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### THE LONG-LIVED EFFECTS OF HISTORIC CLIMATE ON THE WEALTH OF NATIONS

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## ABSTRACT

### The Long-Lived Effects of Historic Climate on the Wealth of Nations

We investigate the long-run consequences of historic, climatic temperatures (1730-2000) for the modern cross-country income distribution. Using a newly constructed dataset of climatic temperatures stretching over three centuries (18th, 19th, and 20th), we estimate a robust and significant time-varying, non-monotonic effect of climatic temperature upon current incomes for a cross-section of 167 countries. We find a large, positive effect of 18th century climatic temperature and an even larger, negative effect of 19th century climatic temperature upon current incomes. When historic, climatic temperature is introduced, the effect of 20th century climatic temperature on current income is either weakly positive or insignificant. Our findings are robust to various sub-samples, additional geographic controls, and alternative income measures. The negative relationship between current, climatic temperature and current income that is commonly estimated appears to reflect the long-run effect of climatic variations in the 18th and 19th centuries.

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# 1 Introduction

The nature of the relationship between climate and economic outcomes has long fascinated philosophers and social scientists alike.<sup>1</sup> The canonical perspective is that climatic temperature (the long-run average temperature) has a negative effect upon economic performance, via a variety of channels.<sup>2</sup> Much of the previous research assumes that temperature that is contemporaneous with economic outcomes captures the relevant effects of climatic temperature. Recently, the wider availability and growing temporal coverage of climatic data has begun to make feasible the empirical evaluation of time-varying effects of climate. A case in point is [Dell, Jones, and Olken \[2008, 2009\]](#), who leverage the cross-country, interannual variability of temperature and precipitation over 1950-2000 to estimate their dynamic effects upon economic growth. Such research informs us about the short-run consequences of temperature and precipitation variability for income.<sup>3</sup> However, these short-run effects may be quite different from the effects of long-run climatic variations (semicentennial or centennial) on income. Albeit slow-moving and persistent, climate has varied over recent centuries.

We estimate the long-run consequences of climatic temperature for economic performance in a large sample of 167 countries. Using a variety of data sources, we construct a new data set on historic temperature at the country-level. Our primary source of historic temperatures is the [Mann, Bradley, and Hughes \[1998a, 2004\]](#) reconstructed climatic data set spanning 1730-1993. We map the gridded temperature data to countries using historic population densities to create a set of population-weighted, 30-year average temperatures (the classic definition of climatic temperature) for each country for the 18th, 19th, and 20th centuries. We then document the effects of current (late 20th century) and historic (mid-18th and mid-19th century) climatic temperatures on the current cross-country dis-

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<sup>1</sup>Inter alia, [Montesquieu \[1748\]](#), [Huntington \[1915\]](#), [Myrdal \[1968\]](#), [Kamarck \[1976\]](#), [Lewis \[1978\]](#), [Landes \[1998\]](#).

<sup>2</sup>Notable contributions include [Gallup, Sachs, and Mellinger \[1998, 1999\]](#), [Masters and McMillan \[2001\]](#), [Sachs \[2001\]](#), [Nordhaus \[2006\]](#).

<sup>3</sup>There has also been a concurrent impact on microeconomic research (e.g., [Deschênes and Greenstone \[2007\]](#), [Deschênes and Moretti \[2007\]](#), etc.). All of these studies concentrate upon the *within*-country effects of short-run variation, which is not our focus in this paper.

tribution of real income per capita.

Our findings are both surprising and intriguing. Climatic temperature has a time-varying, non-monotonic effect upon income. Specifically, we find that 18th century climatic temperature has a positive and large effect upon current incomes, while 19th century climatic temperature has a negative and even larger effect upon current incomes. By contrast, once the influence of historic climate has been accounted for, 20th century climatic temperature has a small and positive effect upon current income. These results are robust to a host of sub-sample stability and specification checks apart from one exception – the effect of 20th century climatic temperature is not consistently significant across the robustness checks.

Quantitatively, historic, climatic temperatures have substantial, additional explanatory power for current income. When added to a regression of current income upon current, climatic temperature, explanatory power rises by 80% ( $R^2$  rises from 0.15 to 0.27). Moreover, the overall marginal effects of climatic temperature on current per capita income are different across the benchmark and augmented specifications. For example, the income change associated with a country shifting from the 50th to the 90th percentile of the temperature distribution in each century doubles in magnitude: it moves from  $-24\%$  when historic, climatic temperatures are omitted, to  $-49\%$  when they are included.

