth rate in rich countries and a statistically insignificant 0.07 percentage point higher growth rate in poor countries. In our data, global mean precipitation levels have fallen nearly 100 mm in the last 50 years, so a 100 mm variation in precipitation is on the same order historically as the 1°C rise in temperature. By this metric, the effects of mean precipitation typically appear a factor of 10 times smaller than the temperature effect in poor countries.¹⁴ Moreover, we show below that the statistical significance of the precipitation effects in rich countries is sensitive to specification, suggesting that they should be interpreted with caution.¹⁵

Poorer countries tend to be both hotter and more agricultural. In columns 4 and 5, we consider whether being “poor” proxies for these characteristics. Column 4 adds the interaction between temperature and “hot,” defined as having above median temperature in the 1950s. The negative effect of temperature appears through being poor, not through being hot, with the poor coefficient remaining unchanged.¹⁶ Column 5 controls for the interaction between temperature and “agricultural,” defined as having an above median agricultural GDP share in 1995.¹⁷ Once again, the negative effect of temperature appears through being poor.¹⁸ While it is impossible to definitively separate the impacts of poverty from those of the agriculture share or mean temperature (or the many other variables that are correlated with poverty), this evidence suggests that being poor usefully characterizes a locus of substantial negative temperature effects.

The point estimates in Table 2 tend to show that rich countries experience increased growth with a rise in temperature, but this result is not statistically significant. The *t*-statistics are below 1.0 for all specifications except the last, which controls for agricultural intensity. Looking ahead to further results in the paper and the online Appendices, which examine alternative panel specifications, data sources,

¹⁴ As an alternative metric, the standard deviation of precipitation across the entire sample (after removing fixed effects) is about 25 mm, so a one standard increase in precipitation would increase growth in poor countries by a (statistically insignificant) 0.02 percentage points, or about 1/40 the estimated effect of a one standard deviation in temperature.

¹⁵ In Section III, precipitation is shown to have a more robust, positive effect on agricultural output in poor countries. These results on average precipitation also do not capture the impact of extreme precipitation events, such as extended droughts or flooding. However, online Appendix Figure A3 suggests that the negative effects of precipitation in rich countries are driven by very large outlier events, suggesting that indeed floods may be important. Also, given the large heterogeneity in growing seasons between countries, we do not distinguish between rain in the growing, harvest, planting, or dry seasons as done, e.g., by Maccini and Yang (2009).

¹⁶ In results not reported in the table, we have also experimented with different definitions of “hot,” such as being above the seventy-fifth or ninetieth percentiles of the world average temperature distribution, as well as a linear temperature variable. The results from these alternative specifications are qualitatively similar to the results presented in the table. See the online Appendix.

¹⁷ We use 1995 data for agricultural share because data coverage from earlier years is sparse. Using earlier data cuts sample sizes considerably but produces broadly similar results.

¹⁸ As reported in the online Appendix, regressions that control only for temperature fluctuations and their interaction with the agriculture share (i.e., not including interactions with national income) produce statistically insignificant effects for agriculture, further suggesting that poverty is the more informative characteristic. Furthermore, regressions that include linear interactions with initial income, temperature, and agriculture share (as opposed to binary dummies) continue to show that initial poverty is the relevant distinction.

and samples, the econometric findings show a similar pattern—typically positive but rarely statistically significant temperature effects in rich countries.

C. Models with Lags

The above results, using the simple model with no lags, reject the null hypothesis that temperature has no effect on growth in poor countries. This section considers more flexible models with up to 10 lags of temperature to better understand the dynamics of these temperature effects, nesting both the level and growth effects of temperature described in Section IIA.

Table 3 presents results from estimating equation (4) with no lags, one lag, five lags, or ten lags of the weather variables. In columns 1–4, temperature and its lags are the only weather variables included. Columns 5–8 present results where precipitation and its lags are also included. All temperature and precipitation variables are interacted with poor and rich country dummies. The bottom two rows of each column present, separately, the cumulated effect of temperature for poor and rich countries, calculated by summing the respective temperature variable and its lags. In models with more than one lag, given space constraints, the table reports only the first three lags and the sum of all the lags.¹⁹

Table 3 shows that the cumulative effect of temperature in poor countries remains substantially negative, with fairly stable point estimates, as more lags are included. With no lags, in columns 1 and 5, a one-time 1°C temperature increase in a poor country reduces growth by 1.35–1.39 percentage points. With one lag included, the cumulative effect is a reduction of 0.98–1.10 percentage points. The results are broadly consistent in magnitude and statistical significance as we add more lags, with a 1°C temperature increase producing a 1.04–1.23 percentage point reduction in growth. The only exception is the cumulative effect with ten lags of temperature, when we also include ten lags of precipitation (column 8), which is 0.858 and no longer statistically significant.

The individual lag coefficients show little evidence of a level effect of temperature on output. That is, the effects of above average temperature appear to persist in the medium run, rather than being reversed. Recalling the empirical framework from Section IIA, level effects are reversed when the temperature shock is reversed. In the model with one lag, i.e., columns 2 and 6, a level effect would appear as equal and opposite coefficients on the immediate effect and the first lag. More generally, even if level effects occur with lags, i.e., if last year's temperature affects this year's harvest, level effects are eventually reversed once the shock disappears. Therefore, to the extent temperature effects are level effects, the cumulated sum of the temperature effect and all its lags should be zero. That the lags in Table 3 do not sum to zero suggests that the effects of temperature persist in the medium run, i.e., they look more like growth effects than level effects.

Of course, temperature effects may be mitigated beyond the ten year horizon examined here. In Section IV, we consider an alternative empirical approach that examines longer run historical relationships between changes in temperature and

¹⁹The full set of lags for Table 3, column 10, is reported in online Appendix Table A34.

TABLE 3—MODELS WITH LAGS

	No lags (1)	1 lag (2)	5 lags (3)	10 lags (4)	No lags (5)	1 lag (6)	5 lags (7)	10 lags (8)
Temperature × Poor	−1.394*** (0.408)	−1.610*** (0.525)	−1.555*** (0.572)	−1.597*** (0.565)	−1.347*** (0.408)	−1.559*** (0.522)	−1.514*** (0.577)	−1.580*** (0.579)
L1: Temperature × Poor		0.514 (0.439)	0.614 (0.489)	0.572 (0.498)		0.576 (0.433)	0.666 (0.479)	0.627 (0.481)
L2: Temperature × Poor			−0.334 (0.566)	−0.368 (0.580)			−0.338 (0.570)	−0.354 (0.586)
L3: Temperature × Poor			−0.105 (0.480)	−0.175 (0.489)			−0.064 (0.489)	−0.152 (0.506)
Temperature × Rich	0.261 (0.312)	0.206 (0.323)	0.227 (0.330)	0.219 (0.348)	0.262 (0.311)	0.215 (0.322)	0.235 (0.338)	0.234 (0.356)
L1: Temperature × Rich		0.135 (0.300)	0.143 (0.297)	0.166 (0.317)		0.137 (0.298)	0.143 (0.299)	0.168 (0.323)
L2: Temperature × Rich			0.165 (0.257)	0.158 (0.263)			0.181 (0.262)	0.172 (0.273)
L3: Temperature × Rich			−0.100 (0.271)	−0.129 (0.277)			−0.110 (0.277)	−0.137 (0.286)
Includes precipitation vars.	No	No	No	No	Yes	Yes	Yes	Yes
Observations	4,924	4,924	4,916	4,906	4,924	4,924	4,916	4,906
R ²	0.22	0.22	0.22	0.23	0.22	0.22	0.23	0.23
Within R ²	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01
Sum of all temp. coeff. in poor countries	−1.394*** (0.408)	−1.096*** (0.418)	−1.235** (0.527)	−1.171* (0.611)	−1.347*** (0.408)	−0.983** (0.416)	−1.041** (0.530)	−0.858 (0.647)
Sum of all temp. coeff. in rich countries	0.261 (0.312)	0.341 (0.400)	−0.180 (0.566)	−0.152 (0.786)	0.262 (0.311)	0.352 (0.396)	−0.191 (0.546)	−0.189 (0.758)

Notes: All specifications use WDI data and include country FE, region × year FE, and poor × year FE. Robust standard errors are in parentheses, adjusted for two-way clustering at parent-country and year-region levels. Sample includes all countries with at least 20 years of growth observations. Columns 5–8 also include Precipitation × Poor and Precipitation × Rich, with the same number of lags as the temperature variables shown in the table. Columns 3 and 7 also include the fourth and fifth lags of Temperature × Poor, Temperature × Rich, Precipitation × Poor and Precipitation × Rich. Similarly columns 4 and 8 also include the fourth through tenth lags of Temperature × Poor, Temperature × Rich, Precipitation × Poor and Precipitation × Rich; those coefficients are suppressed in the table to save space. Sum of all temperature coefficients in poor countries shows the sum (and calculated standard error) of Temperature × Poor and all of the lags of Temperature × Poor included in the regression; sum of all temperature coefficients in rich countries is calculated analogously.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

changes in growth. That analysis finds longer run effects that are broadly consistent with these panel results but less statistically significant than the findings in Table 3.

D. Robustness

This section considers a variety of robustness checks, summarized in Table 4. Numerous additional analyses are presented in the online Appendix. We consider robustness to alternative panel specifications, samples and data sources, and further examine nonlinear temperature effects.

Panel Specifications.—We find that the results are broadly consistent across a range of alternative panel specifications, particularly the results with no lags. Table 4, panel A reports the results from models with no lags, while panels B and C report cumulative effects from models with five and ten lags, respectively.²⁰ To facilitate comparisons, the relevant results from Tables 2 and 3 are repeated in the first column of Table 4. The results in column 2, which incorporate country-specific trends as well as region \times year and poor \times year fixed effects, appear to be somewhat larger in magnitude than the baseline results, suggesting that the results are not being driven by secular time trends within countries.²¹ As discussed in online Appendix II and presented in online Appendix Table A1, the results are robust to more general dynamic panel regression models that use various lag structures. As an additional specification check, online Appendix Tables A37–38 report regressions that include one to ten leads of temperature. In no case are the leads significant, even when the contemporaneous temperature term is omitted. When controlling for leads, the contemporaneous and cumulated lag temperature effects remain of similar magnitude to those in the main results.

Finally, we have also investigated alternative formulations of the temperature and precipitation variables. First, we have considered using logs rather than levels of annual average temperature and precipitation. This specification strengthens the results. Second, we have constructed weather anomalies, normalizing annual temperature and precipitation by subtracting each country's mean and dividing by each country's standard deviation. This specification produces similarly sized impacts although standard errors typically increase, suggesting a model based on absolute temperature differences may be more appropriate. These results are all available in the online Appendix.

Sample and Data Sources.—Since countries' growth data starts at different dates, Table 4 (column 3) repeats the main specification on a balanced sample where all countries are present in the sample for the entire period.²² The point estimates are almost identical to the baseline results, although the standard errors in the five and ten lag specifications increase, as one might expect given that we have reduced the amount of data in the model. Expanding the data to include countries with less than 20 years of data also continues to show substantial negative effects in poor countries (column 4), with little change from the baseline specification.

Table 4 column 5 reconsiders the main specification using growth data from the Penn World Tables rather than the WDI. The results are very similar, though the 10 lag result is now statistically significant. Column 6 uses temperature and precipitation data aggregated using area-weighting rather than population-weighting and shows similar effects, though the zero-lag effect for rich countries is now statistically

²⁰The results in panel A correspond to column 3 of Table 2. Panels B and C correspond to columns 7 and 8 of Table 3. Results from models with one and three lags are qualitatively similar and are omitted to conserve space.

²¹Including country and region \times year fixed effects only (i.e., dropping the poor \times year fixed effects) produces similar estimated temperature effects in poor countries to the baseline results, though the results with five and ten lags attenuate somewhat. Similar results also emerge when we use common global year fixed effects instead of region \times year fixed effects and also drop the poor \times year fixed effects. We have also estimated a first differenced version of (4). This produces very similar results for the 0 lag model, while the estimates become substantially more negative and more imprecise as we add additional lags. These results are available in the online Appendix.

²²Note that temperature and precipitation data is present over the entire period, so having different start dates for the growth data is not an issue for calculating the lags in the model, since we can always calculate the lags of the weather data even if the growth data is missing.

TABLE 4—ALTERNATIVE SPECIFICATIONS OF PANEL RESULTS

	Baseline (1)	All FE and country specific trends (2)	Balanced sample: 1971–2003 (3)	Add countries with < 20 years of data (4)	GDP data from PWT (5)	Area- weighted climate data (6)	Sub- Saharan Africa only (7)	Sub- Saharan Africa excluded (8)
<i>Panel A. Models with no lags</i>								
Temp. immediate effect—poor	−1.347*** (0.408)	−1.723*** (0.603)	−1.377*** (0.484)	−1.158*** (0.424)	−0.860*** (0.299)	−0.891** (0.347)	−1.881*** (0.631)	−0.904* (0.531)
Temp. immediate effect—rich	0.262 (0.311)	0.417 (0.473)	0.387 (0.323)	0.595 (0.381)	0.343 (0.228)	0.480** (0.220)		0.295 (0.323)
Precip. immediate effect—poor	0.070 (0.058)	0.026 (0.137)	0.040 (0.084)	0.029 (0.051)	0.050 (0.069)	0.074 (0.063)	0.131 (0.111)	0.032 (0.071)
Precip. immediate effect—rich	−0.083* (0.050)	−0.066 (0.089)	−0.101* (0.058)	−0.022 (0.061)	−0.074 (0.060)	−0.087 (0.056)		−0.087* (0.053)
Observations	4,924	4,924	2,592	5,396	5,494	4,924	1,366	3,430
<i>Panel B. Models with 5 lags</i>								
Temp. cumulative effect—poor	−1.041** (0.530)	−2.025** (0.907)	−0.931 (0.943)	−1.067** (0.494)	−0.738*** (0.269)	−0.874* (0.522)	−0.705 (0.840)	−1.318* (0.684)
Temp. cumulative effect—rich	−0.191 (0.546)	0.245 (0.961)	0.276 (0.654)	−0.073 (0.582)	−0.022 (0.517)	−0.053 (0.504)		−0.377 (0.562)
Precip. cumulative effect—poor	0.238 (0.194)	0.211 (0.290)	0.221 (0.215)	0.084 (0.139)	0.193 (0.169)	0.241 (0.191)	0.868 (0.611)	−0.003 (0.141)
Precip. cumulative effect—rich	−0.127 (0.088)	−0.084 (0.208)	−0.161 (0.196)	−0.039 (0.142)	−0.134 (0.094)	−0.129 (0.089)		−0.121 (0.089)
Observations	4,916	4,916	2,592	5,285	5,272	4,916	1,366	3,422
<i>Panel C. Models with 10 lags</i>								
Temp. cumulative effect—poor	−0.858 (0.647)	−1.964 (1.211)	−0.951 (1.242)	−0.791 (0.641)	−0.768** (0.337)	−0.683 (0.635)	−0.803 (0.994)	−0.969 (0.843)
Temp. cumulative effect—rich	−0.189 (0.758)	0.582 (1.414)	0.198 (0.913)	−0.059 (0.827)	−0.443 (0.822)	−0.064 (0.738)		−0.469 (0.783)
Precip. cumulative effect—poor	0.429* (0.227)	0.573 (0.413)	0.455* (0.244)	0.236 (0.180)	0.254 (0.182)	0.435** (0.221)	0.922 (0.770)	0.234 (0.153)
Precip. cumulative effect—rich	−0.195 (0.137)	−0.142 (0.370)	−0.141 (0.394)	−0.183 (0.178)	−0.070 (0.134)	−0.196 (0.138)		−0.180 (0.143)
Observations	4,906	4,906	2,590	5,146	4,946	4,906	1,366	3,412

Notes: All specifications use WDI data and include country FE, region \times year FE, and poor \times year FE unless otherwise noted. Robust standard errors adjusted for two-way clustering at the parent-country and year-region levels are in parentheses. Except where noted, panel A follows the same specification as column 5 of Table 2, panel B follows the same specification as column 7 of Table 3, and panel C follows the same specification as column 8 of Table 3. In column 7, the sub-Saharan Africa sample incorporates three rich countries—South Africa, Gabon, and Mauritius.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

significant.²³ Splitting the sample into sub-Saharan African countries (column 7) and all other countries (column 8), the model with zero lags shows that the negative

²³ Weighting by rural population or urban population yields similar results to using total population weights; see the online Appendix.

impacts of temperature are especially pronounced in sub-Saharan Africa, but are still negative and statistically significant elsewhere, and the difference between the sub-Saharan Africa and non-sub-Saharan Africa samples is not statistically significant.²⁴ When we examine either the five or ten lag models, the negative point estimates are comparable in magnitude in both samples.²⁵

National accounts are notoriously hard to measure, particularly in developing countries (Deaton and Heston 2010; Ciccone and Jarocinski 2010; Young 2009). To investigate the extent to which measurement problems in the data are driving the results, we have examined the impact of temperature on exports. Since exports from poor countries are reported by the importing countries, these data are much more accurately measured than national accounts data. As reported in Jones and Olken (2010), analyzing export growth data as recorded by the US and other importing countries shows similarly large negative effects of increased temperature on poor countries' exports, but not on rich countries' exports. This finding indicates that the core panel finding is not driven by potentially low-quality national accounts data in poor countries.

Finally, we have investigated concerns that the temperature and precipitation data quality may be lower for poor countries, and concerns in particular that weather stations may enter or exit our sample in response to economic conditions. First, we have repeated our analysis of Africa with a number of alternative weather datasets.²⁶ Results are broadly similar in all samples, although limited size for alternative datasets reduces the estimates' precision. Second, the Global Historical Climatology Network (GHCN) dataset (the main underlying source for the Matsuura and Willmott (2007) data we use here) indicates whether a weather station is missing an observation in a given year. Using panel regression models, we find no relationship between economic conditions or political instability and the number of weather stations that are missing data in a given country and year.²⁷

Nonlinear Temperature Effects.—In our analysis, temperature enters linearly, whereas one might suspect that temperature has nonlinear effects.²⁸ To further investigate this possibility, beyond the interaction terms examined in Table 2, we examined more flexible aggregations of the subnational temperature data. Using daily temperature and precipitation data available on a 1.0×1.0 degree grid (NCC

²⁴ Given the very small number (3) of rich countries in sub-Saharan Africa, we group these together into a unified sub-Saharan African sample.

²⁵ Our results do differ from Barrios, Bertinelli, and Strobl (2010), who in their investigation of rainfall in sub-Saharan Africa include temperature as a control in one specification, finding no effects. Our specification differs from theirs on many dimensions. Barrios, Bertinelli, and Strobl (2010) examine fewer countries and fewer years of data, use a different temperature variable, and use a somewhat different empirical specification.

²⁶ These alternative datasets are the Global Precipitation Climatology Project, the National Center for Environment Prediction, and the UN Food and Agricultural Organization Climatic Data, which provide alternative precipitation series. See online Appendix for analysis and further discussion.

²⁷ In particular, we run panel regressions relating the share of stations that are missing in a given country and year (the dependent variable) to economic growth and political instability measures (interacted with poor country dummies). These regressions show no effect of these economic and political variables on station reporting in poor countries. See the online Appendix.

²⁸ For example, Deschenes and Greenstone (2007) find nonlinear temperature effects for agriculture and mortality, and Schlenker, Hanemann, and Fisher (2006), Schlenker and Roberts (2006), and Schlenker and Roberts (2009) find important nonlinear temperature effects for agriculture.

2005), we calculated the number of “people-days” spent at each temperature and precipitation level throughout the year for each country. We then repeated the panel analysis above (e.g., equation (4) with no lags) allowing the temperature and precipitation effects to vary arbitrarily at different temperature and precipitation ranges. Unfortunately, we did not have sufficient power to tease out detailed effects of the distribution of days within different temperature ranges, given that our dependent variable is measured at the annual, country level. While the results are imprecise, the point estimates suggest that the impact of temperature on GDP is roughly linear, supporting the focus on annual averages (see the online Appendix).

We have also conducted additional analysis of nonlinear effects of the average temperature variable, finding little evidence for such nonlinearities. First, we verified that both hot and cold deviations from the national temperature mean have effects of similar absolute magnitude on growth. Second, we found that temperature shocks do not affect poor countries differentially depending on whether the country is typically hot or cold, though the tiny number of cold poor countries prevents a definitive conclusion.²⁹ Although our power to assess nonlinearities is limited given the few degrees of variation in temperature within each country, the evidence here does not show substantial nonlinearities.

III. Channels

The large and persistent effects of temperature shocks on aggregate output in poor countries suggest further investigation of the temperature-economy relationship. Many macroeconomic models of climatic effects emphasize a limited set of channels, especially agriculture, and income level effects, rather than effects on factor accumulation or other dimensions that could impact growth. The microeconomic literature, by contrast, considers broader dimensions of climatic effects, including physical and cognitive labor productivity, conflict, and health, all of which could have economy-wide implications.³⁰ At the same time, the micro evidence often comes from local environments, usually in rich countries, which may or may not extend to national settings or to poor countries. In this section, we apply our panel methodology to explore whether the effects of temperature are primarily limited to agriculture, or whether temperature affects other important dimensions. Such analysis tests the narrow focus of mainstream aggregate climate-economy models and may also help inform our finding of possible growth effects in the distributed lag structure.

Note that these analyses are reduced-form, and therefore do not identify the possibly complex structural relationships between temperature, growth, and other outcomes. For example, higher temperature could lead directly to political instability by making a population more prone to riot (US Riot Commission 1968; Carlsmith and Anderson 1979). Conversely higher temperatures could lower agriculture yields, with the resulting GDP reduction provoking political instability. Teasing out structural relationships between these many variables would require a number of ad hoc identifying assumptions and lies far beyond the scope of this

²⁹ These results are presented in online Appendix Table A39.

³⁰ Footnote 1 provides a brief summary of this very large literature.

single study. We focus instead on net effects, which we can identify clearly, to shed light on the breadth and type of potential channels through which temperature may affect aggregate output. The results, which show impacts not only on agriculture, but also on industrial output and political stability, emphasize temperature's broad influences.

A. Agriculture, Industry, and Investment

Table 5 examines the impact of temperature and precipitation on several components of GDP. Panel A begins with zero-lag models to test the null hypotheses of no effects of temperature. Columns 1–3 examine growth in agricultural value-added, industrial value-added, and aggregate investment, respectively.³¹ These variables are taken from the World Development Indicators.

The results in panel A show substantial, negative effects of temperature in poor countries on agricultural and industrial value-added. Column 1 shows that a 1°C higher temperature in poor countries is associated with 2.66 percentage points lower growth in agricultural output. For wealthier countries, the point estimate is substantially smaller and not statistically significant, showing 0.22 percentage points lower growth in agricultural output for each additional 1°C of temperature. As might be expected, precipitation positively impacts agriculture—each additional 100 mm of annual rainfall is associated with 0.18 percentage points higher growth in agricultural output in poor countries and 0.16 percentage points higher growth in agricultural output in richer countries, though these effects are not statistically significant.³²

Column 2 of panel A shows negative temperature impacts on the growth of industrial value-added in poor countries. Specifically, a 1°C higher temperature in poor countries is associated with 2.04 percentage points lower growth in industrial output. In related work, Jones and Olken (2010) examine export growth in 2-digit trade data, and also find negative effects of temperature on both agricultural products and industrial products in poor countries. Many of the industrial sectors affected by temperature in the exports data, such as electronic equipment and light metal manufactures, are not downstream processors of agricultural products. Hsiang (2010) also documents similar impacts on industrial output in his study of temperature shocks in 28 Caribbean countries. The results on investment in column 3 also suggest negative impacts of temperature in poor countries, though the results are not statistically significant.³³

³¹ We find negative effects of similar magnitude on the residual category services, which is typically computed as the difference between total value-added and the sum of agricultural and industrial value added (see online Appendix).

³² Note that we are estimating only the average impact of temperature and precipitation without accounting for whether it was in the season that would be most beneficial or harmful to agricultural production. This likely creates an errors-in-variables problem, which may suggest that we are understating the true effect of temperature and precipitation on agriculture (see, e.g., Schlenker and Roberts 2009).

³³ Note, however, that there is a weakly significant precipitation effect in rich countries. Using daily data on precipitation (NCC 2005), we find that having a larger number of days with very high precipitation has a significant negative effect on aggregate output in rich countries (see online Appendix). One conjecture is that construction responds negatively to rain, providing the investment effect. Note also that aggregate investment in poor countries does show a statistically significant decline of 3.0 percentage points when using the full Penn World Tables sample, which is 50 percent larger.

TABLE 5—COMPONENTS OF OUTPUT GROWTH

Panel A. Models with no lags

	Dependent variable is		
	Growth in agriculture value added	Growth in industrial value added	Growth in investment
	(1)	(2)	(3)
Temperature	No lags	No lags	No lags
Immediate effect—poor	−2.666*** (0.948)	−2.036** (0.878)	−0.895 (1.269)
Immediate effect—rich	−0.222 (0.650)	0.514 (0.452)	0.182 (0.870)
Precipitation			
Immediate effect—poor	0.182 (0.135)	0.238 (0.146)	−0.019 (0.223)
Immediate effect—rich	0.16 (0.119)	−0.007 (0.100)	−0.419* (0.217)
Observations	3,835	3,835	4,419

Panel B. Models with lags

	Dependent variable is								
	Growth in agriculture value added			Growth in industrial value added			Growth in investment		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Temperature	1 lag	5 lags	10 lags	1 lag	5 lags	10 lags	1 lag	5 lags	10 lags
Cumulative effect—poor	−1.26 (0.882)	−1.051 (1.007)	−1.337 (1.203)	−1.835 (1.123)	−0.958 (1.365)	−2.242 (1.796)	1.170 (1.287)	0.128 (1.665)	−0.219 (1.797)
Cumulative effect—rich	0.328 (0.678)	0.002 (0.754)	0.236 (1.203)	0.653 (0.572)	0.111 (0.734)	0.321 (1.096)	0.598 (0.894)	−1.38 (1.333)	−1.283 (1.356)
Immediate effect—poor	−3.684*** (1.389)	−3.703*** (1.385)	−3.797*** (1.416)	−2.091** (0.987)	−2.334** (1.112)	−2.578** (1.172)	−2.235 (1.946)	−1.851 (1.972)	−2.229 (2.025)
Immediate effect—rich	−0.543 (0.792)	−0.468 (0.793)	−0.566 (0.815)	0.457 (0.486)	0.433 (0.498)	0.404 (0.500)	−0.079 (1.185)	0.19 (1.199)	0.282 (1.172)
Precipitation									
Cumulative effect—poor	0.094 (0.120)	0.129 (0.159)	0.052 (0.185)	0.328** (0.158)	0.205 (0.237)	0.230 (0.322)	0.148 (0.268)	0.007 (0.289)	−0.283 (0.349)
Cumulative effect—rich	0.207* (0.120)	0.394*** (0.143)	0.476** (0.233)	−0.071 (0.135)	−0.083 (0.229)	−0.113 (0.303)	−0.317 (0.203)	−0.017 (0.336)	−0.519 (0.364)
Immediate effect—poor	0.220 (0.180)	0.235 (0.197)	0.252 (0.208)	0.188 (0.187)	0.108 (0.168)	0.078 (0.166)	−0.106 (0.361)	−0.174 (0.402)	−0.190 (0.405)
Immediate effect—rich	0.154 (0.172)	0.153 (0.184)	0.169 (0.192)	0.012 (0.124)	0.001 (0.132)	0.002 (0.137)	−0.434* (0.262)	−0.468* (0.282)	−0.457 (0.283)
Observations	3,835	3,827	3,817	3,835	3,827	3,817	4,419	4,411	4,401

Notes: Growth in agriculture value-added and industrial value-added are from the WDI; growth in investment is also from the WDI. All specifications include country FE, region \times year FE, and poor \times year FE. Robust standard errors are in parentheses, adjusted for two-way clustering at parent-country and year-region levels. Sample includes all countries with at least 20 years of PWT growth observations (i.e., the same set of countries considered in the previous tables).

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Panel B examines the lag structure of these effects. For each dependent variable (growth in agriculture, growth in industry, and growth in investment), we present results with 1, 5, and 10 lags. For all three dependent variables, the impact effect (i.e., the coefficient on contemporaneous temperature) is negative and large, though the investment variable is not statistically significant. For agriculture, the point estimates of the cumulative effects, while imprecise, are somewhat smaller than the immediate effects, suggesting the presence of some combination of growth and level effects for these variables. For industrial value added, the point estimates of the cumulative effects are closer in magnitude to the immediate effect.

These findings on industrial value added reject a narrow view of climatic effects. While confirming agricultural effects, the results further show large shocks to industrial output growth in poor countries. There are several possible, nonmutually exclusive explanations for temperature's impact on industrial output. First, this effect could partly represent a demand-side spillover from the negative effect of temperature on agricultural output. Second, this effect may reflect labor productivity losses, consistent with a large literature documenting the impact of temperature on output in factory and other settings. For example, Graff Zivin and Niedell (2010) demonstrate substantial contractions in labor supply on hot days in those US industries with high exposure to weather (e.g., those with work outdoors and those without access to air conditioning).³⁴ Their estimated magnitudes are large. For high temperature exposure occupations, temperatures over 100° Fahrenheit (37.7°C) lead to 23 percent lower labor supply than temperatures between 76–80° Fahrenheit (24.4–26.6°C). If poor countries' industrial sectors are more sensitive to temperature than those of rich countries (for example, because they are not air conditioned), then these types of labor supply or other labor productivity effects could explain the substantial impact of temperature on manufacturing that we observe.

B. Political Economy

Temperature may also impact growth if increased temperature leads to political instability, which in turn may impede factor accumulation and productivity growth. Empirically, political instability is associated with lower economic growth (Alesina 1996), and there is substantial empirical evidence that riots and protests are more likely in warmer weather (e.g., US Riot Commission 1968; Carlsmith and Anderson

³⁴Building on classic ideas in economic development that link productivity to temperature (Montesquieu 1750, Marshall 1920), Huntington (1915) documented that high temperature reduces the productivity of piece-rate Connecticut factory workers and Florida cigar makers. More recently, Link and Pepler (1970), Wyon (1976), Meese et al. (1982), and others have found substantial negative impacts of higher temperatures on the productivity of factory workers. More generally, the large literature on climate and productivity, which includes laboratory experiments and experiments in actual work places (i.e., factories, call centers, and office buildings), robustly finds a decrement in work performance when temperatures exceed those associated with thermal neutrality. The review of Seppänen, Fisk, and Faulkner (2003) finds a median 2 percent decrement in work performance per degree Celsius temperature rise above 25°C. Moreover, in a meta-analysis of more than 150 studies, Ramsey and Kwon (1992) distinguish between simple mental tasks (i.e., simple perpetual motor, reaction time) and more complex tasks (i.e., tracking, vigilance, dual tasks). While effects of heat stress appear limited or simple mental tasks, statistically significant effects appear at high temperatures for the second class of tasks. Simpler tasks may be less affected because when the body becomes impaired by or expends energy to counteract the negative impacts of heat stress (i.e., dehydration, increased sweating and loss of sodium, etc.), the automatic processes in simple tasks are prioritized over complex cognitive tasks that are typically less essential for survival.

1979; Boyanowsky 1999).³⁵ Alternatively, economic impacts of higher temperatures might provoke dissatisfied citizens to seek institutional change (Burke and Leigh 2010; Brückner and Ciccone 2011).

We examine the impact of temperature on several measures of political instability. First, the *Polity IV* dataset (Marshall and Jaggers 2004) rates the political system in each country annually from -10 (fully autocratic) to $+10$ (fully democratic). This POLITY variable further designates “interregnum periods,” which are years when the political system is in flux and no clear political regime has emerged.

The second set of measures comes from the *Archigos* dataset on political leaders (Goemans, Gleditsch, and Chiozza 2006). This dataset classifies the primary national political leader for each country and year and codes all leader transitions into two categories: “regular” transitions, which take place according to the prevailing institutional rules of the country; and “irregular” transitions (such as coups), which do not follow the prevailing institutional rules. We consider a dummy variable for years with leadership transitions, as well as separate dummy variables for regular and irregular transitions.

The results are presented in Table 6. Looking first at POLITY, an additional 1°C in poor countries is associated with a 2.7 percentage point increase in the probability of any change in POLITY.^{36, 37} The *Archigos* results show a similar pattern and are stronger statistically. A 1° rise of temperature raises the probability of leader transitions by 3.1 percentage points in poor countries (column 2). Moreover, this effect comes not from regular leadership transitions (column 3) but from irregular leader transitions, i.e., coups (column 4). This effect of 4.4 percentage points is large, as the baseline probability of an irregular leader transition is only 4.5 percent per year in poor countries. By contrast, we see no effects on leader transitions in rich countries.

Combined, the POLITY and *Archigos* data tell a similar story. Higher temperatures are associated with political instability in poor countries. Whether temperature has direct effects on political instability, which in turn affects economic growth, or whether temperature has direct effects on economic growth, which in turn affects political instability, or both, is difficult to distinguish, since poor economic performance and political instability are likely mutually reinforcing. Nevertheless, the impact of temperature on political instability in poor countries is suggestive of an institutional mechanism through which temperature might affect productivity growth, rather than just the level of income.³⁸

³⁵ Medical studies have documented that levels of platelet paroxitine, a chemical that blocks impulsivity and aggression, fall when temperatures increase and have linked low levels of platelet paroxitine to higher rates of aggression (Tihonen et al. 1997). Violent crime also increases with temperature (Jacob, Lefgren, and Moretti 2007).

³⁶ In the online Appendix, we decompose this change into contemporaneous increases in POLITY (toward democracy), decreases (toward autocracy), or shifts into interregnum periods (between regimes). We find about half of the changes induced by temperature are decreases in POLITY and about half are interregnum periods, though the decomposition is weak statistically. See online Appendix Table A36.

³⁷ The results on precipitation appear smaller, but suggest that political change in poor countries is more likely in years with lower rainfall.

³⁸ These results, emphasizing political instability, complement but differ from recent literature finding that weather-associated output contractions predict democratization (Burke and Leigh 2010; Brückner and Ciccone 2011). Here we look at a more general class of political changes and make no claim that the effects of temperature shocks are felt on political variables through an output channel.

TABLE 6—POLITICAL ECONOMY EFFECTS

	Any change in POLITY score (1)	Leader transition (2)	Regular leader transition (3)	Irregular leader transition (4)	Start of conflicts (conditional on conflict = 0 in $t - 1$) (5)	End of conflicts (conditional on conflict > 0 in $t - 1$) (6)
Temperature	-0.013 (0.009)	-0.002 (0.015)	0.004 (0.015)	-0.005 (0.004)	-0.006 (0.006)	0.005 (0.060)
Temperature × Poor	0.040** (0.016)	0.033 (0.023)	-0.017 (0.017)	0.050*** (0.013)	0.012 (0.013)	0.003 (0.068)
Precipitation	0.001 (0.003)	0.003 (0.002)	0.003 (0.003)	0.000 (0.001)	0.000 (0.001)	0.023 (0.019)
Precipitation × Poor	0.008 (0.005)	-0.008* (0.004)	-0.008** (0.004)	0.000 (0.002)	0.000 (0.002)	-0.031 (0.020)
Observations	5,388	6,624	6,624	6,624	5,702	852
R^2	0.14	0.18	0.2	0.11	0.09	0.43
Within R^2	0.003	0.001	0.001	0.004	0.000	0.004
Temperature effect in poor countries	0.027* (0.015)	0.031* (0.017)	-0.013 (0.010)	0.044*** (0.013)	0.007 (0.011)	0.008 (0.037)
Precipitation effect in poor countries	-0.009** (0.004)	-0.005 (0.004)	-0.005* (0.003)	0.000 (0.002)	0.000 (0.002)	-0.009 (0.007)

Notes: Column 1 uses data from the POLITY IV dataset; columns 2–4 use data from the Archigos dataset; and columns 5–6 use data from the PRIO dataset. Columns 1–4 include country FE, region × year FE, and poor × year FE; columns 5–6 include country FE and year FE. Robust standard errors are in parentheses, adjusted for two-way clustering at parent-country and year-region levels. Sample includes all countries with at least 20 years of WDI growth observations (i.e., the same set of countries considered in the previous tables).