Our results suggest that the negative relationship between current, climatic temperature and current income that is commonly estimated in cross-country regressions, in fact reflects the long-run effect of climatic temperature in the 18th and 19th centuries. This implies that climatic temperature does not contribute a significant direct disadvantage for current economic outcomes. Instead, it is likely to have a powerful indirect influence through its historical effects on economic development.<sup>4</sup> We discuss how our findings regarding climatic temperature may be reconciled with other research that finds large negative, contemporaneous effects of comparatively short-run (e.g., annual) temperature

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<sup>4</sup>Easterly and Levine [2003] and Rodrik, Subramanian, and Trebbi [2004] allude to such a possibility when they demonstrate that aspects of geography (latitude, settler mortality, mineral endowments, etc.) have no direct effect on income, but have strong indirect effects through institutions. However, see Sachs [2003] for a vigorous counterargument.

measures upon current incomes and/or economic growth.

The idea that aspects of the physical environment have an impact on current economic performance through their interaction with historic events has featured in a number of recent contributions, including Engerman and Sokoloff [1994], Sokoloff and Engerman [2000], Engerman and Sokoloff [2003, 2005], Acemoglu, Johnson, and Robinson [2001, 2002], Nunn and Puga [2007], and Nunn [2009].<sup>5</sup> An advantage of temperature as a physical characteristic is that, unlike comparatively fixed geographic characteristics (such as latitude, elevation, ruggedness, etc.), its time-varying character allows us to disentangle the historic effects of climate on current economic outcomes from its contemporaneous effect.<sup>6</sup>

Our reduced-form approach to the climatic temperature-income relationship allows us to identify general patterns without imposing any restrictions on the underlying structure of the transmission mechanisms. Nevertheless, it is interesting to ask, what channels mediate the effect of climatic temperature on modern incomes? Thus, we examine the relationship of current and historic climatic temperatures to modern agricultural productivity, institutional quality, human capital (educational attainment and life expectancy), and the disease environment.

The paper proceeds as follows. In section 2, we describe the climatic data set and its construction. We then describe the macroeconomic and other geographic data that enter into the analysis, concluding with a discussion of the econometric methods that we employ. In section 3, we present our findings. We begin with our baseline results and their interpretation. We then discuss the set of sub-sample stability and specification (additional geographic controls) checks that we undertake. We then consider the

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<sup>5</sup>In part motivated by Diamond [1997]’s arguments about the importance of historic biogeography, a closely related literature has arisen which attempts to investigate the *very* long-run (viz., from 10,000 B.C.) effect of geographic characteristics upon economic development (e.g., Olsson and Hibbs, Jr. [2005] and Putterman [2008]). Such causes are also an integral component of recent theoretical work on economic growth by Galor [2009].

<sup>6</sup>Nunn and Puga [2007] employ an interesting identification strategy to estimate time-varying effects of a time-invariant geographic characteristic (ruggedness). Namely, they interact the geographic characteristic with a time-varying, historic variable (in their case, slave exports). In this manner, one can disentangle the effects of a geographic characteristic that operate through its interaction with the historic event from its other effects.

relationship of current and historic climate to a set of candidate channels. We end the section with some discussion and interpretation of our results. Finally, in section 4, we summarize our findings and their implications for future research.

## 2 Data Description and Econometric Methods

As noted in the introduction, we bring together a variety of data sources to construct the country-level current and historic, climatic temperature measures. First, we describe the temperature, population, and boundary datasets and how they enter into the construction of country-level, climatic (mean) temperatures. Second, we discuss the rough patterns visible in the current and historic, climatic temperature series. Third, we review the nature of the reconstructed temperature and population data and the evidence for their reliability. After discussing the climate data, we briefly describe the macroeconomic data and additional geographic controls that we consider. We conclude the section with a description of the econometric methods that we use in the empirics.

### 2.1 Construction of Climatic Temperatures

The temperature datasets that we use are:

- the CRUTEM3 global surface temperature dataset from the University of East Anglia’s Climatic Research Unit. The temperature data (in degrees Celsius/C) are at a monthly frequency at a 5 degree grid spatial resolution, from 1850–present. The coverage in the earlier years is somewhat sparse, reflecting the availability of the underlying instrumental data.<sup>7</sup> See [Brohan, Kennedy, Harris, Tett, and Jones \[2006\]](#), [Jones, New, Parker, Martin, and Rigor \[1999\]](#) and the [Climatic Research Unit](#) website for complete details.
- the [Mann et al. \[1998a, 2004\]](#) reconstructed global surface temperature anomalies (hereafter, MBH). The temperature data (in degrees C) are at an annual frequency

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<sup>7</sup>Wide coverage is available only post-1900.



at a 5 degree grid spatial resolution, from 1730–1993. The spatial coverage (dimensions) does not vary over the period. See these papers and the associated data documentation for complete details.

One of the limitations of the temperature data is immediately clear from the above description. The spatial resolution is comparatively low – a 5 degree (latitude/longitude) grid size corresponds to an approximately 550 kilometer grid size at the equator. Since we match the data to countries, the spatial resolution is not as binding as it would be if we were to consider direct gridpoint effects.<sup>8</sup> If anything, the coarseness of the temperature data reduces the variability of the country-level aggregated temperature measures, inhibiting our ability to separately identify current and historic climate effects.

The first step in using the temperature data is to convert the anomalies (differences in temperature relative to some baseline) to absolute temperature measures. We use the CRUTEM3 data to construct the 1902-1980 mean temperature which forms the baseline for the MBH data. These mean temperatures are then added to the anomalies data to recover the absolute temperatures at the gridpoints from 1730-1993.

Following the World Meteorological Organization (WMO), we define the climatic temperature as the mean temperature for a location over a thirty-year period [[World Meteorological Organization, 2008](#)]. Accordingly, we take the annual gridpoint data and construct a set of thirty-year mean temperatures for each gridpoint, starting with the period 1730-1759 (the earliest thirty-year window available in the MBH data). For our application, we used the 1730-1759 mean temperature as a measure of 18th century climate and 1830-1859 mean temperature as a measure of 19th century climate.<sup>9</sup> A natural question arises regarding the choice of start dates for the climatic temperature windows – why use 1730 and 1830? There are three reasons. First, the underlying reconstructed

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<sup>8</sup>See [Nordhaus \[2006\]](#) for an application that takes the opposite approach. He disaggregates the macroeconomic data and matches it to geographic gridpoints. In our approach, we are allowing a country’s borders and spatial extent to be endogenous to historic, climatic temperature. A country’s borders and spatial extent are therefore channels by which historic temperature may influence current performance. See section 2.5 for a general discussion of endogenous channels.

<sup>9</sup>Apart from Australia periodically appearing as a statistical outlier, our results are robust to using alternative windows to measure 18th and 19th century climates.

temperature series is only available from 1730. Thus, this is the earliest date that we can consider. Second, the early to mid-18th century is when the glimmers of the industrial revolution begin to be visible in the historic income data, leading us to choose to use a climatic window starting at the earliest available date. Third, the acceleration in European income growth is believed to have begun in earnest from 1820-1840, suggesting our choice of a mid-19th century start date for another climatic window.<sup>10</sup> Since MBH does not span the full 20th century, we use the CRUTEM3 data to construct 1970-1999 mean temperature as a measure of late 20th century climate (the climatic period contemporaneous with the economic data).

In a second step, we spatially join the gridpoint climatic temperature data to the administrative boundaries data from the U.S. Geological Survey's Global GIS database [2003]. The administrative boundaries data allows us to link the climatic temperature data to the country-level economic data, via common country identifiers.

In a third step, we spatially join global population density maps from 1730, 1830, and 1970 to the climatic temperature-boundaries dataset. The historic population density maps come from the Historical Database of the Global Environment (HYDE, version 3.1), constructed by the Netherlands's Environmental Assessment Agency (denoted MNP). The population data are at a decadal frequency at a 5 minute grid spatial resolution, from 1700–2000. Spatial coverage does not vary over the period. It should be noted that the comparatively high spatial resolution of the data gives a somewhat spurious sense of its accuracy. In fact, the basic units of population are the ISO 3166-2 sub-country units constructed by Klein Goldewijk, de Man, Meijer, and Wonink [2004].<sup>11</sup> Interestingly, these sub-country units roughly correspond in size to the features in the climatic temperature-boundaries dataset.

Finally, we use the population density maps in the initial year of a climate window to construct time-appropriate, population-weighted mean temperature for each time pe-

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<sup>10</sup>See Maddison [2005] for a discussion of the economic history.

<sup>11</sup>See Klein Goldewijk [2005] and the data documentation for complete details on the population data construction.

riod and country. We opt to use historic, initial population densities instead of current population density to avoid contaminating the weights with population shifts that are possibly endogenous to climatic temperature.