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

The final columns of Table 6 consider the impact of temperature on conflict. We use the PRIO conflict data (PRIO 2006), which indicates for every country-year whether the country was involved in a high-intensity conflict (defined as $\geq 1,000$ conflict deaths/year) or a low-intensity conflict (defined as 25 to 1,000 conflict deaths/year). Column 5 examines the start of conflicts (i.e., the probability a conflict begins given no conflict in the previous period), and column 6 examines the end of conflicts (i.e., the probability a conflict ends given conflict in the previous period).³⁹ We find no significant effect of temperature on either the start or conclusion of conflicts.⁴⁰ The political impacts of temperature thus appear more concentrated in political instability rather than civil or interstate wars.

³⁹Given how rare conflicts are, we use year fixed effects rather than region-by-year fixed effects in these specifications.

⁴⁰These results differ from Miguel, Satyanath, and Sergenti (2004), who find—also using the PRIO dataset—that greater precipitation is associated with a lower probability of conflict. We have replicated the Miguel, Satyanath, and Sergenti (2004) results in our data, and find that the differences between the findings in Table 6 and those in Miguel, Satyanath, and Sergenti (2004) come from a different sample of countries (Miguel, Satyanath, and Sergenti (2004) examine only sub-Saharan African countries from 1981–1999) and the fact that Miguel, Satyanath, and Sergenti (2004) use a somewhat different empirical specification from the one in Table 6. These replication results are presented in the online Appendix.

IV. Medium-Run Estimates

In this section, we reexamine the historical data to investigate temperature shifts over the medium run. The above, short-run panel estimates indicate substantial effects of temperature shocks in poor countries, with per capita income growth falling approximately 1 percentage point for a 1°C rise in temperature. In the medium run, the effect of sustained temperature increases might attenuate over time if economies adapt. On the other hand, sustained higher temperatures may reinforce growth-related problems by placing continued pressure on political systems or other relevant factors.

We therefore consider the longer run analogue of our panel specification, examining the relationship between temperature changes and growth changes in the early and late periods in our dataset. There is substantial heterogeneity in temperature increases over this period, with countries such as Tunisia, Zambia, and Botswana warming by approximately 1°C since the mid 1980s, while others such as Laos, Kenya, and Nigeria experienced almost no warming over the same period. We exploit this variation to ask whether countries with sustained warming saw sustained changes in growth.

Specifically, we estimate the following regression

$$\bar{g}_{i2} - \bar{g}_{i1} = \alpha + \theta_r + \gamma(\bar{T}_{i2} - \bar{T}_{i1}) + \varepsilon_i,$$

where \bar{g}_{i1} is the mean growth rate in country i in the early period (1970–1985 in our main specification), and \bar{g}_{i2} is the mean growth rate in the late period (1986–2000).⁴¹ Mean temperature and precipitation in these periods are \bar{T}_{i1} and \bar{T}_{i2} , while θ_r captures region fixed effects and a dummy for being poor, and ε_i is an independently distributed error term. This first-differenced regression is the longer run version of the fixed effects panel model in equation (4). To see this, start with equation (4) with no lags, take averages of the left- and right-hand sides for a given period, and then first-difference. We have one observation per country, having differenced out any initial conditions or other fixed national characteristics that might influence growth.⁴²

A graphical version of the results is shown in Figure 2, and the regression results are shown in Table 7. Figure 2 plots the change in growth between the 1970–1985 and 1985–2000 against the change in average temperature during the same periods, separately for poor and rich countries, along with a simple regression line (and associated standard errors). The graphs show a statistically significant downward sloping relationship in poor countries, with no statistically significant relationship in rich countries.⁴³

Turning to Table 7, the baseline specification compares the 1970–1985 period to the 1986–2000 period and shows substantial, statistically significant negative effects of warming on poor countries. In column 1, a temperature rise of 1°C reduces

⁴¹ We begin in the 1970s, rather than an earlier decade, such as the 1960s, because we lose most of the poor countries in our sample when we extend the sample back to the 1960s. We present results for a variety of alternative time periods below.

⁴² Note also that, in cross section, average growth is substantially lower in warmer countries over this period. While interesting, this is less well identified than the first-differenced results, which net out unobserved fixed country characteristics.

⁴³ The point estimates for rich countries suggest an upward slope, although it is not statistically significant, and flattens further when using median regression (see Table 7).

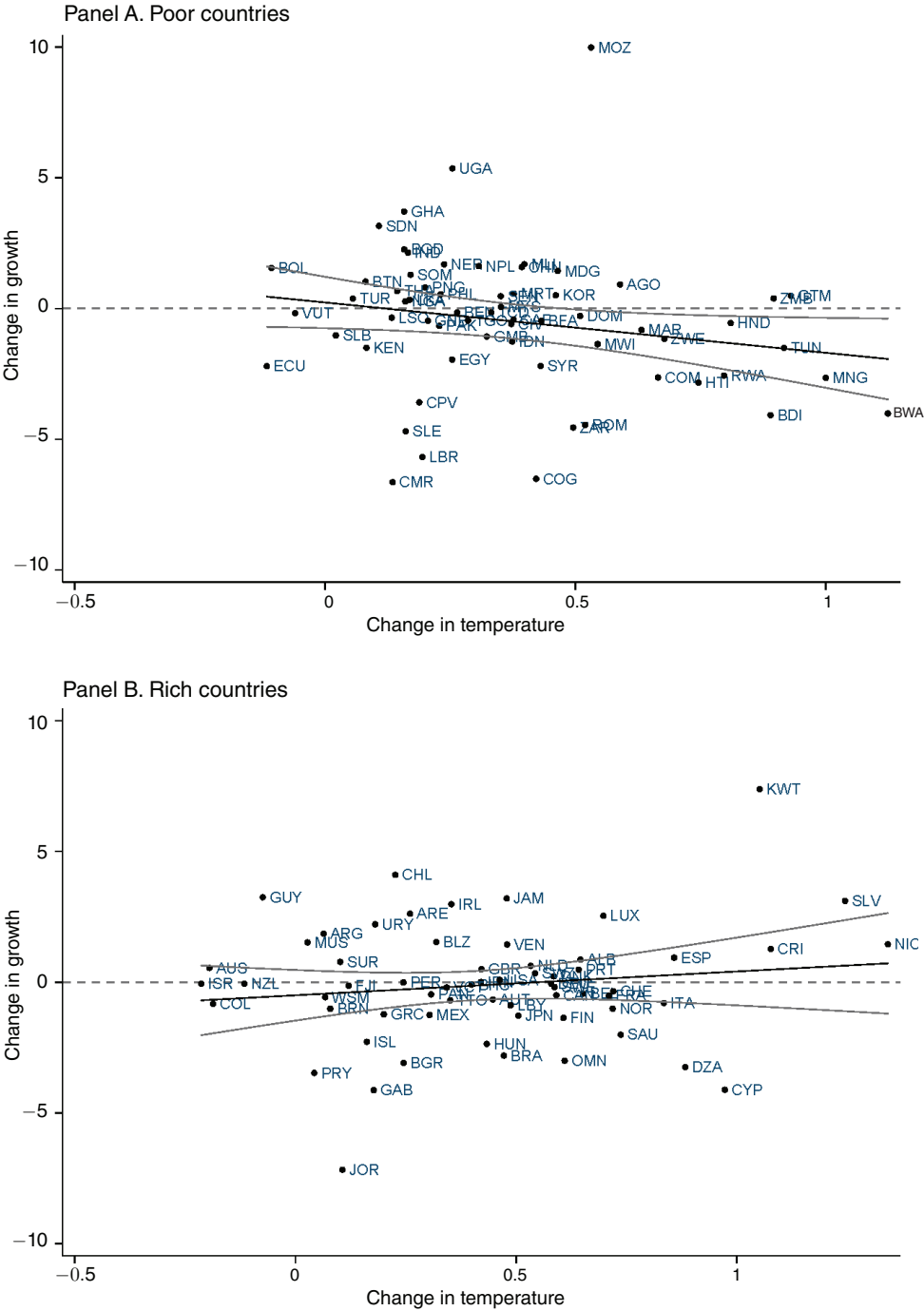


FIGURE 2. CHANGES IN GROWTH AND TEMPERATURE IN THE MEDIUM RUN

Notes: Panels A and B plot the change in average annual growth against the change in average annual temperature between the periods 1970–1985 and 1986–2000, for rich and poor countries, respectively. The solid line shows a simple linear regression, and the lighter color line shows the 95 percent confidence interval in the regression line.

annual growth in poor countries by 1.9 percentage points. The inclusion of region fixed effects does not substantially change this effect, as shown in column 2, though the result is no longer statistically significant. When we use median regressions to reduce the impact of outliers (columns 3 and 4), the estimated impact for poor countries becomes slightly larger and substantially more statistically significant. We have also examined robustness to using alternative comparison years. In all cases the temperature effect on poor countries is, as in column 2, negative but not statistically significant (see online Appendix Table A40). When we split the sample into sub-Saharan African countries (column 5) and all other countries (column 6), we find similar effects in both samples, though the estimates are not statistically significant.⁴⁴ Finally, using PWT data instead of WDI data we estimate that a 1°C increase in temperature reduces annual growth in poor countries by 2.3 percentage points (column 7). Overall, this analysis provides some suggestive evidence that the effects seen in the annual data persist over the medium run. Put another way, we find little evidence that poor countries eliminate all negative consequences of warming over the time horizons considered here.

V. Discussion

A. Temperature and Economic Development

The negative cross-sectional association between temperature and per capita income (see Figure 1) has long been known (e.g., Huntington 1915). Yet there has been a vigorous debate over whether this correlation is due to a direct impact of temperature on economic activity (e.g., Sachs 2003), or whether some third variable (e.g., a country's institutions) drives prosperity in contemporary times, leaving little or no room for geography (e.g., Acemoglu, Johnson, and Robinson 2002; Rodrik, Subramanian, and Trebbi 2004). This debate has primarily proceeded by treating temperature variables as fixed for a given country, which makes testing these alternative hypotheses challenging.

By using temperature variation within countries, we can better identify its effects. Our results show that temperature per se has an important impact on national economic performance. While not ruling out many other forces that may play important roles in economic development, the evidence here rejects the hypothesis that temperature does not influence national production. Moreover, the estimated impacts are large in magnitude, in fact, more than large enough to explain the cross-sectional temperature-income relationship between rich and poor countries. To see this, recall that the cross-sectional relationship shows a decline in per capita income of 8.5 log points, or about 8 percent, for a 1°C increase in temperature (see Figure 1). Our panel estimates show that a 1°C temperature increase reduces poor country growth rates by 1.3 percentage points. In a world with no adaptation, our panel estimates imply that cross-country temperature differences would need to be sustained for

⁴⁴ As in Table 4 above, because nearly all countries in sub-Saharan Africa are poor, we do not separately distinguish between rich and poor countries when focusing on this region.

TABLE 7—CHANGES IN GROWTH AND TEMPERATURE IN THE MEDIUM RUN

	Dependent variable: change in mean growth rate						
	Baseline sample				Africa only	Excluding Africa	PWT data
	OLS (1)	(2)	Median regression (3) (4)		(5)	(6)	(7)
Change in temperature	0.952 (1.021)	1.325 (0.980)	0.004 (0.584)	0.440 (0.747)	−1.654 (2.250)	1.318 (1.004)	1.576 (1.135)
Change in temp. × poor country	−2.886** (1.420)	−3.010** (1.456)	−2.261** (0.932)	−2.540** (1.177)		−2.980** (1.435)	−3.917** (1.532)
Change in precipitation	−0.070 (0.097)	−0.047 (0.123)	0.028 (0.113)	0.038 (0.111)	0.034 (0.565)	−0.020 (0.121)	0.025 (0.111)
Change in precip. × poor country	0.060 (0.191)	0.050 (0.214)	0.120 (0.182)	0.315 (0.208)		0.009 (0.212)	0.010 (0.238)
Region FE	No	Yes	No	Yes	No	Yes	Yes
Poor country dummy	Yes	Yes	Yes	Yes	No	Yes	Yes
Early period	1970–1985	1970–1985	1970–1985	1970–1985	1970–1985	1970–1985	1970–1985
Late period	1986–2000	1986–2000	1986–2000	1986–2000	1986–2000	1986–2000	1986–2000
Observations	125	125	125	125	35	87	120
R ²	0.04	0.11			0.06	0.19	0.12
Within R ²	0.03	0.04			0.04	0.04	0.06
Temp. effect on poor countries	−1.934* (0.986)	−1.684 (1.088)	−2.257*** (0.726)	−2.100** (0.919)	−1.654 (2.250)	−1.661 (1.047)	−2.341** (1.029)
Precip. effect on poor countries	−0.010 (0.164)	0.003 (0.167)	0.148 (0.143)	0.354** (0.175)	0.034 (0.565)	−0.012 (0.153)	0.035 (0.211)

Notes: All specifications have one observation per country. Change in temperature and precipitation are computed for each country as the difference between the mean value in the late period and the mean value in the early period (these periods are indicated in the table for each specification). The dependent variable is the change in mean growth rate comparing the indicated late and early periods. Region fixed effects and a dummy for being an initially poor country are included as indicated for each specification. Robust standard errors in parentheses. For Africa only, we do not split out by poor/rich since we have so few rich country observations in sub-Saharan Africa.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

only 7 years to generate the cross-sectional correlation between temperature and per capita income seen in Figure 1.⁴⁵ In practice, adaptation may mitigate these effects substantially in the long run.

B. Building Estimates for the Impact of Future Climate Change

Estimating the future implications of climatic change is a difficult exercise given numerous uncertainties about the extent of climatic change and the economic effects that may ensue. Our estimates use recent historical evidence to inform the short- and medium-run consequences of temperature increases, but bridging to long-run implications is more challenging. First, countries may adapt to permanent changes in climate more successfully than they adapt to the annual or decade-long temperature

⁴⁵ Dell, Jones, and Olken (2009) consider how explicit assumptions about adaptation, convergence, and other forces over the long run can reconcile short- and long-run empirical relationships between temperature and income.

shocks that we examine empirically. Adaptation can take place at a local level but also at a global level, where new adaptive technologies may be developed that find wide-scale use.⁴⁶ Second, several potential effects of future climatic change, including potential effects on sea levels, biodiversity, and storm frequency, are not captured within our historical analysis. Third, global-scale general equilibrium effects, including adjustments in trade patterns and convergence forces, may offset asymmetric national effects on poor countries.⁴⁷

While tackling these challenges is beyond the scope of this paper, its findings do suggest important ways in which future implementations of climate-economy models could be modified to better match the historical climate-economy relationship. First, current climate-economy models are built around a relatively narrow set of channels, primarily agriculture, through which climate could impact economic activity. Our analysis finds large effects, in industrial value-added and political stability, that are not considered by most current IAM climate-economy analyses. Second, IAM approaches often build underlying sector-specific models from evidence of behavior in rich countries. Our results, whether looking at aggregate output or underlying channels, repeatedly demonstrate that poor countries experience extremely different (and negative) effects compared to rich countries, so extrapolating analyses of rich countries is likely to understate effects in poorer regions. Finally, most existing literature assumes that temperature will affect the level of output, as opposed to the growth rate of output. In our method, we consider the possibility of both level and growth effects. Because growth effects compound over time, even modest growth effects can accumulate into large income effects.

VI. Conclusion

This paper examines the historical relationship between temperature fluctuations and economic growth. We find substantial effects of temperature shocks, but only in poor countries. In poor countries, a 1°C rise in temperature in a given year reduces economic growth by 1.3 percentage points on average. The estimates further suggest that temperature shocks may affect the rate of economic growth, rather than just the level of output. However, whereas the short-run impacts appear very robust, the case for persistent growth effects in the distributed lag structure depends on the specification. Estimates using medium-run shifts from 1970 to 2000 rather than annual variation produce similar though noisy estimates, suggesting that adaptation may not undo the effects of temperature changes in the medium term.

By focusing on fluctuations in temperature, we seek to inform old debates over temperature's role in economic development and new debates over future impacts of climate change. Our findings of large effects of temperature shocks on poor countries provide counterevidence to claims that temperature does not influence national production. While higher temperatures reduce agricultural output in poor countries,

⁴⁶To investigate the possibility of global adaptation, we have looked at whether the estimated impacts of temperature become less pronounced over time. While the point estimates suggest smaller temperature impacts in more recent decades, the difference is not statistically significant. See online Appendix Tables A31 and A32.

⁴⁷A key advantage of the panel analysis in this paper is to enhance identification by sweeping out fixed effects for country and time. However, this approach by necessity eliminates the capacity to estimate global-scale effects.

we also find that they lead to reductions in industrial output and political stability. These results underscore the breadth of mechanisms underlying the climate-economy relationship and emphasize channels not usually considered in the aggregate climate literature. Further work is needed to identify precise causal mechanisms surrounding each of these channels. While teasing out the mechanisms is challenging, this paper suggests such analysis is of first-order importance, as the economic effects in poor countries appear large.

Given uncertainty over adaptation, international spillovers, technical change, and other issues, the estimates here—driven primarily from short-run fluctuations in temperature—alone cannot provide precise predictions about the estimated impacts of future climate change. The results do, however, provide clear guidance on critical economic dimensions that integrated assessment models and other attempts to think about global climate change should incorporate. A credible model should be able to match the historical moments in the data uncovered here: the stark differences between rich and poor countries, the possibility of growth effects rather than just level effects, and the possibility that climate change will affect the economy outside of agriculture. Incorporating these effects into current models of climate change will yield predictions that more closely match historical evidence about the relationship between temperature and economic performance.