## 2.2 Patterns in Climatic Temperatures

Table 1 presents some summary statistics of the temperature and other key variables used in this paper. Our full sample consists of 167 countries for which both temperature and current income exist. The two types of variation in the temperature data that we exploit in this paper can be gleaned from this table: the cross-century and the cross-country variation in climate. With regards to the former, what we see in table 1 is a slight decrease in average climatic temperature of 0.06 degrees C, going from the 18th to the 19th century, followed by a rise of 0.32 degrees C in the 20th century.<sup>12</sup> There is clearly a large persistent element in climatic temperatures, which is not surprising. However, the cross-century variation is still sufficient to separately identify the effects of current and historic temperatures. The cross-country variation within any century is substantial, with the hottest countries having average temperatures in the high 20s degrees C and the coldest countries having average temperatures that are slightly below 0 degrees C.

## 2.3 Reliability of the Temperature and Population Data

Due to the paucity of high resolution, direct (instrumental) temperature data prior to the 20th century, researchers have deployed statistical methods to reconstruct historic temperature series from both direct and indirect, or proxy, measures. In their temperature reconstruction, MBH draw upon a wide spatial network of annual temperature indicators, including instrumental records, tree rings, ice cores, ice melts, coral bands, and other geological evidence. The temperature signal from these myriad data series is then recovered by calibrating the relationship between the climatic indicators and the

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<sup>12</sup>Interestingly, despite the aggregation of the temperature data to the country-level, these patterns replicate the features seen time and again in various historic global temperature series [Jones and Mann, 2004].

instrumental record where they overlap. The estimated relationship may then be used to “predict” temperature in earlier periods as a function of the temperature proxies (see [Committee on Surface Temperature Reconstructions for the Last 2,000 Years \[2006\]](#) for a discussion of the general approach).

How reliable is the temperature signal in the dataset? Since its initial publication in [1998a](#) and subsequent posting of corrections [[Mann et al., 2004](#)], the MBH data have been the subject of a host of cross-validation studies (e.g., [Jones, Osborn, and Briffa \[2001\]](#), [Bradley, Briffa, Cole, Hughes, and Osborn \[2003\]](#), [Mann, Rutherford, Wahl, and Ammann \[2005, 2007\]](#), [Li, Nychka, and Ammann \[2007\]](#)). A study by [Wahl and Ammann \[2007\]](#) undertook a variety of different statistical corrections to the underlying MBH methodology and found that the patterns amongst the reconstructions remained robust. Despite such reassurances, a core concern remains that temperature reconstructions tend to *understate* the degree of variability of past climate [[von Storch, Zorita, and González-Rouco, 2009](#)]. As we noted earlier with respect to spatial resolution, any reduced variability in the temperature series will inhibit our ability to disentangle the current and historic climatic temperature effects.

The MNP’s HYDE geo-referenced population time series is also reconstructed. Similar to the temperature reconstructions, a variety of historical and proxy data are used to construct measures of past population distribution. These are then carefully linked to modern population databases to verify their efficacy and ensure continuity (e.g., [Tobler, Deichmann, Gottsegen, and Maloy \[1995\]](#)). Cross-validation with respect to other historical population databases was then undertaken, including [Mitchell \[2007\]](#) and [Maddison \[1995\]](#).

## 2.4 Income, Geographic Controls, and Channels

Since our primary focus is the explanation of cross-country patterns of material well-being, the core macroeconomic variable that we investigate is real income per capita. We use the Penn World Table [[Heston, Summers, and Aten, 2006](#)] measure of real GDP per

capita (1996 constant international dollars) in the year 2000 as our baseline dependent variable. As robustness checks, we also considered real GDP per worker and average real GDP per capita over 1980-2000, similarly extracted from the Penn World Table. For each income variable, we take its natural logarithm.

The geographic controls that we employ include: the absolute latitude of a country's population centroid (calculated according to the method in [U.S. Census Bureau \[2001\]](#)); population-weighted mean frost days [[Masters and McMillan, 2001](#)]; an indicator for landlocked (extended from the data underlying [Gallup et al. \[1998, 1999\]](#)); an indicator for the Latin American and Caribbean region; and an indicator for the Sub-Saharan African region. The regional designations are taken from the World Bank's country geographic classification [[2009a](#)].

The potential set of channels by which climate may impact material well-being is large. We focus on a select subset, which represents what we consider to be the most likely candidates – agricultural productivity, institutions, and human capital (broadly defined). The channel variables that we consider include: net real agricultural productivity per agricultural population in the year 2000 [[Food and Agricultural Organization of the United Nations \(FAO\), 2009](#)]; the Polity 2 measure of institutional quality in the year 2000 [[Marshall, Jaggers, and Gurr, 2007](#)], normalized to lie between 0 (complete autocracy) and 1 (complete democracy); life expectancy in the year 2000 [[World Bank, 2009b](#)]; average educational attainment of the population in the year 1999 [[Barro and Lee, 2000](#)]; and malarial risk, defined to be the proportion of the population of a country living in areas of high risk of malarial exposure in 1994 [[Gallup et al., 1998, 1999](#)]. Further details regarding the underlying data sources is available in table [A.1](#) in the appendix. Summary statistics for the key variables used in this paper are presented in table [1](#).

## 2.5 Econometric Methods

The general regression specification is:

$$y_i = \alpha + \beta_1 temp_{1970-1999,i} + \beta_2 temp_{1830-1859,i} + \beta_3 temp_{1730-1759,i} + \sum_{k=1}^K \gamma_k x_{k,i} + \varepsilon_i, \quad (1)$$

where  $i$  indexes countries,  $y$  denotes the dependent variable (income or one of the channels),  $temp$  denotes mean temperature for country  $i$  during the time period in the subscript,  $x$  is a set of  $K$  additional explanatory variables,  $\varepsilon$  is a mean-zero error term, and the remaining Greek letters denote parameters. In our baseline specification, we only include the climatic temperature variables as explanatory variables ( $\gamma_k = 0 \forall k$ ), estimating a reduced-form effect of climatic temperature on the dependent variable.<sup>13</sup>

In all of our specifications, we do not include explanatory variables that are correlated with economic performance and known to be endogenous (e.g., institutions, human capital, physical capital etc.). Since these variables are endogenous to the development process, their inclusion would bias the coefficients on the exogenous climate variables. Moreover, they may represent likely channels by which historic temperatures impact current incomes (in the language of path analysis, they intervene and mediate an indirect effect of historic temperatures). Accordingly, we do investigate the relationship between these potential channels and current and historic temperatures (alluded to earlier).

We also undertake a host of robustness checks, including sub-sample regressions and the addition of other geographic controls (noted above). The coefficients are estimated by ordinary least squares. Standard errors are Huber-Eicker-White heteroskedasticity-robust.

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<sup>13</sup>It would be interesting to undertake a broader investigation of the role of a country's historic climate by including historic, climatic measures of precipitation, wind, humidity, etc. into the analysis. Unfortunately, such historic or reconstructed series do not currently exist with a sufficiently global coverage to make such an extension feasible.

### 3 Empirical Results

In this section, we detail our baseline results on the relationship between current incomes and current and historic, climatic temperature. We then present a set of robustness checks of our findings, including estimation over various sub-samples, the addition of other geographic controls, and the use of alternative income measures. We then evaluate current and historic, climatic temperature’s effects upon a set of economic channels, which in turn are likely to influence incomes. We conclude with some discussion and interpretation of our results.

#### 3.1 Baseline Results

As a benchmark against which to judge the effects of historic climate, regression 1 in table 2 reports OLS estimates of (1), where we only include current, climatic temperature (1970-1999) as an explanatory variable. For our full sample, we find that a one degree C rise in current, climatic temperature is associated with a 6.1% reduction in real GDP per capita. This estimate is largely in line with those reported in previous studies that have used other current temperature data to study the cross-sectional temperature-income relationship (e.g., Dell et al. [2009]). The negative relationship between income and current, climatic temperature can also be seen in the scatterplot in the upper-left panel of figure 1.

In regression 2, we add mean temperature in the 19th (1830-1859) and 18th (1730-1759) centuries as explanatory variables. Several aspects of the full sample estimates are worth highlighting. First, the  $R^2$  of the regression increases from 0.15 to 0.27, suggesting that historic, climatic temperatures has substantial explanatory power for current income over and above that of current, climatic temperature. These three temperature variables can account for over a quarter of the variability in the modern income distribution. Second, the coefficients on the historic temperature variables are highly significant and have opposite signs – positive for 18th century and negative for 19th century. Third, the

magnitude of the 19th century climatic temperature effect is larger than the 18th century effect. Fourth, current, climatic temperature is positively associated with income once we control for the effect of historic, climatic temperatures. However, the comparative magnitude of current, climatic temperature's effect is small. Finally, the sum of the estimated coefficients on current and historic, climatic temperatures is -0.059, which is similar in magnitude to the effect we obtain when we regress income on current, climatic temperature alone (-0.061). This suggests that the latter is capturing a long-run effect of climatic temperature on income, which our baseline specification breaks up into current and historic components. Thus, we are able to ascertain that the negative relationship between current, climatic temperature and current income is *not* due to current, climatic temperature's effect on income (which is estimated to be small and positive), but rather arises from the large, negative effect of 19th century climatic temperature.