REFERENCES

- Acemoglu, Daron, Simon Johnson, and James A. Robinson.** 2001. "The Colonial Origins of Comparative Development: An Empirical Investigation." *American Economic Review* 91 (5): 1369–1401.
- Acemoglu, Daron, Simon Johnson, and James A. Robinson.** 2002. "Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution." *Quarterly Journal of Economics* 117 (4): 1231–94.
- Adams, Richard M., Cynthia Rosenzweig, Robert M. Peart, Joe T. Ritchie, Bruce A. McCarl, David Glyer, R. Bruce Curry, James W. Jones, Kenneth J. Boote, and L. Hartwell Allen Jr.** 1990. "Global Climate Change and US Agriculture." *Nature* 345 (6272): 219–24.
- Alesina, Alberto.** 1996. "Political Instability and Economic Growth." *Journal of Economic Growth* 1 (2): 189–211.
- Balk, Deborah, et al.** 2004. Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI), the World Bank; and Centro Internacional de Agricultura Tropical (CIAT), 2004. Global Rural-Urban Mapping Project (GRUMP), Palisades, NY: CIESIN, Columbia University. Available at <http://sedac.ciesin.columbia.edu/gpw> (accessed 2004).
- Barrios, Salvador, Luisito Bertinelli, and Eric Strobl.** 2010. "Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the African Growth Tragedy." *Review of Economics and Statistics* 92 (2): 350–66.
- Bond, Steve, Asli Leblebicioglu, and Fabio Schiantarelli.** 2010. "Capital Accumulation and Growth: A New Look at the Empirical Evidence." *Journal of Applied Econometrics* 25 (7): 1073–99.
- Boyanowsky, Ehor.** 1999. "Violence and Aggression in the Heat of Passion and in Cold Blood: The Ecs-TC Syndrome." *International Journal of Law and Psychiatry* 22 (3): 257–71.
- Brohan, P., J. J. Kennedy, I. Harris, S. F. B. Tett, and P. D. Jones.** 2006. "Uncertainty Estimates in Regional and Global Observed Temperature Changes: A New Data Set from 1850." *Journal of Geophysical Research* 111 (D12): 1–21.
- Brückner, Markus, and Antonio Ciccone.** 2011. "Rain and the Democratic Window of Opportunity." *Econometrica* 79 (3): 923–47.
- Burke, Paul J., and Andrew Leigh.** 2010. "Do Output Contractions Trigger Democratic Change?" *American Economic Journal: Macroeconomics* 2 (4): 124–57.
- Cameron, A. Colin, Jonah B. Gelbach, and Douglas L. Miller.** 2011. "Robust Inference with Multiway Clustering." *Journal of Business and Economic Statistics* 29 (2): 238–49.

- Carlsmith, J. Merrill, and Craig A. Anderson.** 1979. "Ambient Temperature and the Occurrence of Collective Violence: A New Analysis." *Journal of Personality and Social Psychology* 37 (3): 337–44.
- Ciccone, Antonio, and Marek Jarociński.** 2010. "Determinants of Economic Growth: Will Data Tell?" *American Economic Journal: Macroeconomics* 2 (4): 227–46.
- Curriero, Frank C., Karlyn S. Heiner, Jonathan M. Samet, Scott L. Zeger, Lisa Strug, Jonathan A. Patz.** 2002. "Temperature and Mortality in 11 Cities of the Eastern United States." *American Journal of Epidemiology* 155 (1): 80–87.
- Deaton, Angus, and Alan Heston.** 2010. "Understanding PPPs and PPP-based National Accounts." *American Economic Journal: Macroeconomics* 2 (4): 1–35.
- Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken.** 2009. "Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates." *American Economic Review* 99 (2): 198–204.
- Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken.** 2012. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century: Dataset." *American Economic Journal: Macroeconomics*. <http://dx.doi.org/10.1257/mac.4.3.66>.
- Deschenes, Olivier, and Michael Greenstone.** 2007. "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather." *American Economic Review* 97 (1): 354–85.
- Deschenes, Olivier, and Enrico Moretti.** 2009. "Extreme Weather Events, Mortality, and Migration." *Review of Economics and Statistics* 91 (4): 659–81.
- Field, Simon.** 1992. "The Effect of Temperature on Crime." *British Journal of Criminology* 32 (3): 340–51.
- Gallup, John Luke, and Jeffrey D. Sachs.** 2001. "The Economic Burden of Malaria." *American Journal of Tropical Medicine and Hygiene* 64 (1, 2) 85–96.
- Gallup, John Luke, Jeffrey D. Sachs, and Andrew D. Mellinger.** 1999. "Geography and Economic Development." *International Regional Science Review* 22 (2): 179–232.
- Gates, Warren.** 1967. "The Spread of Ibn Khaldun's Ideas on Climate and Culture." *Journal of the History of Ideas* 28 (3): 415–22.
- Goemans, Hein, Kristian Gleditsch, and Giacomo Chiozza.** 2006. "Archigos: A Database of Leaders 1875–2004." <http://mail.rochester.edu/~hgoemans/data>.
- Greene, William H.** 2002. *Econometric Analysis* (Fourth edition). Upper Saddle River, NJ: Prentice Hall.
- Guiteras, Raymond.** 2007. "The Impact of Climate Change on Indian Agriculture." Unpublished.
- Heston, Alan, Robert Summers, and Bettina Aten.** 2006. *Penn World Table Version 6.2*, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, September 2006.
- Hornbeck, Richard.** Forthcoming. "The Enduring Impact of the American Dust Bowl: Short and Long-run Adjustments to Environmental Catastrophe." *American Economic Review*.
- Hsiang, Solomon M.** 2010. "Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America." *Proceedings of the National Academy of Sciences* 107 (35): 15367–72.
- Huntington, Ellsworth.** 1915. *Civilization and Climate*. New Haven: Yale University Press.
- Intergovernmental Panel on Climate Change (IPCC).** 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva. <http://www.ipcc.ch/>.
- Jacob, Brian, Lars Lefgren, and Enrico Moretti.** 2007. "The Dynamics of Criminal Behavior: Evidence from Weather Shocks." *Journal of Human Resources* 42 (3): 489–527.
- Johnson, Simon, William Larson, Chris Papageorgiou, and Arvind Subramanian.** 2009. "Is Newer Better? Penn World Table Revisions and Their Impact on Growth Estimates." National Bureau of Economic Research Working Paper 15455.
- Jones, Benjamin F., and Benjamin A. Olken.** 2010. "Climate Shocks and Exports." *American Economic Review* 100 (2): 454–59.
- Link James, and Robert Pepler.** 1970. "Associated Fluctuations in Daily Temperature, Productivity and Absenteeism." *ASHRAE Transactions* Vol. 76, Part II, Paper number 2167 RP-57, 326–37.
- Maccini, Sharon, and Dean Yang.** 2009. "Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall." *American Economic Review* 99 (3): 1006–26.
- Marshall, Alfred.** 1920. *Principles of Economics*. London: Macmillan and Co., (Orig. pub. 1890).
- Marshall, Monty G., and Keith Jagers.** 2004. *Polity IV Project: Political Regime Characteristics and Transitions, 1800–2002*. College Park, MD: Center for International Development and Conflict Management, University of Maryland. <http://www.systemicpeace.org/polity/polity4.htm>.

- Matsuura, Kenji, and Cort Willmott.** 2007. *Terrestrial Air Temperature and Precipitation: 1900–2006 Gridded Monthly Time Series*. Version 1.01. University of Delaware. <http://climate.geog.udel.edu/~climate/>.
- Meehl, G. A., C. Tebaldi, and D. Nychka.** 2004. "Changes in Frost Days in Simulations of Twentyfirst Century Climate." *Climate Dynamics* 23 (5): 495–511.
- Meese, G., R. Kok, M. Lewis, and D. Wyon.** 1982. "Effects of Moderate Cold and Heat Stress on Factory Workers in Southern Africa." *South African Journal of Science* 78: 189–97.
- Mendelsohn, Robert, Ariel Dinar, and Apurva Sanghi.** 2001. "The Effect of Development on the Climate Sensitivity of Agriculture." *Environment and Development Economics* 6 (1): 85–101.
- Miguel, Edward, Shanker Satyanath, and Ernest Sergenti.** 2004. "Economic Shocks and Civil Conflict: An Instrumental Variables Approach." *Journal of Political Economy* 112 (4): 725–53.
- Montesquieu, Charles de Secondat.** 1750. *The Spirit of Laws*. London: J. Nourse and P. Vaillant.
- Nicholls, Robert, and Stephen P. Leatherman, eds.** 1995. "Potential Impacts of Accelerated Sea-Level Rise on Developing Countries." *Journal of Coastal Research*, Special Issue No. 14.
- Ngo-Duc, T., J. Polcher, and K. Laval.** 2005. "A 53-year Forcing Dataset for Land Surface Models." *Journal of Geophysical Research* 110, 13.
- Nordhaus, William D.** 2006. "Geography and Macroeconomics: New Data and New Findings." *Proceedings of the National Academy of Science* 103 (10): 3510–17.
- PRIO.** 2006. Armed Conflict Data Version 4. Available at <http://new.prio.no/CSCW-Datasets/Data-on-Armed-Conflict/UppsalaPRIO-Armed-Conflicts-Dataset/>.
- Ramsey, Jerry D., and Yeong G. Kwon.** 1992. "Recommended Alert Limits for Perceptual Motor Loss in Hot Environments." *International Journal of Industrial Ergonomics* 9 (3): 245–57.
- Rodrik, Dani, Arvind Subramanian, and Francesco Trebbi.** 2004. "Institutions Rule: The Primacy of Institutions over Geography and Integration in Economic Development." *Journal of Economic Growth* 9 (2): 131–65.
- Sachs, Jeffrey D.** 2003. "Institutions Don't Rule: Direct Effects of Geography on Per Capita Income." National Bureau of Economic Research Working Paper 9490.
- Sachs, Jeffrey, and Pia Malaney.** 2002. "The Economic and Social Burden of Malaria." *Nature* 415 (6872): 680–85.
- Sachs, Jeffrey D., and Andrew M. Warner.** 1997. "Sources of Slow Growth in African Economies." *Journal of African Economies* 6 (3): 335–76.
- Seppänen, Olli, William Fisk, and D. Faulkner.** 2003. "Cost Benefit Analysis of the Night-Time Ventilative Cooling in Office Building." Paper presented at Healthy Buildings 2003 Conference, Singapore, December 8.
- Schlenker, Wolfram, W. Michael Hanemann, and Anthony C. Fisher.** 2006. "The Impact of Global Warming on US Agriculture: An Econometric Analysis of Optimal Growing Conditions." *Review of Economics and Statistics* 88 (1): 113–25.
- Schlenker, Wolfram, and Michael J. Roberts.** 2006. "Nonlinear Effects of Weather on Corn Yields." *Review of Agricultural Economics* 28 (3): 391–98.
- Schlenker, Wolfram, and Michael J. Roberts.** 2009. "Nonlinear Temperature Effects Indicate Severe Damages to US Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences* 106 (37): 15594–98.
- Stern, Nicholas.** 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.
- Tihonen, Jari, Pirkko Räsänen, and Helinä Hakko.** 1997. "Seasonal Variation in The Occurrence of Homicide in Finland." *American Journal of Psychiatry* 154 (12): 1711–14.
- US Riot Commission.** 1968. *Report of the National Advisory Commission on Civil Disorders*. New York: Bantam Books.
- World Bank.** 2007. 2007 World Development Indicators Online Edition. <http://data.worldbank.org/products/data-books/WDI-2007>. (accessed April 2007).
- Wyon, David.** 1976. "Assessing the Effects of Moderate Heat and Cold Stress on Human Efficiency." In *Proceedings of the Symposium, Factories for Profit—Environmental Design*. Pretoria, South Africa: National Building Research Institute.
- Young, Alwyn.** 2009. "The African Growth Miracle." Unpublished.
- Zivin, Joshua Graff, and Matthew J. Neidell.** 2010. "Temperature and the Allocation of Time: Implications for Climate Change." National Bureau of Economic Research Working Paper 15717.

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1. Haitao Xu, Xiongfeng Pan, Shucen Guo, Yuduo Lu. 2021. Forecasting Chinese CO₂ emission using a non-linear multi-agent intertemporal optimization model and scenario analysis. *Energy* **228**, 120514. [[Crossref](#)]
2. Lotanna E. Emediegwu. 2021. Health impacts of daily weather fluctuations: Empirical evidence from COVID-19 in U.S. counties. *Journal of Environmental Management* **291**, 112662. [[Crossref](#)]
3. Richard G. Newell, Brian C. Prest, Steven E. Sexton. 2021. The GDP-Temperature relationship: Implications for climate change damages. *Journal of Environmental Economics and Management* **108**, 102445. [[Crossref](#)]
4. Maria Teresa Trentinaglia, Marco Parolini, Franco Donzelli, Alessandro Olper. 2021. Climate change and obesity: A global analysis. *Global Food Security* **29**, 100539. [[Crossref](#)]
5. Luca Gerotto, Paolo Pellizzari. 2021. A replication of Pindyck's willingness to pay: on the efforts required to obtain results. *SN Business & Economics* **1**:5. . [[Crossref](#)]
6. E. Somanathan, Rohini Somanathan, Anant Sudarshan, Meenu Tewari. 2021. The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing. *Journal of Political Economy* 000-000. [[Crossref](#)]
7. Olatunji Abdul Shobande. 2021. Is climate change a monetary phenomenon? Evidence from time series analysis. *International Journal of Sustainable Development & World Ecology* **29**, 1-13. [[Crossref](#)]
8. Rodrigo Garcia-Verdu, Alexis Meyer-Cirkel, Akira Sasahara, Hans Weisfeld. 2021. Importing inputs for climate change mitigation: The case of agricultural productivity. *Review of International Economics* **97**. . [[Crossref](#)]
9. Jessie Ruth Schleypen, Malcolm N. Mistry, Fahad Saeed, Shouro Dasgupta. 2021. Sharing the burden: quantifying climate change spillovers in the European Union under the Paris Agreement. *Spatial Economic Analysis* **181**, 1-16. [[Crossref](#)]
10. Yonatan Dinku, Dereje Regasa. 2021. Ethnic Diversity and Local Economies. *South African Journal of Economics* **9**. . [[Crossref](#)]
11. Maximilian Kotz, Leonie Wenz, Annika Stechemesser, Matthias Kalkuhl, Anders Levermann. 2021. Day-to-day temperature variability reduces economic growth. *Nature Climate Change* **11**:4, 319-325. [[Crossref](#)]
12. Kwangwon Ahn, Zhuang Chu, Daeyong Lee. 2021. Effects of renewable energy use in the energy mix on social welfare. *Energy Economics* **96**, 105174. [[Crossref](#)]
13. Tackseung Jun, Rajiv Sethi. 2021. Extreme weather events and military conflict over seven centuries in ancient Korea. *Proceedings of the National Academy of Sciences* **118**:12, e2021976118. [[Crossref](#)]
14. Abbas Ali Chandio, Korhan K. Gokmenoglu, Munir Ahmad, Yuansheng Jiang. 2021. Towards Sustainable Rice Production in Asia: The Role of Climatic Factors. *Earth Systems and Environment* **247**. . [[Crossref](#)]
15. Achyuta Adhvaryu, James Fenske, Gaurav Khanna, Anant Nyshadham. 2021. Resources, conflict, and economic development in Africa. *Journal of Development Economics* **149**, 102598. [[Crossref](#)]
16. Xiaoli Wu, An Pan, Qunzhi She. 2021. Direct and indirect effects of climate aid on carbon emissions in recipient countries. *Journal of Cleaner Production* **290**, 125204. [[Crossref](#)]

17. Geoffrey Barrows, Hélène Ollivier. 2021. Foreign demand, developing country exports, and CO2 emissions: Firm-level evidence from India. *Journal of Development Economics* **149**, 102587. [[Crossref](#)]
18. S. Wagura Ndiritu. 2021. Drought responses and adaptation strategies to climate change by pastoralists in the semi-arid area, Laikipia County, Kenya. *Mitigation and Adaptation Strategies for Global Change* **26**:3. . [[Crossref](#)]
19. Haron Agegnehu Endalew, Subir Sen. 2021. Effects of climate shocks on Ethiopian rural households: an integrated livelihood vulnerability approach. *Journal of Environmental Planning and Management* **64**:3, 399-431. [[Crossref](#)]
20. Fernando Antonio Ignacio González, Silvia London, Maria Emma Santos. 2021. Disasters and economic growth: evidence for Argentina. *Climate and Development* **36**, 1-12. [[Crossref](#)]
21. Jingbin He, Xinru Ma. 2021. Extreme Temperatures and Firm-Level Stock Returns. *International Journal of Environmental Research and Public Health* **18**:4, 2004. [[Crossref](#)]
22. Qifan Xia, Chaofeng Qian, Debin Du, Yang Zhang. 2021. Conflict or cooperation? How does precipitation change affect transboundary hydrogeopolitics?. *Journal of Water and Climate Change* . [[Crossref](#)]
23. Tamma Carleton, Jules Cornetet, Peter Huybers, Kyle C. Meng, Jonathan Proctor. 2021. Global evidence for ultraviolet radiation decreasing COVID-19 growth rates. *Proceedings of the National Academy of Sciences* **118**:1, e2012370118. [[Crossref](#)]
24. Ignace De Vos, Gerdie Everaert. 2021. Bias-Corrected Common Correlated Effects Pooled Estimation in Dynamic Panels. *Journal of Business & Economic Statistics* **39**:1, 294-306. [[Crossref](#)]
25. Shuai Chen, Binlei Gong. 2021. Response and adaptation of agriculture to climate change: Evidence from China. *Journal of Development Economics* **148**, 102557. [[Crossref](#)]
26. Mirza Nouman Ali Talib, Masood Ahmed, Mirza Muhammad Naseer, Beata Slusarczyk, József Popp. 2021. The Long-Run Impacts of Temperature and Rainfall on Agricultural Growth in Sub-Saharan Africa. *Sustainability* **13**:2, 595. [[Crossref](#)]
27. Solji Nam, Jungwoo Shin, Jaena Ryu, Haneer Ryu. 2021. Climate impacts on geographical changes in the energy industry. *Business Strategy and the Environment* **30**:1, 478-488. [[Crossref](#)]
28. R. Jisung Park, A. Patrick Behrer, Joshua Goodman. 2021. Learning is inhibited by heat exposure, both internationally and within the United States. *Nature Human Behaviour* **5**:1, 19-27. [[Crossref](#)]
29. Xinde Ji, Kelly M. Cobourn. 2021. Weather Fluctuations, Expectation Formation, and Short-Run Behavioral Responses to Climate Change. *Environmental and Resource Economics* **78**:1, 77-119. [[Crossref](#)]
30. Sansi Yang, Le Yu, Ganxiao Leng, Huanguang Qiu. 2021. Livestock farmers' perception and adaptation to climate change: panel evidence from pastoral areas in China. *Climatic Change* **164**:1-2. . [[Crossref](#)]
31. Sandeep Rao, Santosh Koirala, Chandra Thapa, Suman Neupane. 2021. When rain matters! Investments and value relevance. *Journal of Corporate Finance* **102**, 101827. [[Crossref](#)]
32. Vladimir Otrachshenko, Olga Popova, José Tavares. 2021. EXTREME TEMPERATURE AND EXTREME VIOLENCE: EVIDENCE FROM RUSSIA. *Economic Inquiry* **59**:1, 243-262. [[Crossref](#)]
33. Olga Nekesa Mulama, Caroline Wanjiru Kariuki. Panel Analysis of the Relationship Between Weather Variability and Sectoral Output in Kenya 1-16. [[Crossref](#)]

34. Matthew A. Borg, Jianjun Xiang, Olga Anikeeva, Dino Pisaniello, Alana Hansen, Kerstin Zander, Keith Dear, Malcolm R. Sim, Bi Peng. 2021. Occupational heat stress and economic burden: a review of global evidence. *Environmental Research* **72**, 110781. [[Crossref](#)]
35. Naser Amanzadeh, Toshihide H. Arimura, Mohammad Vesal, Seyed Farshad Fatemi Ardestami. 2021. The Distributional Effects of Climate Change: Evidence from Iran. *SSRN Electronic Journal* **3**. . [[Crossref](#)]
36. Franziska Funke, Linus Mattauch, Inge van den Bijgaart, Charles Godfray, Cameron J. Hepburn, David Klenert, Marco Springmann, Nicolas Treich. 2021. Is Meat Too Cheap? Towards Optimal Meat Taxation. *SSRN Electronic Journal* **134**. . [[Crossref](#)]
37. Richard S. J. Tol. 2021. The Economic Impact of Weather and Climate. *SSRN Electronic Journal* . [[Crossref](#)]
38. Joachim Klement. 2021. Geo-Economics Chapter 9: The Impact of Climate Change. *SSRN Electronic Journal* . [[Crossref](#)]
39. Sharon Nanyongo Njie, Ikedinachi Ayodele Power Wogu, Uchenna Kingsley Ogbuehi, Sanjay Misra, Oluwakemi Deborah Udoh. Rising Global Challenges in Energy Demand and the Politics of Climate Change in Government Operations 242-263. [[Crossref](#)]
40. Felix Pretis. 2021. Exogeneity in climate econometrics. *Energy Economics* **421**, 105122. [[Crossref](#)]
41. Chai Molina, Erol Akçay, Ulf Dieckmann, Simon A. Levin, Elena A. Rovenskaya. 2020. Combating climate change with matching-commitment agreements. *Scientific Reports* **10**:1. . [[Crossref](#)]
42. Nikos Fatouros, Yiguo Sun. 2020. Natural Disasters and Economic Growth: A Semiparametric Smooth Coefficient Model Approach. *Journal of Risk and Financial Management* **13**:12, 320. [[Crossref](#)]
43. Hassan Al-Najjar, Gokmen Ceribasi, Emrah Dogan, Mazen Abualtayef, Khalid Qahman, Ahmed Shaqfa. 2020. Stochastic time-series models for drought assessment in the Gaza Strip (Palestine). *Journal of Water and Climate Change* **11**:S1, 85-114. [[Crossref](#)]
44. Anthony R. Harding, Katharine Ricke, Daniel Heyen, Douglas G. MacMartin, Juan Moreno-Cruz. 2020. Climate econometric models indicate solar geoengineering would reduce inter-country income inequality. *Nature Communications* **11**:1. . [[Crossref](#)]
45. Nicole Glanemann, Sven N. Willner, Anders Levermann. 2020. Paris Climate Agreement passes the cost-benefit test. *Nature Communications* **11**:1. . [[Crossref](#)]
46. Yongping Sun, Ying Yang, Nan Huang, Xin Zou. 2020. The impacts of climate change risks on financial performance of mining industry: Evidence from listed companies in China. *Resources Policy* **69**, 101828. [[Crossref](#)]
47. M. V. Kazakova. 2020. Quantifying the Potential Macroeconomic Consequences of Global Climate Change: What the Literature Says. *Administrative Consulting* :10, 45-60. [[Crossref](#)]
48. Danyelle Branco, José Féres. 2020. Weather Shocks and Labor Allocation: Evidence from Rural Brazil. *American Journal of Agricultural Economics* **13**. . [[Crossref](#)]
49. Otto Brøns-Petersen, Søren Havn Gjedsted. 2020. Climate change and institutional change: what is the relative importance for economic performance?. *Environmental Economics and Policy Studies* **91**. . [[Crossref](#)]
50. Sebnem Kalemli-Özcan, Alex Nikolsko-Rzhevskyy, Jun Hee Kwak. 2020. Does trade cause capital to flow? Evidence from historical rainfall. *Journal of Development Economics* **147**, 102537. [[Crossref](#)]

51. Teevrat Garg, Maulik Jagnani, Vis Taraz. 2020. Temperature and Human Capital in India. *Journal of the Association of Environmental and Resource Economists* 7:6, 1113-1150. [[Crossref](#)]
52. Joshua Graff Zivin, Yingquan Song, Qu Tang, Peng Zhang. 2020. Temperature and high-stakes cognitive performance: Evidence from the national college entrance examination in China. *Journal of Environmental Economics and Management* 104, 102365. [[Crossref](#)]
53. Kaixing Huang, Hong Zhao, Jikun Huang, Jinxia Wang, Christopher Findlay. 2020. The impact of climate change on the labor allocation: Empirical evidence from China. *Journal of Environmental Economics and Management* 104, 102376. [[Crossref](#)]
54. Khuda Bakhsh, Aasma Latif, Rafaqet Ali, Muhammad Asim Yasin. 2020. Relationship between adaptation to climate change and provincial government expenditure in Pakistan. *Environmental Science and Pollution Research* 79. . [[Crossref](#)]
55. Shanjun Li, Jianwei Xing, Lin Yang, Fan Zhang. 2020. Transportation and the Environment in Developing Countries. *Annual Review of Resource Economics* 12:1, 389-409. [[Crossref](#)]
56. I. Martínez-Zarzoso. 2020. Searching for Grouped Patterns of Heterogeneity in the Climate–Migration Link. *Weather, Climate, and Society* 12:4, 695-710. [[Crossref](#)]
57. Roman Hoffmann, Anna Dimitrova, Raya Muttarak, Jesus Crespo Cuaresma, Jonas Peisker. 2020. A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change* 10:10, 904-912. [[Crossref](#)]
58. Maxim Pinkovskiy, Xavier Sala-i-Martin. 2020. Shining a Light on Purchasing Power Parities. *American Economic Journal: Macroeconomics* 12:4, 71-108. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
59. Manuel Raul Pelaez-Samaniego, Juan L. Espinoza, José Jara-Alvear, Pablo Arias-Reyes, Fernando Maldonado-Arias, Patricia Recalde-Galindo, Pablo Rosero, Tsai Garcia-Perez. 2020. Potential and Impacts of Cogeneration in Tropical Climate Countries: Ecuador as a Case Study. *Energies* 13:20, 5254. [[Crossref](#)]
60. Achyuta Adhvaryu, Namrata Kala, Anant Nyshadham. 2020. The Light and the Heat: Productivity Co-Benefits of Energy-Saving Technology. *The Review of Economics and Statistics* 102:4, 779-792. [[Crossref](#)]
61. Anuska Jain, Roisin O'Sullivan, Vis Taraz. 2020. Temperature and economic activity: evidence from India. *Journal of Environmental Economics and Policy* 9:4, 430-446. [[Crossref](#)]
62. Luigi Aldieri, Concetto Paolo Vinci. 2020. Climate change and knowledge spillovers for cleaner production: New insights. *Journal of Cleaner Production* 271, 122729. [[Crossref](#)]
63. Erkan KARA, Ahmet DİKEN. 2020. İKLİM DEĞİŞİKLİĞİ: YAĞIŞLARIN EKONOMİK BÜYÜME ÜZERİNE ETKİSİ. *Süleyman Demirel Üniversitesi Vizyoner Dergisi* 665-679. [[Crossref](#)]
64. Stefan Mittnik, Willi Semmler, Alexander Haider. 2020. Climate Disaster Risks—Empirics and a Multi-Phase Dynamic Model. *Econometrics* 8:3, 33. [[Crossref](#)]
65. Hiroyuki Kasahara, Bingjing Li. 2020. Grain exports and the causes of China's Great Famine, 1959–1961: County-level evidence. *Journal of Development Economics* 146, 102513. [[Crossref](#)]
66. Nicole Rennó Castro, Humberto Francisco Silva Spolador, Fábio Ricardo Marin. 2020. Assessing the economy–climate relationships for Brazilian agriculture. *Empirical Economics* 59:3, 1161-1188. [[Crossref](#)]
67. Jaqueline Oliveira, Paula Pereda. 2020. The impact of climate change on internal migration in Brazil. *Journal of Environmental Economics and Management* 103, 102340. [[Crossref](#)]

68. Matthias Kalkuhl, Leonie Wenz. 2020. The impact of climate conditions on economic production. Evidence from a global panel of regions. *Journal of Environmental Economics and Management* **103**, 102360. [[Crossref](#)]
69. Chengzheng Li, Jiajia Cong, Haiying Gu. 2020. Could Weather Fluctuations Affect Local Economic Growth? Evidence from Counties in the People's Republic of China. *Asian Development Review* **37**:2, 201-224. [[Crossref](#)]
70. Martin Hadad, Jacques C. Tardif, France Conciatori, Justin Waito, Alana Westwood. 2020. Climate and atmospheric circulation related to frost-ring formation in *Picea mariana* trees from the Boreal Plains, interior North America. *Weather and Climate Extremes* **29**, 100264. [[Crossref](#)]
71. Patrick T Brown, Juan Moreno-Cruz, Ken Caldeira. 2020. Break-even year: a concept for understanding intergenerational trade-offs in climate change mitigation policy. *Environmental Research Communications* **2**:9, 095002. [[Crossref](#)]
72. Edward T. Wei. 2020. Improving brain power by applying a cool TRPM8 receptor agonist to the eyelid margin. *Medical Hypotheses* **142**, 109747. [[Crossref](#)]
73. Tiago Sequeira, Hugo Morão. 2020. Growth accounting and regressions: New approach and results. *International Economics* **162**, 67-79. [[Crossref](#)]
74. Robyn Anderson, Philipp E Bayer, David Edwards. 2020. Climate change and the need for agricultural adaptation. *Current Opinion in Plant Biology* **56**, 197-202. [[Crossref](#)]
75. Seyed M. Karimi, Hamid Pournan, Mahdi Majbouri, Maziar Moradi-Lakeh, Hassan Hakimian. 2020. Saharan sand and dust storms and neonatal mortality: Evidence from Burkina Faso. *Science of The Total Environment* **729**, 139053. [[Crossref](#)]
76. Chengzheng Li, Haiying Gu. 2020. Climate change and mortality evolution in China. *Journal of Environmental Management* **267**, 110622. [[Crossref](#)]
77. Thadeu Gasparetto, Cornel Nessler. 2020. Diverse Effects of Thermal Conditions on Performance of Marathon Runners. *Frontiers in Psychology* **11**. . [[Crossref](#)]
78. Sultana Zeenat Fouzia, Jianhong Mu, Yong Chen. 2020. Local labour market impacts of climate-related disasters: a demand-and-supply analysis. *Spatial Economic Analysis* **15**:3, 336-352. [[Crossref](#)]
79. R. Damania, S. Desbureaux, E. Zaveri. 2020. Does rainfall matter for economic growth? Evidence from global sub-national data (1990–2014). *Journal of Environmental Economics and Management* **102**, 102335. [[Crossref](#)]
80. Thierry Coulibaly, Moinul Islam, Shunsuke Managi. 2020. The Impacts of Climate Change and Natural Disasters on Agriculture in African Countries. *Economics of Disasters and Climate Change* **4**:2, 347-364. [[Crossref](#)]
81. Adam Lampert. 2020. Discounting as a double-edged sword: the values of both future goods and present economic growth decrease with the discount rate. *Journal of Environmental Economics and Policy* **1135**, 1-11. [[Crossref](#)]
82. Junaid Maqsood, Aitazaz A. Farooque, Xander Wang, Farhat Abbas, Bishnu Acharya, Hassan Afzaal. 2020. Contribution of Climate Extremes to Variation in Potato Tuber Yield in Prince Edward Island. *Sustainability* **12**:12, 4937. [[Crossref](#)]
83. Jason Russ. 2020. Water runoff and economic activity: The impact of water supply shocks on growth. *Journal of Environmental Economics and Management* **101**, 102322. [[Crossref](#)]
84. Nikolai Cook, Anthony Heyes. 2020. Brain freeze: outdoor cold and indoor cognitive performance. *Journal of Environmental Economics and Management* **101**, 102318. [[Crossref](#)]

85. Lei Wen, Xiaoyu Yuan. 2020. Forecasting CO₂ emissions in China's commercial department, through BP neural network based on random forest and PSO. *Science of The Total Environment* **718**, 137194. [[Crossref](#)]
86. R. Jisung Park, Joshua Goodman, Michael Hurwitz, Jonathan Smith. 2020. Heat and Learning. *American Economic Journal: Economic Policy* **12**:2, 306-339. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
87. Ivan Rudik. 2020. Optimal Climate Policy When Damages are Unknown. *American Economic Journal: Economic Policy* **12**:2, 340-373. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
88. XIAO-CHEN YUAN, ZHIMING YANG, YI-MING WEI, BING WANG. 2020. THE ECONOMIC IMPACTS OF GLOBAL WARMING ON CHINESE CITIES. *Climate Change Economics* **11**:02, 2050007. [[Crossref](#)]
89. José Luis Martínez-González, Jordi Suriñach, Gabriel Jover, Javier Martín-Vide, Mariano Barriendos-Vallvé, Enric Tello. 2020. Assessing climate impacts on English economic growth (1645–1740): an econometric approach. *Climatic Change* **160**:2, 233-249. [[Crossref](#)]
90. Nicolas Taconet, Aurélie Méjean, Céline Guivarch. 2020. Influence of climate change impacts and mitigation costs on inequality between countries. *Climatic Change* **160**:1, 15-34. [[Crossref](#)]
91. Marc Helbling. 2020. Attitudes towards climate change migrants. *Climatic Change* **160**:1, 89-102. [[Crossref](#)]
92. Nathan W. Chan, Casey J. Wichman. 2020. Climate Change and Recreation: Evidence from North American Cycling. *Environmental and Resource Economics* **76**:1, 119-151. [[Crossref](#)]
93. Qing Pei. 2020. Division of Hunan and Hubei Provinces in the Qing Dynasty: Pragmatism in the Unity of Heaven and Governance. *The Professional Geographer* **72**:2, 283-296. [[Crossref](#)]
94. Giulia Caruso, Emiliano Colantonio, Stefano Antonio Gattone. 2020. Relationships between Renewable Energy Consumption, Social Factors, and Health: A Panel Vector Auto Regression Analysis of a Cluster of 12 EU Countries. *Sustainability* **12**:7, 2915. [[Crossref](#)]
95. Yi Yang, Beibei Liu, Peng Wang, Wei-Qiang Chen, Timothy M. Smith. 2020. Toward sustainable climate change adaptation. *Journal of Industrial Ecology* **24**:2, 318-330. [[Crossref](#)]
96. Orhan Karaca. 2020. Why are some regions rich and others poor? The impact of climate on regional income disparities. *Applied Economics Letters* **27**:5, 353-356. [[Crossref](#)]
97. UNAL SEVEN, SEMIH TUMEN. 2020. AGRICULTURAL CREDITS AND AGRICULTURAL PRODUCTIVITY: CROSS-COUNTRY EVIDENCE. *The Singapore Economic Review* **1**, 1-23. [[Crossref](#)]
98. Siriklao Sangkhaphan, Yang Shu. 2020. The Effect of Rainfall on Economic Growth in Thailand: A Blessing for Poor Provinces. *Economies* **8**:1, 1. [[Crossref](#)]
99. Torben M. Andersen, Joydeep Bhattacharya, Pan Liu. 2020. Resolving intergenerational conflict over the environment under the Pareto criterion. *Journal of Environmental Economics and Management* **100**, 102290. [[Crossref](#)]
100. Daniel Ayalew Ali, Klaus Deininger, Daniel Monchuk. 2020. Using satellite imagery to assess impacts of soil and water conservation measures: Evidence from Ethiopia's Tana-Beles watershed. *Ecological Economics* **169**, 106512. [[Crossref](#)]
101. Hyunkuk Cho. 2020. Ambient temperature, birth rate, and birth outcomes: evidence from South Korea. *Population and Environment* **41**:3, 330-346. [[Crossref](#)]
102. Hiroaki Sakamoto, Masako Ikefuji, Jan R. Magnus. 2020. Adaptation for Mitigation. *Environmental and Resource Economics* **75**:3, 457-484. [[Crossref](#)]