The effects of historic, climatic temperature are not only statistically significant, but also economically significant. As an illustrative example, consider a country at the median of the global temperature distribution in each century. If that country were to move to the 90th percentile of the global temperature distribution in each century, its current income per capita income would be predicted to fall by 49.5% using the estimates from regression 2 in table 2. If the effects of historic, climatic temperature are neglected (regression 1 in table 2), the marginal effect of such a move is roughly halved in magnitude to -24%. Interestingly, if that country were to move to the 75th percentile of the global temperature distribution in each century, its current income per capita would be predicted to fall by 17.5% under the regression 2 estimates. This is not significantly different from the -20.5% estimated under regression 1. For countries in the tails of the global temperature distribution, the economic importance of historic, climatic temperature are most stark.

As a concrete example, if Sudan had experienced Canada's climatic temperatures instead of its own over the last three centuries then the results of regression 2 suggest that its income per capita in the year 2000 would have been 6.7 times larger. On the other hand, under regression 1, a similar thought experiment using only the 20th century tem-



perature difference between Sudan and Canada would predict that Sudan’s income would be only 3.7 times larger. The contrast in estimated marginal effects is perhaps evidence of adaptation: favorable climate today has less of an impact on economic performance as people today have developed ways of coping with adverse climate.

A visual guide to the nature of the identifying variation amongst the regressors of regression 2 in the full sample is presented in figure 1. The partial association plots in the upper-right and lower panels demonstrate how the intercentennial variation in climatic temperature is sufficient to separately identify the current and historic effects. These plots reveal some outliers (USA and Australia in the upper-right and lower-left panels; and Bolivia, Ethiopia and Eritrea in the lower-right pane ). To determine whether these visual outliers are driving the results, we re-estimated our baseline specification excluding these 5 countries. The results are in the second row of table 2 (labeled visual outliers). We find a similar pattern of coefficient signs, relative magnitudes, and explanatory power as in the full sample results. Interestingly, the statistical significance of the historic temperature coefficients is unchanged, while the coefficient on current temperature is no longer significant. Some of the precision associated with the current temperature coefficient in the full sample appears to be due to the inclusion of Bolivia, Ethiopia, and Eritrea. However, notice that the point estimate of the coefficient is essentially unchanged compared to the full sample.

## 3.2 Robustness Checks

In this subsection, we report the three types of robustness checks that we perform: (i) restricting attention to various sub-samples; (ii) adding various geographic controls; and, (iii) using alternative measures of current economic performance.

### 3.2.1 Sub-sample Stability

One common concern in the literature is that the results may be driven by countries in Sub-Saharan Africa. To address this concern we re-estimate our baseline regressions 1

and 2 excluding these countries. The results are given in the third row of table 2. The absolute magnitudes of the temperature coefficients and the  $R^2$ s fall, but the same pattern of signs, relative magnitudes, and marginal explanatory power of the historic temperature variables arises as in the full sample. Moreover, all of these results are highly statistically significant.

We also check whether the results are robust to a host of other sub-samples, which exclude various sets of countries that have been highlighted in the literature. This includes sub-samples that exclude: the Neo-Europes (Australia, Canada, New Zealand, and the United States), high income countries, low and medium income countries, and OPEC countries.<sup>14</sup> These results are reported in the fourth through seventh rows of table 2. While the magnitudes of the effects of temperature on income vary across these sub-samples, the general pattern in terms of signs and relative magnitudes is remarkably robust. Most surprisingly, it is even evident in the sample which excludes low and middle income countries – these effects manifest amongst the high income countries (albeit attenuated).