103. Brigadier Libanda, Kelvin Bwalya, Namwiinga B. Nkolola, Ngonga Chilekana. 2020. Quantifying long-term variability of precipitation and temperature over Zambia. *Journal of Atmospheric and Solar-Terrestrial Physics* **198**, 105201. [[Crossref](#)]
104. Marcus Painter. 2020. An inconvenient cost: The effects of climate change on municipal bonds. *Journal of Financial Economics* **135**:2, 468-482. [[Crossref](#)]
105. Xiongfeng Pan, Haitao Xu, Yuduo Lu. 2020. Long-term forecasting of industrial CO2 emissions in 31 provinces of China. *Environmental Science and Pollution Research* **27**:5, 5168-5191. [[Crossref](#)]
106. Paul A. Griffin. 2020. Energy finance must account for extreme weather risk. *Nature Energy* **5**:2, 98-100. [[Crossref](#)]
107. Kevin R. Roche, Michèle Müller-Itten, David N. Dralle, Diogo Bolster, Marc F. Müller. 2020. Climate change and the opportunity cost of conflict. *Proceedings of the National Academy of Sciences* **117**:4, 1935-1940. [[Crossref](#)]
108. Jan Krause, Gerrit Nanninga, Patrick Ring, Ulrich Schmidt, Daniel Schunk. 2020. Ambient Temperature, Social Perception and Social Behavior. *SSRN Electronic Journal* . [[Crossref](#)]
109. Samuel Jovan Okullo. 2020. Determining the Social Cost of Carbon: Under Damage and Climate Sensitivity Uncertainty. *Environmental and Resource Economics* **75**:1, 79-103. [[Crossref](#)]
110. Frank Weikai Li, Yupeng Lin, Zuben JIN, Zilong Zhang. 2020. Do Firms Adapt to Climate Change? Evidence from Establishment-Level Data. *SSRN Electronic Journal* . [[Crossref](#)]
111. Christoph Hambel, Holger Kraft, Rick van der Ploeg. 2020. Asset Pricing and Decarbonization: Diversification versus Climate Action. *SSRN Electronic Journal* . [[Crossref](#)]
112. Michael Donadelli, Patrick Grüning, Steffen Hitzemann. 2020. Understanding Macro and Asset Price Dynamics During the Climate Transition. *SSRN Electronic Journal* **102** . [[Crossref](#)]
113. Hannes Boehm. 2020. Physical Climate Change Risks and the Sovereign Creditworthiness of Emerging Economies. *SSRN Electronic Journal* **117** . [[Crossref](#)]
114. Jihye Kang, Je Hee Um, Tae Yong Jung, Donghun Kim. 2019. Estimation of the Social Discount Rate (SDR) with Climate Change Uncertainty: The Case of Korea. *Journal of Climate Change Research* **10**:4, 255-263. [[Crossref](#)]
115. Kimberly L. Oremus. 2019. Climate variability reduces employment in New England fisheries. *Proceedings of the National Academy of Sciences* **116**:52, 26444-26449. [[Crossref](#)]
116. Joseph Mawejje, Rachel K. Sebudde. 2019. Constraints or Complaints? Business Climate and Firm Performance Perceptions in Uganda. *The Journal of Development Studies* **55**:12, 2513-2525. [[Crossref](#)]
117. Roland Cunha Montenegro, Vidas Lekavičius, Jurica Brajković, Ulrich Fahl, Kai Hufendiek. 2019. Long-Term Distributional Impacts of European Cap-and-Trade Climate Policies: A CGE Multi-Regional Analysis. *Sustainability* **11**:23, 6868. [[Crossref](#)]
118. Sajjad Ali, Li Gucheng, Liu Ying, Muhammad Ishaq, Tariq Shah. 2019. The Relationship between Carbon Dioxide Emissions, Economic Growth and Agricultural Production in Pakistan: An Autoregressive Distributed Lag Analysis. *Energies* **12**:24, 4644. [[Crossref](#)]
119. Paul Griffin, David Lont, Martien Lubberink. 2019. Extreme high surface temperature events and equity-related physical climate risk. *Weather and Climate Extremes* **26**, 100220. [[Crossref](#)]
120. Pedro H. Albuquerque, Wassim Rajhi. 2019. Banking stability, natural disasters, and state fragility: Panel VAR evidence from developing countries. *Research in International Business and Finance* **50**, 430-443. [[Crossref](#)]

121. Rafi Amir-ud-Din, Muhammad Usman, Faisal Abbas, Sajid Amin Javed. 2019. Human versus physical capital: issues of accumulation, interaction and endogeneity. *Economic Change and Restructuring* 52:4, 351-382. [[Crossref](#)]
122. Karine Constant, Marion Davin. 2019. Unequal Vulnerability to Climate Change and the Transmission of Adverse Effects Through International Trade. *Environmental and Resource Economics* 74:2, 727-759. [[Crossref](#)]
123. Daniel Osberghaus. 2019. The Effects of Natural Disasters and Weather Variations on International Trade and Financial Flows: a Review of the Empirical Literature. *Economics of Disasters and Climate Change* 3:3, 305-325. [[Crossref](#)]
124. M. Mehedi Hasan, Mohammad Alauddin, Md. Abdur Rashid Sarker, Mohammad Jakaria, Mahiuddin Alamgir. 2019. Climate sensitivity of wheat yield in Bangladesh: Implications for the United Nations sustainable development goals 2 and 6. *Land Use Policy* 87, 104023. [[Crossref](#)]
125. Dennis Wesselbaum. 2019. The Influence of Climate on Migration. *Australian Economic Review* 52:3, 363-372. [[Crossref](#)]
126. Adria Molotsky. 2019. Income Shocks and Partnership Formation: Evidence from Malawi. *Studies in Family Planning* 50:3, 219-242. [[Crossref](#)]
127. Richard S.J. Tol. 2019. A social cost of carbon for (almost) every country. *Energy Economics* 83, 555-566. [[Crossref](#)]
128. Panagiotis Tsigaris, Joel Wood. 2019. The potential impacts of climate change on capital in the 21st century. *Ecological Economics* 162, 74-86. [[Crossref](#)]
129. Franziska Piontek, Matthias Kalkuhl, Elmar Kriegler, Anselm Schultes, Marian Leimbach, Ottmar Edenhofer, Nico Bauer. 2019. Economic Growth Effects of Alternative Climate Change Impact Channels in Economic Modeling. *Environmental and Resource Economics* 73:4, 1357-1385. [[Crossref](#)]
130. Han Li, Yao Zhou, Yehua Dennis Wei. 2019. Institutions, Extreme Weather, and Urbanization in the Greater Mekong Region. *Annals of the American Association of Geographers* 109:4, 1317-1340. [[Crossref](#)]
131. Xiumei Yu, Xiaoyan Lei, Min Wang. 2019. Temperature effects on mortality and household adaptation: Evidence from China. *Journal of Environmental Economics and Management* 96, 195-212. [[Crossref](#)]
132. Andrew G. Meyer. 2019. Elite Influence on Climate Change Skepticism: Evidence from Close Gubernatorial Elections. *Journal of the Association of Environmental and Resource Economists* 6:4, 783-822. [[Crossref](#)]
133. Rok Spruk, Mitja Kovac. 2019. Transaction costs and economic growth under common legal system: State-level evidence from Mexico. *Economics & Politics* 31:2, 240-292. [[Crossref](#)]
134. Chunli Zhao, Jianguo Chen, Guofeng Su, Hongyong Yuan. 2019. Assessment of the climate change adaptation capacity of urban agglomerations in China. *Mitigation and Adaptation Strategies for Global Change* 66. . [[Crossref](#)]
135. Nemera Mamo, Sambit Bhattacharyya, Alexander Moradi. 2019. Intensive and extensive margins of mining and development: Evidence from Sub-Saharan Africa. *Journal of Development Economics* 139, 28-49. [[Crossref](#)]
136. Martin Henseler, Ingmar Schumacher. 2019. The impact of weather on economic growth and its production factors. *Climatic Change* 154:3-4, 417-433. [[Crossref](#)]
137. Noah S. Diffenbaugh, Marshall Burke. 2019. Global warming has increased global economic inequality. *Proceedings of the National Academy of Sciences* 116:20, 9808-9813. [[Crossref](#)]

138. Vally Koubi. 2019. Climate Change and Conflict. *Annual Review of Political Science* **22**:1, 343-360. [[Crossref](#)]
139. Rohan Best, Paul J. Burke. 2019. Macroeconomic impacts of the 2010 earthquake in Haiti. *Empirical Economics* **56**:5, 1647-1681. [[Crossref](#)]
140. Xiaoguang Chen, Lu Yang. 2019. Temperature and industrial output: Firm-level evidence from China. *Journal of Environmental Economics and Management* **95**, 257-274. [[Crossref](#)]
141. Ronald R. Kumar, Peter J. Stauvermann. 2019. The Effects of a Revenue-Neutral Child Subsidy Tax Mechanism on Growth and GHG Emissions. *Sustainability* **11**:9, 2585. [[Crossref](#)]
142. Marco Letta, Richard S. J. Tol. 2019. Weather, Climate and Total Factor Productivity. *Environmental and Resource Economics* **73**:1, 283-305. [[Crossref](#)]
143. David Ubilava, Maryam Abdolrahimi. 2019. The El Niño impact on maize yields is amplified in lower income teleconnected countries. *Environmental Research Letters* **14**:5, 054008. [[Crossref](#)]
144. R Vinnarasi, C T Dhanya. 2019. Quantifying the shifts and intensification in the annual cycles of diurnal temperature extremes for human comfort and crop production. *Environmental Research Letters* **14**:5, 054016. [[Crossref](#)]
145. Imed Attiaoui, Tâlel Boufateh. 2019. Impacts of climate change on cereal farming in Tunisia: a panel ARDL-PMG approach. *Environmental Science and Pollution Research* **26**:13, 13334-13345. [[Crossref](#)]
146. Francesco Lamperti, Antoine Mandel, Mauro Napoletano, Alessandro Sapio, Andrea Roventini, Tomas Balint, Igor Khorenzhenko. 2019. Towards agent-based integrated assessment models: examples, challenges, and future developments. *Regional Environmental Change* **19**:3, 747-762. [[Crossref](#)]
147. Robert S. Pindyck. 2019. The social cost of carbon revisited. *Journal of Environmental Economics and Management* **94**, 140-160. [[Crossref](#)]
148. RICCARDO COLACITO, BRIDGET HOFFMANN, TOAN PHAN. 2019. Temperature and Growth: A Panel Analysis of the United States. *Journal of Money, Credit and Banking* **51**:2-3, 313-368. [[Crossref](#)]
149. John Liu, Yoram Bauman, Yating Chuang. 2019. Climate Change and Economics 101: Teaching the Greatest Market Failure. *Sustainability* **11**:5, 1340. [[Crossref](#)]
150. Philip B. Duffy, Christopher B. Field, Noah S. Diffenbaugh, Scott C. Doney, Zoe Dutton, Sherri Goodman, Lisa Heinzerling, Solomon Hsiang, David B. Lobell, Loretta J. Mickley, Samuel Myers, Susan M. Natali, Camille Parmesan, Susan Tierney, A. Park Williams. 2019. Strengthened scientific support for the Endangerment Finding for atmospheric greenhouse gases. *Science* **363**:6427, eaat5982. [[Crossref](#)]
151. O. A. Zamulin, K. I. Sonin. 2019. Economic growth: Nobel prize in economic sciences 2018 and the lessons for Russia. *Voprosy Ekonomiki* :1, 11-36. [[Crossref](#)]
152. Eric Keels. 2019. Praying for Rain? Water Scarcity and the Duration and Outcomes of Civil Wars. *Defence and Peace Economics* **30**:1, 27-45. [[Crossref](#)]
153. Florian Flachenecker, Martin Kornejew. 2019. The causal impact of material productivity on microeconomic competitiveness and environmental performance in the European Union. *Environmental Economics and Policy Studies* **21**:1, 87-122. [[Crossref](#)]
154. Peter H. Howard. The social cost of carbon: capturing the costs of future climate impacts in US policy 659-694. [[Crossref](#)]

155. Yu Sheng, Xinpeng Xu. 2019. The productivity impact of climate change: Evidence from Australia's Millennium drought. *Economic Modelling* **76**, 182-191. [[Crossref](#)]
156. Ram Fishman, Paul Carrillo, Jason Russ. 2019. Long-term impacts of exposure to high temperatures on human capital and economic productivity. *Journal of Environmental Economics and Management* **93**, 221-238. [[Crossref](#)]
157. Edith Ginglinger, Quentin Moreau. 2019. Climate Risk and Capital Structure. *SSRN Electronic Journal* . [[Crossref](#)]
158. Rodrigo García-Verdú, Alexis Meyer-Cirkel, Akira Sasahara, Hans Weisfeld. 2019. Importing Inputs for Climate Change Mitigation: The Case of Agricultural Productivity. *SSRN Electronic Journal* . [[Crossref](#)]
159. Michael Donadelli, Marcus Jüppner, Antonio Paradiso, Christian Schlag. 2019. Temperature Volatility Risk. *SSRN Electronic Journal* . [[Crossref](#)]
160. Hiroyuki Kasahara, Bingjing Li. 2019. Grain Exports and the Causes of China's Great Famine, 1959-1961: County-Level Evidence. *SSRN Electronic Journal* . [[Crossref](#)]
161. Callum Macpherson. 2019. The Potential Impact of Investor Fossil Fuel Divestment Behaviour on Oil Prices. *SSRN Electronic Journal* . [[Crossref](#)]
162. Stefano Gagliarducci, Daniele Paserman, Eleonora Patacchini. 2019. Hurricanes, Climate Change Policies and Electoral Accountability. *SSRN Electronic Journal* . [[Crossref](#)]
163. Jianchun Fang, Chi Keung Marco Lau, Zhou Lu, Wanshan Wu, Lili Zhu. 2019. Natural disasters, climate change, and their impact on inclusive wealth in G20 countries. *Environmental Science and Pollution Research* **26**:2, 1455-1463. [[Crossref](#)]
164. Michael Barnett, William A. Brock, Lars Peter Hansen. 2019. Pricing Uncertainty Induced by Climate Change. *SSRN Electronic Journal* . [[Crossref](#)]
165. Ruihong Jiang, Chengguo Weng. 2019. Climate Change Risk and Agriculture-related Stocks. *SSRN Electronic Journal* . [[Crossref](#)]
166. Yongping Sun, Xin Zou, Xunpeng Shi, Ping Zhang. 2019. The economic impact of climate risks in China: evidence from 47-sector panel data, 2000–2014. *Natural Hazards* **95**:1-2, 289-308. [[Crossref](#)]
167. Falko Ueckerdt, Katja Frieler, Stefan Lange, Leonie Wenz, Gunnar Luderer, Anders Levermann. 2019. The economically optimal warming limit of the planet. *Earth System Dynamics* **10**:4, 741-763. [[Crossref](#)]
168. Christoph Hambel, Holger Kraft, Eduardo S. Schwartz. 2019. The Social Cost of Carbon in a Non-Cooperative World. *SSRN Electronic Journal* . [[Crossref](#)]
169. Venky Nagar, Jordan Schoenfeld. 2019. Measuring Corporate Weather Exposure using Computational Linguistics. *SSRN Electronic Journal* . [[Crossref](#)]
170. Tinghua Duan, Frank Weikai Li. 2019. Worrying About Climate Change: Evidence from Mortgage Lending. *SSRN Electronic Journal* . [[Crossref](#)]
171. Canute B. Hyandye, Abeyou Worqul, Lawrence W. Martz, Alfred N. N. Muzuka. 2018. The impact of future climate and land use/cover change on water resources in the Ndembera watershed and their mitigation and adaptation strategies. *Environmental Systems Research* **7**:1. . [[Crossref](#)]
172. Maximilian Auffhammer. 2018. Quantifying Economic Damages from Climate Change. *Journal of Economic Perspectives* **32**:4, 33-52. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
173. James B. Ang, Satyendra Kumar Gupta. 2018. Agricultural yield and conflict. *Journal of Environmental Economics and Management* **92**, 397-417. [[Crossref](#)]

174. Bruce Cater, Byron Lew. 2018. The impact of climate on the law of one price: A test using North American food prices from the 1920s. *Canadian Journal of Economics/Revue canadienne d'économique* **51**:4, 1191-1220. [[Crossref](#)]
175. KAORI TEMBATA, KENJI TAKEUCHI. 2018. THE IMPACT OF CLIMATE VARIABILITY ON DROUGHT MANAGEMENT: EVIDENCE FROM JAPANESE RIVER BASINS. *Climate Change Economics* **09**:04, 1850010. [[Crossref](#)]
176. BRANTLEY LIDDLE. 2018. WARMING AND INCOME GROWTH IN THE UNITED STATES: A HETEROGENEOUS, COMMON FACTOR DYNAMIC PANEL ANALYSIS. *Climate Change Economics* **09**:04, 1850012. [[Crossref](#)]
177. Kyle Emerick. 2018. Agricultural productivity and the sectoral reallocation of labor in rural India. *Journal of Development Economics* **135**, 488-503. [[Crossref](#)]
178. Abdelaziz Boukhelkhal, Ismail Bengana. 2018. Cointegration and causality among electricity consumption, economic, climatic and environmental factors: Evidence from North -Africa region. *Energy* **163**, 1193-1206. [[Crossref](#)]
179. Xiaobing Zhao, Mason Gerety, Nicolai V. Kuminoff. 2018. Revisiting the temperature-economic growth relationship using global subnational data. *Journal of Environmental Management* **223**, 537-544. [[Crossref](#)]
180. Katharine Ricke, Laurent Drouet, Ken Caldeira, Massimo Tavoni. 2018. Country-level social cost of carbon. *Nature Climate Change* **8**:10, 895-900. [[Crossref](#)]
181. Mariaflavia Harari, Eliana La Ferrara. 2018. Conflict, Climate, and Cells: A Disaggregated Analysis. *The Review of Economics and Statistics* **100**:4, 594-608. [[Crossref](#)]
182. Amsalu Yalew, Georg Hirte, Hermann Lotze-Campen, Stefan Tscharaktschiew. 2018. Climate Change, Agriculture, and Economic Development in Ethiopia. *Sustainability* **10**:10, 3464. [[Crossref](#)]
183. Andrea Bastianin, Alessandro Lanza, Matteo Manera. 2018. Economic impacts of El Niño southern oscillation: evidence from the Colombian coffee market. *Agricultural Economics* **49**:5, 623-633. [[Crossref](#)]
184. F. Lamperti, G. Dosi, M. Napoletano, A. Roventini, A. Sapio. 2018. Faraway, So Close: Coupled Climate and Economic Dynamics in an Agent-based Integrated Assessment Model. *Ecological Economics* **150**, 315-339. [[Crossref](#)]
185. Olivier Deschenes. 2018. Temperature Variability and Mortality: Evidence from 16 Asian Countries. *Asian Development Review* **35**:2, 1-30. [[Crossref](#)]
186. Muthukumara Mani, Sushenjit Bandyopadhyay, Shun Chonabayashi, Anil Markandya, Thomas Mosier. Climate and Living Standards 33-50. [[Crossref](#)]
187. Vally Koubi. 2018. Exploring the relationship between climate change and violent conflict. *Chinese Journal of Population Resources and Environment* **16**:3, 197-202. [[Crossref](#)]
188. Martina Linnenluecke, Tom Smith, Robert E. Whaley. 2018. The unpaid social cost of carbon. *Accounting Research Journal* **31**:2, 122-134. [[Crossref](#)]
189. Casey J. Wichman. 2018. Interpreting nonlinear semi-elasticities in reduced-form climate damage estimation. *Climatic Change* **148**:4, 641-648. [[Crossref](#)]
190. Zhengtao Zhang, Ning Li, Hong Xu, Xi Chen. 2018. Analysis of the Economic Ripple Effect of the United States on the World due to Future Climate Change. *Earth's Future* **6**:6, 828-840. [[Crossref](#)]

191. Felix Pretis, Moritz Schwarz, Kevin Tang, Karsten Haustein, Myles R. Allen. 2018. Uncertain impacts on economic growth when stabilizing global temperatures at 1.5°C or 2°C warming. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376:2119, 20160460. [[Crossref](#)]
192. Wolfram Schlenker, Maximilian Auffhammer. 2018. The cost of a warming climate. *Nature* 557:7706, 498-499. [[Crossref](#)]
193. Marshall Burke, W. Matthew Davis, Noah S. Diffenbaugh. 2018. Large potential reduction in economic damages under UN mitigation targets. *Nature* 557:7706, 549-553. [[Crossref](#)]
194. Sebastian Bathiany, Vasilis Dakos, Marten Scheffer, Timothy M. Lenton. 2018. Climate models predict increasing temperature variability in poor countries. *Science Advances* 4:5, eaar5809. [[Crossref](#)]
195. Chiara Falco, Franco Donzelli, Alessandro Olper. 2018. Climate Change, Agriculture and Migration: A Survey. *Sustainability* 10:5, 1405. [[Crossref](#)]
196. Muhammad Iftikhar Ul Husnain, Arjunan Subramanian, Azad Haider. 2018. Robustness of geography as an instrument to assess impact of climate change on agriculture. *International Journal of Climate Change Strategies and Management* 21. . [[Crossref](#)]
197. Onur Sapci, Jason F. Shogren. 2018. Environmental quality, human capital and growth. *Journal of Environmental Economics and Policy* 7:2, 184-203. [[Crossref](#)]
198. Martin Falk, Xiang Lin. 2018. Sensitivity of winter tourism to temperature increases over the last decades. *Economic Modelling* 71, 174-183. [[Crossref](#)]
199. Iona Hyojung Lee. 2018. Industrial output fluctuations in developing countries: General equilibrium consequences of agricultural productivity shocks. *European Economic Review* 102, 240-279. [[Crossref](#)]
200. Debin Fang, Xiaoling Zhang, Qian Yu, Trenton Chen Jin, Luan Tian. 2018. A novel method for carbon dioxide emission forecasting based on improved Gaussian processes regression. *Journal of Cleaner Production* 173, 143-150. [[Crossref](#)]
201. Solomon Asfaw, Giuseppe Maggio. 2018. Gender, Weather Shocks and Welfare: Evidence from Malawi. *The Journal of Development Studies* 54:2, 271-291. [[Crossref](#)]
202. Qian Dang, Megan Konar. 2018. Trade Openness and Domestic Water Use. *Water Resources Research* 54:1, 4-18. [[Crossref](#)]
203. Bo Feng, Mark Partridge, Mark Rembert. The Perils of Modelling How Migration Responds to Climate Change 53-75. [[Crossref](#)]
204. Johan Gars, Daniel Spiro. 2018. Trade and the Risk of Renewable-Resource Collapse. *Journal of the Association of Environmental and Resource Economists* 5:1, 155-206. [[Crossref](#)]
205. Joshua Graff Zivin, Solomon M. Hsiang, Matthew Neidell. 2018. Temperature and Human Capital in the Short and Long Run. *Journal of the Association of Environmental and Resource Economists* 5:1, 77-105. [[Crossref](#)]
206. Sandra Batten. 2018. Climate Change and the Macro-Economy: A Critical Review. *SSRN Electronic Journal* . [[Crossref](#)]
207. Kirill Borissov, Lucas Bretschger, Alexandra Vinogradova. 2018. Carbon Pricing, Technology Transition, and Skill-Based Development. *SSRN Electronic Journal* . [[Crossref](#)]
208. Christoph Hambel, Holger Kraft, Eduardo S. Schwartz. 2018. The Carbon Abatement Game. *SSRN Electronic Journal* . [[Crossref](#)]

209. Daron Acemoglu, Will Rafey. 2018. Mirage on the Horizon: Geoengineering and Carbon Taxation Without Commitment. *SSRN Electronic Journal* . [[Crossref](#)]
210. Marcus Painter. 2018. An Inconvenient Cost: The Effects of Climate Change on Municipal Bonds. *SSRN Electronic Journal* . [[Crossref](#)]
211. Vis Taraz. 2018. Unintended Consequences of a Public Works Program: Agricultural Yields, Weather Shocks and India's Employment Guarantee. *SSRN Electronic Journal* . [[Crossref](#)]
212. Joshua Goodman, Michael Hurwitz, Jisung Park, Jonathan Smith. 2018. Heat and Learning. *SSRN Electronic Journal* . [[Crossref](#)]
213. Lucas Bretschger, Alexandra Vinogradova. 2018. Escaping Damocles' Sword: Endogenous Climate Shocks in a Growing Economy. *SSRN Electronic Journal* . [[Crossref](#)]
214. Julia M. Puauschunder. 2018. Looking Forward to World Peak: Climate Change-Induced Market Prospects. *SSRN Electronic Journal* . [[Crossref](#)]
215. Sally Shen, Alex LaPlante, Alexey Rubtsov. 2018. Strategic Asset Allocation With Climate Change. *SSRN Electronic Journal* . [[Crossref](#)]
216. Samuel J Okullo. 2018. Determining the Social Cost of Carbon: Under Damage and Climate Sensitivity Uncertainty. *SSRN Electronic Journal* . [[Crossref](#)]
217. Christos Makridis. 2018. Can You Feel the Heat? Extreme Temperatures, Stock Returns, and Economic Sentiment. *SSRN Electronic Journal* . [[Crossref](#)]
218. Michael P. Keane, Timothy Neal. 2018. The Impact of Climate Change on US Agriculture: The Roles of Adaptation Techniques and Emissions Reductions. *SSRN Electronic Journal* . [[Crossref](#)]
219. Ali Syed, Urooj Afshan Jabeen. Climate Change Impact on Agriculture and Food Security 223-237. [[Crossref](#)]
220. Rok Spruk. 2018. The Rise and Fall of Argentina. *SSRN Electronic Journal* . [[Crossref](#)]
221. Farzana Hossain, Reshad Ahsan. 2018. When It Rains, It Pours: Estimating the Spatial Spillover Effect of Rainfall. *SSRN Electronic Journal* . [[Crossref](#)]
222. Marcus C. Sarofim, Michael R. Giordano. 2018. A quantitative approach to evaluating the GWP timescale through implicit discount rates. *Earth System Dynamics* 9:3, 1013-1024. [[Crossref](#)]
223. Anouch Missirian, Wolfram Schlenker. 2017. Asylum applications respond to temperature fluctuations. *Science* 358:6370, 1610-1614. [[Crossref](#)]
224. Adam Isen, Maya Rossin-Slater, Reed Walker. 2017. Relationship between season of birth, temperature exposure, and later life wellbeing. *Proceedings of the National Academy of Sciences* 114:51, 13447-13452. [[Crossref](#)]
225. Vally Koubi. 2017. Climate Change, the Economy, and Conflict. *Current Climate Change Reports* 3:4, 200-209. [[Crossref](#)]
226. A. Touré Halimatou, Traoré Kalifa, N. Kyei-Baffour. 2017. Assessment of changing trends of daily precipitation and temperature extremes in Bamako and Ségou in Mali from 1961- 2014. *Weather and Climate Extremes* 18, 8-16. [[Crossref](#)]
227. Mary Regina Boland, Pradipta Parhi, Pierre Gentine, Nicholas P. Tatonetti. 2017. Climate Classification is an Important Factor in Assessing Quality-of-Care Across Hospitals. *Scientific Reports* 7:1. . [[Crossref](#)]
228. Kendra Sakaguchi, Anil Varughese, Graeme Auld. 2017. Climate Wars? A Systematic Review of Empirical Analyses on the Links between Climate Change and Violent Conflict. *International Studies Review* 19:4, 622-645. [[Crossref](#)]

229. Muhammad Arshad, Harald Kächele, Timothy J. Krupnik, T. S. Amjath-Babu, Sreejith Aravindakshan, Azhar Abbas, Yasir Mehmood, Klaus Müller. 2017. Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. *International Journal of Sustainable Development & World Ecology* **24**:6, 532-544. [[Crossref](#)]
230. Delavane Diaz, Frances Moore. 2017. Quantifying the economic risks of climate change. *Nature Climate Change* **7**:11, 774-782. [[Crossref](#)]
231. Richard Damania, Sébastien Desbureaux, Marie Hyland, Asif Islam, Scott Moore, Aude-Sophie Rodella, Jason Russ, Esha Zaveri. Drenched Fields and Parched Farms 19-34. [[Crossref](#)]
232. Sam Fankhauser. 2017. Adaptation to Climate Change. *Annual Review of Resource Economics* **9**:1, 209-230. [[Crossref](#)]
233. Solomon Asfaw, Alessandro Carraro, Benjamin Davis, Sudhanshu Handa, David Seidenfeld. 2017. Cash transfer programmes, weather shocks and household welfare: evidence from a randomised experiment in Zambia. *Journal of Development Effectiveness* **9**:4, 419-442. [[Crossref](#)]
234. Geoffrey Heal. 2017. The Economics of the Climate. *Journal of Economic Literature* **55**:3, 1046-1063. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
235. Peter H. Howard, Thomas Sterner. 2017. Few and Not So Far Between: A Meta-analysis of Climate Damage Estimates. *Environmental and Resource Economics* **68**:1, 197-225. [[Crossref](#)]
236. Olivia Serdeczny, Sophie Adams, Florent Baarsch, Dim Coumou, Alexander Robinson, William Hare, Michiel Schaeffer, Mahé Perrette, Julia Reinhardt. 2017. Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change* **17**:6, 1585-1600. [[Crossref](#)]
237. T. Balint, F. Lamperti, A. Mandel, M. Napoletano, A. Roventini, A. Sapio. 2017. Complexity and the Economics of Climate Change: A Survey and a Look Forward. *Ecological Economics* **138**, 252-265. [[Crossref](#)]
238. Joshua Wilde, Bénédicte H. Apouey, Toni Jung. 2017. The effect of ambient temperature shocks during conception and early pregnancy on later life outcomes. *European Economic Review* **97**, 87-107. [[Crossref](#)]
239. David Castells-Quintana, Maria del Pilar Lopez-Urbe, Thomas K.J. McDermott. 2017. Geography, institutions and development: a review of the long-run impacts of climate change. *Climate and Development* **9**:5, 452-470. [[Crossref](#)]
240. Simo Leppänen, Laura Solanko, Riitta Kosonen. 2017. The Impact of Climate Change on Regional Government Expenditures: Evidence from Russia. *Environmental and Resource Economics* **67**:1, 67-92. [[Crossref](#)]
241. Adeel Ahmed, Evelyn S. Devadason, Abul Quasem Al-Amin. 2017. Modeling technical change in climate analysis: evidence from agricultural crop damages. *Environmental Science and Pollution Research* **24**:13, 12347-12359. [[Crossref](#)]
242. Lara Lázaro. 2017. La COP21 y el Acuerdo de París: una clase magistral en diplomacia en busca de mayor ambición. *Papeles de Europa* **29**:2, 54-68. [[Crossref](#)]
243. Kyle C. Meng. 2017. Using a Free Permit Rule to Forecast the Marginal Abatement Cost of Proposed Climate Policy. *American Economic Review* **107**:3, 748-784. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
244. Stephan J. Goetz, Meri Davlasheridze. 2017. State-Level Cooperative Extension Spending and Farmer Exits. *Applied Economic Perspectives and Policy* **39**:1, 65-86. [[Crossref](#)]
245. Vladimir Otrachshenko, Olga Popova, Pavel Solomin. 2017. Health Consequences of the Russian Weather. *Ecological Economics* **132**, 290-306. [[Crossref](#)]

246. Jeroen C. J. M. van den Bergh. 2017. A third option for climate policy within potential limits to growth. *Nature Climate Change* 7:2, 107-112. [[Crossref](#)]
247. Barack Obama. 2017. The irreversible momentum of clean energy. *Science* 355:6321, 126-129. [[Crossref](#)]
248. Luca Marchiori, Jean-François Maystadt, Ingmar Schumacher. 2017. Is environmentally induced income variability a driver of human migration?. *Migration and Development* 6:1, 33-59. [[Crossref](#)]
249. Chengzheng Li, Jiajia Cong, Haiying Gu. 2017. The Non-Linear Effect of Daily Weather on Economic Performance: Evidence from China. *SSRN Electronic Journal* . [[Crossref](#)]
250. Teevrat Garg, Maulik Jagnani, Vis Taraz. 2017. Human Capital Costs of Climate Change: Evidence from Test Scores in India. *SSRN Electronic Journal* . [[Crossref](#)]
251. Shihe Fu, Peng Zhang. 2017. Air Quality and Manufacturing Firm Productivity: Comprehensive Evidence from China. *SSRN Electronic Journal* . [[Crossref](#)]
252. Ruben Carlo Asuncion, Minsoo Lee. 2017. Impacts of Sea Level Rise on Economic Growth in Developing Asia. *SSRN Electronic Journal* . [[Crossref](#)]
253. Michael Donadelli, Marcus Jppner, Max Riedel, Christian Schlag. 2017. Temperature Shocks and Welfare Costs. *SSRN Electronic Journal* . [[Crossref](#)]
254. Inmaculada Martinez-Zarzoso. 2017. Searching for Grouped Patterns of Heterogeneity in the Climate-Migration Link. *SSRN Electronic Journal* . [[Crossref](#)]
255. Maulik Jagnani, Christopher B. Barrett, Yanyan Liu, Liangzhi You. 2017. In the Weeds: Effects of Temperature on Agricultural Input Decisions in Moderate Climates. *SSRN Electronic Journal* . [[Crossref](#)]
256. Chengzheng Li, Jiajia Cong, Haiying Gu. 2017. Could Weather Fluctuations Affect Local Economic Growth? Evidence from Chinese Counties. *SSRN Electronic Journal* . [[Crossref](#)]
257. Michael Donadelli, Patrick Grning, Marcus Jppner, Renatas Kizys. 2017. Global Temperature, R&D Expenditure, and Growth. *SSRN Electronic Journal* . [[Crossref](#)]
258. Johannes Emmerling, Massimo Tavoni. 2017. Quantifying Non-Cooperative Climate Engineering. *SSRN Electronic Journal* . [[Crossref](#)]
259. Jeffrey Shrader. 2017. Expectations and Adaptation to Environmental Risks. *SSRN Electronic Journal* . [[Crossref](#)]
260. Daniel L. Chen, Susan Yeh. 2017. Government Expropriation Increases Economic Growth and Racial Inequality: Evidence from Eminent Domain. *SSRN Electronic Journal* . [[Crossref](#)]
261. Nick Obradovich. 2017. Climate change may speed democratic turnover. *Climatic Change* 140:2, 135-147. [[Crossref](#)]
262. Shiran Victoria Shen. 2017. Pricing Carbon to Contain Violence. *SSRN Electronic Journal* . [[Crossref](#)]
263. Brant Liddle. 2017. Warming and GDP Growth in the United States: A Heterogeneous, Common Factor Dynamic Panel Analysis. *SSRN Electronic Journal* . [[Crossref](#)]
264. Felix Pretis. 2017. Exogeneity in Climate Econometrics. *SSRN Electronic Journal* . [[Crossref](#)]
265. Katja Frieler, Stefan Lange, Franziska Piontek, Christopher P. O. Reyer, Jacob Schewe, Lila Warszawski, Fang Zhao, Louise Chini, Sebastien Denvil, Kerry Emanuel, Tobias Geiger, Kate Halladay, George Hurtt, Matthias Mengel, Daisuke Murakami, Sebastian Ostberg, Alexander Popp, Riccardo Riva, Miodrag Stevanovic, Tatsuo Suzuki, Jan Volkholz, Eleanor Burke, Philippe Ciais, Kristie Ebi, Tyler D. Eddy, Joshua Elliott, Eric Galbraith, Simon N. Gosling, Fred

- Hattermann, Thomas Hickler, Jochen Hinkel, Christian Hof, Veronika Huber, Jonas Jägermeyr, Valentina Krysanova, Rafael Marcé, Hannes Müller Schmied, Ioanna Mouratiadou, Don Pierson, Derek P. Tittensor, Robert Vautard, Michelle van Vliet, Matthias F. Biber, Richard A. Betts, Benjamin Leon Bodirsky, Delphine Deryng, Steve Frolking, Chris D. Jones, Heike K. Lotze, Hermann Lotze-Campen, Ritvik Sahajpal, Kirsten Thonicke, Hanqin Tian, Yoshiaki Yamagata. 2017. Assessing the impacts of 1.5 °C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b). *Geoscientific Model Development* 10:12, 4321-4345. [[Crossref](#)]
266. Simo Leppänen, Svetlana Ledyeva, Riitta Kosonen. 2016. Weather as a Competitive Factor between Local and Foreign Manufacturing Companies in Russia. *Journal of Industry, Competition and Trade* 16:4, 499-513. [[Crossref](#)]
267. Hugo J. Faria, Hugo M. Montesinos-Yufa, Daniel R. Morales, Carlos E. Navarro. 2016. Unbundling the roles of human capital and institutions in economic development. *European Journal of Political Economy* 45, 108-128. [[Crossref](#)]
268. Yury Kolokolov, Anna Monovskaya. 2016. Guess-Work and Reasonings on Centennial Evolution of Surface Air Temperature in Russia. Part IV: Towards Economic Estimations of Climate-Related Damages from the Bifurcation Analysis Viewpoint. *International Journal of Bifurcation and Chaos* 26:12, 1630033. [[Crossref](#)]
269. Solomon Hsiang. 2016. Climate Econometrics. *Annual Review of Resource Economics* 8:1, 43-75. [[Crossref](#)]
270. T. A. Carleton, S. M. Hsiang. 2016. Social and economic impacts of climate. *Science* 353:6304, aad9837-aad9837. [[Crossref](#)]
271. Hugo J. Faria, Hugo M. Montesinos-Yufa, Daniel R. Morales, Carlos E. Navarro. 2016. Unbundling the roles of human capital and institutions in economic development. *European Journal of Political Economy* . [[Crossref](#)]
272. Cristina Cattaneo, Giovanni Peri. 2016. The migration response to increasing temperatures. *Journal of Development Economics* 122, 127-146. [[Crossref](#)]
273. Tyler Beck Goodspeed. 2016. Environmental Shocks and Sustainability in Microfinance: Evidence from the Great Famine of Ireland. *The World Bank Economic Review* 46, lhw043. [[Crossref](#)]
274. Marshall Burke, Kyle Emerick. 2016. Adaptation to Climate Change: Evidence from US Agriculture. *American Economic Journal: Economic Policy* 8:3, 106-140. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
275. Robert E. Kopp, Rachael L. Shwom, Gernot Wagner, Jiacan Yuan. 2016. Tipping elements and climate-economic shocks: Pathways toward integrated assessment. *Earth's Future* 4:8, 346-372. [[Crossref](#)]
276. Tyler Beck Goodspeed. 2016. Microcredit and adjustment to environmental shock: Evidence from the Great Famine in Ireland. *Journal of Development Economics* 121, 258-277. [[Crossref](#)]
277. John Hassler, Per Krusell, Jonas Nycander. 2016. Climate policy. *Economic Policy* 31:87, 503-558. [[Crossref](#)]
278. Geoffrey Heal, Jisung Park. 2016. Reflections—Temperature Stress and the Direct Impact of Climate Change: A Review of an Emerging Literature. *Review of Environmental Economics and Policy* 10:2, 347-362. [[Crossref](#)]
279. Kalle Hirvonen. 2016. Temperature Changes, Household Consumption, and Internal Migration: Evidence from Tanzania. *American Journal of Agricultural Economics* 98:4, 1230-1249. [[Crossref](#)]