### 3.2.2 Geographic Controls

Table 3 shows the results when a variety of geographic controls are added to our baseline specification which includes current and historic temperatures. The controls selected have all been shown to be determinants of economic outcomes in previous work. In particular, we control for: absolute latitude (regression 3); mean frost days per year (regression 4); whether or not a country is landlocked (regression 5); whether or not a country is in the Latin American/Caribbean or Sub-Saharan African regions (regression 6); and, all of the above geographic controls simultaneously (regression 7). Of these additional geographic controls, latitude, landlocked status, and Sub-Saharan African status are statistically significant when they are added individually to the baseline regression. When they are included simultaneously, latitude, mean frost days, and the Sub-Saharan Africa indicator

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<sup>14</sup>We use [World Bank \[2009a\]](#) definitions to group countries into low, middle and high income countries.

are significant. It is worth pointing out that this last specification shows that current and historic climate plus the full set of exogenous geographic controls are able to account for fully half of the cross-country variation in real incomes.<sup>15</sup>

In all of these regressions, the inclusion of the various geographic controls reduces the magnitudes of the temperature coefficients, but it does not affect the pattern of signs and relative magnitudes seen in the baseline specification. The statistical significance of the temperature variables is also similar, apart from the current temperature coefficient in regressions 5 and 7. As seen in the sub-sample stability results, there is some fragility of the positive current, climatic temperature effect.

### 3.2.3 Alternative Measures of Current Economic Performance

We also investigated whether or not our findings were sensitive to the measure of current material well-being that we employ. We tried real income per worker in the year 2000 and real income per capita averaged over the years 1980-2000. The results are effectively unchanged.<sup>16</sup>

## 3.3 Channels

Our reduced-form results reveal a robust, significant impact of historic climatic temperature on current incomes, even after controlling for current, climatic temperature. The question then arises as to *how* exactly historic temperatures are influencing current incomes? We now explore a number of channels through which historic temperature may be influencing current incomes.

We consider 5 channels: agricultural productivity, institutional quality, life expectancy, educational attainment, and malarial risk. This is obviously not an exhaustive list, but

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<sup>15</sup>We also undertook an investigation of the robustness of the results to the addition of other historic temperature variables, including the average, annual seasonal difference in temperature (warm season minus cold season) and higher sample moments of the annual temperature, all calculated within each climatic window. Apart from the robustness of the results for mean temperatures, there was no systematic pattern associated with any of these additional climatic temperature variables. Results are available upon request.

<sup>16</sup>These estimates are not presented here, but are available upon request.

we feel that it encompasses the main channels emphasized in the literature. Table 4 presents the results from a set of regressions where the dependent variable is the postulated channel.<sup>17</sup> Looking first at regression 8, which only includes current, climatic temperature as an explanatory variable, we see that the estimated coefficients are all significant and of the expected sign. That is, for channels which are likely to be positively related to income, temperature is negatively associated. For channels which are likely to be negatively related to income, temperature is positively associated.

When we add historic climatic temperatures as explanatory variables in regression 9, we see is a pattern that mimics the one obtained in the baseline temperature-income regressions in table 2. Historic temperatures are significantly associated with each of the channels and the signs of the coefficients alternate, as in the baseline results. Interestingly, the coefficient on current, climatic temperature is not statistically significant in any of the regressions. Using a statistical significance criterion, any of these dependent variables are possible channels by which historic temperatures communicate their effects to current incomes.

However, the marginal explanatory power of historic temperatures differs markedly across the channel variables. A comparison of the  $R^2$ s from regression 8 and 9 indicates that the largest proportionate increase in explanatory power by far occurs with the institutional quality measure ( $R^2$  rises from 0.09 to 0.21). Moderate gains in explanatory power are seen for agricultural productivity ( $R^2$  rises from 0.31 to 0.42) and life expectancy ( $R^2$  rises from 0.16 to 0.24). Small gains are seen for educational attainment ( $R^2$  rises from 0.44 to 0.49) and malarial risk ( $R^2$  rises from 0.41 to 0.43). These results suggest a possible ranking of the likely channels by which historic temperatures influence current incomes, ranging from institutional quality at the high end to malarial risk at the low end.<sup>18</sup>

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<sup>17</sup>Ideally, the influence of such historic channels could be investigated using a two-stage least squares research design. However, with only two possible instruments (namely, 19th and 18th century mean temperatures) and multiple potential channels, we are unable to credibly implement such a design. With additional instruments, it may be feasible to undertake in future research.

<sup>18</sup>The importance of institutional quality as an income channel for geographic characteristics is emphasized by Easterly and Levine [2003] and Rodrik et al. [2004].