280. E De Cian, A F Hof, G Marangoni, M Tavoni, D P van Vuuren. 2016. Alleviating inequality in climate policy costs: an integrated perspective on mitigation, damage and adaptation. *Environmental Research Letters* 11:7, 074015. [[Crossref](#)]
281. Cormac Ó Gráda. 2016. "The Last, the Most Dreadful Resource of Nature": Economic-Historical Reflections on Famine. *Atlantic Economic Journal* 44:2, 225-241. [[Crossref](#)]
282. Armon Rezai, Frederick Van der Ploeg. 2016. Intergenerational Inequality Aversion, Growth, and the Role of Damages: Occam's Rule for the Global Carbon Tax. *Journal of the Association of Environmental and Resource Economists* 3:2, 493-522. [[Crossref](#)]
283. Leonie Wenz, Anders Levermann. 2016. Enhanced economic connectivity to foster heat stress-related losses. *Science Advances* 2:6, e1501026. [[Crossref](#)]
284. Qing Pei, David D Zhang, Guodong Li, Philippe Forêt, Harry F Lee. 2016. Temperature and precipitation effects on agrarian economy in late imperial China. *Environmental Research Letters* 11:6, 064008. [[Crossref](#)]
285. Jianhong E. Mu, Yong Chen. 2016. Impacts of large natural disasters on regional income. *Natural Hazards* 98. . [[Crossref](#)]
286. MARSHALL BURKE, MELANIE CRAXTON, CHARLES D. KOLSTAD, CHIKARA ONDA. 2016. SOME RESEARCH CHALLENGES IN THE ECONOMICS OF CLIMATE CHANGE. *Climate Change Economics* 07:02, 1650002. [[Crossref](#)]
287. Nam Kyu Kim. 2016. Revisiting Economic Shocks and Coups. *Journal of Conflict Resolution* 60:1, 3-31. [[Crossref](#)]
288. Paul Collier, Martina Kirchberger, Måns Söderbom. 2016. The Cost of Road Infrastructure in Low- and Middle-Income Countries. *The World Bank Economic Review* 30:3, 522-548. [[Crossref](#)]
289. Chengzheng Li, Haiying Gu. 2016. Climate Change and Mortality Puzzle in China. *SSRN Electronic Journal* . [[Crossref](#)]
290. Roberto Roson, Richard Damania. 2016. Simulating the Macroeconomic Impact of Future Water Scarcity: An Assessment of Alternative Scenarios. *SSRN Electronic Journal* . [[Crossref](#)]
291. Sandra Batten, Rhiannon Sowerbutts, Misa Tanaka. 2016. Let's Talk About the Weather: The Impact of Climate Change on Central Banks. *SSRN Electronic Journal* . [[Crossref](#)]
292. Maria Arvaniti. 2016. Uncertainty, Extreme Outcomes and Climate Change: A Critique. *SSRN Electronic Journal* . [[Crossref](#)]
293. Rohit Ticku. 2016. Riot Rewards? Religious Conflict and Electoral Outcomes. *SSRN Electronic Journal* . [[Crossref](#)]
294. Cristina Cattaneo, Valentina Bosetti. 2016. Climate-Induced International Migration and Conflicts. *SSRN Electronic Journal* . [[Crossref](#)]
295. Chengzheng Li, Jiajia Cong, Haiying Gu, Xunyong Xiang. 2016. Extreme Heat and Exports: Evidence from Chinese Exporters. *SSRN Electronic Journal* . [[Crossref](#)]
296. Sam Fankhauser. 2016. Adaptation to Climate Change. *SSRN Electronic Journal* . [[Crossref](#)]
297. Andrea Bastianin, Alessandro Lanza, Matteo Manera. 2016. Economic Impacts of El Niño Southern Oscillation: Evidence from the Colombian Coffee Market. *SSRN Electronic Journal* . [[Crossref](#)]
298. Panagiotis Tsigaris. 2016. The Potential Impacts of Climate Change on Piketty's Measure of Wealth Inequality. *SSRN Electronic Journal* . [[Crossref](#)]
299. Minsoo Lee, Mai Lin Villaruel. 2016. Effects of Temperature Shocks on Economic Growth and Welfare in Asia. *SSRN Electronic Journal* . [[Crossref](#)]

300. Emmanuel Alano, Minsoo Lee. 2016. Natural Disaster Shocks and Macroeconomic Growth in Asia: Evidence for Typhoons and Droughts. *SSRN Electronic Journal* . [[Crossref](#)]
301. Bridget Hoffmann. 2016. Temperature and Growth: A Panel Analysis of the United States. *SSRN Electronic Journal* . [[Crossref](#)]
302. Obed Nyangena. 2016. The Impact of Weather Variability on Economic Growth in Kenya. *SSRN Electronic Journal* . [[Crossref](#)]
303. Joseph Atta-Mensah. 2016. Poverty, Climate Change and Weather-Indexed Bonds. *Journal of Mathematical Finance* **06**:02, 275-292. [[Crossref](#)]
304. Jeff Tollefson. 2015. Social cost of carbon emissions in spotlight. *Nature* **527**. . [[Crossref](#)]
305. Jennifer M. Alix-Garcia, Katharine R. E. Sims, Patricia Yáñez-Pagans. 2015. Only One Tree from Each Seed? Environmental Effectiveness and Poverty Alleviation in Mexico's Payments for Ecosystem Services Program. *American Economic Journal: Economic Policy* **7**:4, 1-40. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
306. Marshall Burke, Solomon M. Hsiang, Edward Miguel. 2015. Global non-linear effect of temperature on economic production. *Nature* **527**:7577, 235-239. [[Crossref](#)]
307. Marshall Burke, Solomon M. Hsiang, Edward Miguel. 2015. Climate and Conflict. *Annual Review of Economics* **7**:1, 577-617. [[Crossref](#)]
308. Kirsty H. Lewis, Timothy M. Lenton. 2015. Knowledge problems in climate change and security research. *Wiley Interdisciplinary Reviews: Climate Change* **6**:4, 383-399. [[Crossref](#)]
309. Quamrul Ashraf, Stelios Michalopoulos. 2015. Climatic Fluctuations and the Diffusion of Agriculture. *Review of Economics and Statistics* **97**:3, 589-609. [[Crossref](#)]
310. Gerrit Hansen. 2015. The evolution of the evidence base for observed impacts of climate change. *Current Opinion in Environmental Sustainability* **14**, 187-197. [[Crossref](#)]
311. Lucas W. Davis, Paul J. Gertler. 2015. Contribution of air conditioning adoption to future energy use under global warming. *Proceedings of the National Academy of Sciences* **112**:19, 5962-5967. [[Crossref](#)]
312. Raymond Guiteras, Amir Jina, A. Mushfiq Mobarak. 2015. Satellites, Self-reports, and Submersion: Exposure to Floods in Bangladesh. *American Economic Review* **105**:5, 232-236. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
313. Marshall Burke, John Dykema, David B. Lobell, Edward Miguel, Shanker Satyanath. 2015. Incorporating Climate Uncertainty into Estimates of Climate Change Impacts. *Review of Economics and Statistics* **97**:2, 461-471. [[Crossref](#)]
314. Yelizaveta Skryzhavska, Veli-Pekka Tynkkynen, Simo Leppänen. 2015. Russia's climate policies and local reality. *Polar Geography* **38**:2, 146-170. [[Crossref](#)]
315. B. O. Abidoye, A. F. Odusola. 2015. Climate Change and Economic Growth in Africa: An Econometric Analysis. *Journal of African Economies* **24**:2, 277-301. [[Crossref](#)]
316. Andries F. Hof. 2015. Welfare impacts of climate change. *Nature Climate Change* **5**:2, 99-100. [[Crossref](#)]
317. Frances C. Moore, Delavane B. Diaz. 2015. Temperature impacts on economic growth warrant stringent mitigation policy. *Nature Climate Change* **5**:2, 127-131. [[Crossref](#)]
318. James Fenske, Namrata Kala. 2015. Climate and the slave trade. *Journal of Development Economics* **112**, 19-32. [[Crossref](#)]
319. Derek Lemoine. 2015. The Climate Risk Premium. *SSRN Electronic Journal* . [[Crossref](#)]

320. Chengzheng Li, Xunyong Xiang, Haiying Gu. 2015. Climate Shocks and International Trade: Evidence from China. *SSRN Electronic Journal* . [[Crossref](#)]
321. Michael D. Boldin, Jonathan H. Wright. 2015. Weather-Adjusting Employment Data. *SSRN Electronic Journal* . [[Crossref](#)]
322. Carl Johan Dalgaard, Casper Worm Hansen, Nicolai Kaarsen. 2015. Climate Shocks and (Very) Long-Run Productivity. *SSRN Electronic Journal* . [[Crossref](#)]
323. Rafi Amir-ud-Din. 2015. Comparing Returns from Human and Physical Capital: Black, White and Many Shades of Gray. *SSRN Electronic Journal* . [[Crossref](#)]
324. Cristina Cattaneo, Giovanni Peri. 2015. The Migration Response to Increasing Temperatures. *SSRN Electronic Journal* . [[Crossref](#)]
325. Ayodele Odusola, Babatunde Abidoye. 2015. Effects of Temperature and Rainfall Shocks on Economic Growth in Africa. *SSRN Electronic Journal* . [[Crossref](#)]
326. Christoph Hambel, Holger Kraft, Eduardo S. Schwartz. 2015. Optimal Carbon Abatement in a Stochastic Equilibrium Model with Climate Change. *SSRN Electronic Journal* . [[Crossref](#)]
327. Christoph Hambel, Holger Kraft, Eduardo S. Schwartz. 2015. Optimal Carbon Abatement in a Stochastic Equilibrium Model with Climate Change. *SSRN Electronic Journal* . [[Crossref](#)]
328. William Pizer, Matthew Adler, Joseph Aldy, David Anthoff, Maureen Cropper, Kenneth Gillingham, Michael Greenstone, Brian Murray, Richard Newell, Richard Richels, Arden Rowell, Stephanie Waldhoff, Jonathan Wiener. 2014. Using and improving the social cost of carbon. *Science* **346**:6214, 1189-1190. [[Crossref](#)]
329. Maximilian Auffhammer, Wolfram Schlenker. 2014. Empirical studies on agricultural impacts and adaptation. *Energy Economics* **46**, 555-561. [[Crossref](#)]
330. . Uncertainty, Downside Risk, and the Goals 145-185. [[Crossref](#)]
331. Samuel Bazzi, Christopher Blattman. 2014. Economic Shocks and Conflict: Evidence from Commodity Prices. *American Economic Journal: Macroeconomics* **6**:4, 1-38. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
332. Melissa Dell, Benjamin F. Jones, Benjamin A. Olken. 2014. What Do We Learn from the Weather? The New Climate-Economy Literature. *Journal of Economic Literature* **52**:3, 740-798. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
333. Christopher B. Barrett, Paulo Santos. 2014. The impact of changing rainfall variability on resource-dependent wealth dynamics. *Ecological Economics* **105**, 48-54. [[Crossref](#)]
334. Robert S. Pindyck. 2014. Risk and Return in the Design of Environmental Policy. *Journal of the Association of Environmental and Resource Economists* **1**:3, 395-418. [[Crossref](#)]
335. Christian P. Traeger. 2014. Why uncertainty matters: discounting under intertemporal risk aversion and ambiguity. *Economic Theory* **56**:3, 627-664. [[Crossref](#)]
336. Robin Leichenko, Melanie McDermott, Ekaterina Bezborodko, Michael Brady, Erik Namendorf. 2014. Economic Vulnerability to Climate Change in Coastal New Jersey: A Stakeholder-Based Assessment. *Journal of Extreme Events* **01**:01, 1450003. [[Crossref](#)]
337. Gernot Klepper, Wilfried Rickels. 2014. Climate Engineering: Economic Considerations and Research Challenges. *Review of Environmental Economics and Policy* **8**:2, 270-289. [[Crossref](#)]
338. Mia Ala-Juusela, Masanori Shukuya. 2014. Human body exergy consumption and thermal comfort of an office worker in typical and extreme weather conditions in Finland. *Energy and Buildings* **76**, 249-257. [[Crossref](#)]

339. Solomon M. Hsiang, Marshall Burke. 2014. Climate, conflict, and social stability: what does the evidence say?. *Climatic Change* 123:1, 39-55. [[Crossref](#)]
340. Richard Hornbeck, Pinar Keskin. 2014. The Historically Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Drought. *American Economic Journal: Applied Economics* 6:1, 190-219. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
341. Steven Shapiro. Poor People, Poor Planet: The Psychology of How We Harm and Heal Humanity and Earth 231-254. [[Crossref](#)]
342. Joshua Graff Zivin, Matthew Neidell. 2014. Temperature and the Allocation of Time: Implications for Climate Change. *Journal of Labor Economics* 32:1, 1-26. [[Crossref](#)]
343. David Blakeslee, Ram Fishman. 2014. Weather Shocks, Crime and Agriculture: Evidence from India. *SSRN Electronic Journal* . [[Crossref](#)]
344. Alexander Skorobogatov. 2014. An Ongoing Reversal of Fortune Among Russian Cities: City Age, Natural Resources, and Changing Spatial Income Distribution. *SSRN Electronic Journal* . [[Crossref](#)]
345. Simon Dietz, Nicholas Stern. 2014. Endogenous Growth, Convexity of Damages and Climate Risk: How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions. *SSRN Electronic Journal* . [[Crossref](#)]
346. Ivan Rudik. 2014. Targets, Taxes, and Learning: Optimizing Climate Policy Under Knightian Damages. *SSRN Electronic Journal* . [[Crossref](#)]
347. Sttphane Auray, Aurrien Eyquem, Frddric Jouneau-Sion. 2014. Climatic Conditions and Productivity: An Impact Evaluation in Pre-Industrial England. *SSRN Electronic Journal* . [[Crossref](#)]
348. S. M. Hsiang, M. Burke, E. Miguel. 2013. Quantifying the Influence of Climate on Human Conflict. *Science* 341:6151, 1235367-1235367. [[Crossref](#)]
349. Robert S. Pindyck. 2013. Climate Change Policy: What Do the Models Tell Us?. *Journal of Economic Literature* 51:3, 860-872. [[Abstract](#)] [[View PDF article](#)] [[PDF with links](#)]
350. Gang Chen, Brett Inder, Paula Lorgelly, Bruce Hollingsworth. 2013. THE CYCLICAL BEHAVIOUR OF PUBLIC AND PRIVATE HEALTH EXPENDITURE IN CHINA. *Health Economics* 22:9, 1071-1092. [[Crossref](#)]
351. R. S. Pindyck. 2013. The Climate Policy Dilemma. *Review of Environmental Economics and Policy* 7:2, 219-237. [[Crossref](#)]
352. M. Auffhammer, S. M. Hsiang, W. Schlenker, A. Sobel. 2013. Using Weather Data and Climate Model Output in Economic Analyses of Climate Change. *Review of Environmental Economics and Policy* 7:2, 181-198. [[Crossref](#)]
353. Warren Anderson, Noel D. Johnson, Mark Koyama. 2013. From the Persecuting to the Protective State? Jewish Expulsions and Weather Shocks from 1100 to 1800. *SSRN Electronic Journal* . [[Crossref](#)]
354. Samuel Bazzi, Christopher Blattman. 2013. Economic Shocks and Conflict: Evidence from Commodity Prices. *SSRN Electronic Journal* . [[Crossref](#)]
355. Paulo Bastos, Matias Busso, Sebastian Miller. 2013. Adapting to Climate Change: Long-Term Effects of Drought on Local Labor Markets. *SSRN Electronic Journal* . [[Crossref](#)]
356. Alex Bollfrass, Andrew Shaver. 2013. Some Insurgents Like it Hot: Global Evidence of a Temperature-Conflict Relationship. *SSRN Electronic Journal* . [[Crossref](#)]

- 357. Thomas K. J. McDermott. 2012. Geography and Institutions: On the Origins of Comparative Development. *SSRN Electronic Journal* . [[Crossref](#)]
- 358. Marshall Burke, Kyle Emerick. 2012. Adaptation to Climate Change: Evidence from US Agriculture. *SSRN Electronic Journal* . [[Crossref](#)]
- 359. William A. Brock, Gustav Engström, Anastasios Xepapadeas. 2012. Spatial Climate-Economic Models in the Design of Optimal Climate Policies Across Locations. *SSRN Electronic Journal* . [[Crossref](#)]
- 360. Tyler Beck Goodspeed. 2012. Famine, Finance, and Adjustment to Environmental Shock: Microcredit and the Great Famine in Ireland. *SSRN Electronic Journal* . [[Crossref](#)]
- 361. Razvan Vlaicu, Alex Whalley. 2011. Hierarchical Accountability in Government: Theory and Evidence. *SSRN Electronic Journal* . [[Crossref](#)]