### 3.4 Discussion of the Results

What are we to make of these findings? The larger comparative impact of historic, climatic temperatures relative to current, climatic temperature is actually not that surprising. With persistence and a long time interval, the power of compounding magnifies the effects of small, historic, climatic differences upon the current income distribution. Such compounded effects would be expected to dominate any contemporaneous effect of current, climatic temperature upon current incomes. If our dependent variable were short-run (e.g., annual or decadal) economic growth, we would expect the opposite. Since the time interval is comparatively short, the current effects would be expected to be much larger than any historic effects. In this vein, using annual temperature movements, [Dell et al. \[2008\]](#) find a negative and large effect of contemporaneous, mean temperature upon annual economic growth, and small and insignificant effects of past, mean temperatures.

The surprising aspects of our findings are the magnitudes of the coefficients upon historic, climatic temperatures and their non-monotonicity (changing signs). Taken in isolation, each of the temperature coefficients in our baseline specification is extremely large relative to what is usually estimated if only current temperature is included. The literal interpretation of each of these coefficients is that they represent the unit change effect when all else is held constant. However, in the case of something that is highly persistent, like climatic temperature, the implicit extrapolation undertaken when interpreting each regression coefficient in isolation seems dubious. Nowhere in the sample does a country experience a large temperature change in one century, while its temperature in other centuries are identical. This leads us to prefer the use of the marginal effects associated with a country shifting quantiles in the temperature distribution (as described in section 3.1) when considering the long-run economic implications of temperature shifts. We discuss how to interpret the non-monotonicity in the conclusion.

## 4 Concluding Remarks

Using a newly constructed dataset of country-level, population-weighted, climatic temperatures stretching back 270 years, we estimate a robust and significant time-varying, non-monotonic effect of climatic temperature upon current incomes. In particular, we find a large, positive effect of 18th century climatic temperature and an even larger, negative effect of 19th century climatic temperature upon current incomes. When historic, climatic temperature is controlled, the effect of current climatic temperature on current income is either weakly positive or insignificant. Our results highlight the important role of a country's historic, climatic temperature experience for its current outcomes. In fact, the negative relationship between current, climatic temperature and current income that is commonly estimated appears to reflect the long-run effect of climatic variations in the 18th and 19th centuries.

The non-monotonicity of the temperature effects is intriguing – why does 18th century climatic temperature have a positive effect on current income, while 19th century climatic temperature has a negative effect? Our interpretation is that this is evidence of differences in the interaction between climatic temperature effects and historic events across centuries.<sup>19</sup> We offer a couple of hypotheses. First, the large, negative effect of 19th century temperature upon current incomes suggests a possible linkage to the wider diffusion of technologies associated with the industrial revolution that occurred in that period. If there are complementarities between new technologies and the climates of their origins, then technological adoption would be slower in countries that have climates that are unlike those of technology-originating countries. The United Kingdom and Europe are generally acknowledged to be at the technological frontier during the 19th century. These countries are also at the cooler end of the global temperature distribution. Consequently, their technological innovations will tend to diffuse slower to hotter countries.

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<sup>19</sup>An alternative possibility is that our cross-sectional regression with distributed lags in climatic temperature captures the time-invariant, dynamic effects of temperature. However, *a priori*, it seems unlikely that any dynamics would be time-invariant over such a long interval of time nor is there a clear reason why temperature 150 years ago would consistently have a different sign than temperature from 250 years ago.

Second, the 19th century is the period associated with the largest push of European colonization. An argument similar to that put forward by [Acemoglu et al. \[2001, 2002\]](#) suggests itself – countries that are warmer during the 19th century would have experienced greater European exploitation. They would therefore have inherited a poorer set of endowments and institutions. The results on the channel variables in section [3.3](#) give some weak support for such an interpretation.<sup>20</sup>

Our primary purpose in this paper has been to document the nature of the relationship of historic, climatic temperatures to current incomes. The results highlight the long-lived effects of historic temperatures upon a country’s economic outcomes. A more detailed investigation of the postulated interpretations presented here are left for future research.

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<sup>20</sup>[Horowitz \[forthcoming\]](#) invokes such a hypothesis by using [Acemoglu et al. \[2001\]](#)’s colonial settler mortality as a proxy for historic climate in his investigation of the effect of current temperatures on income. However, we note that settler mortality need not be the only channel by which historic climate may affect incomes.

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Table 1: Summary Statistics

| <i>Variable</i>                         | Mean   | Standard Deviation | Skewness | Kurtosis | Median | Interquartile Range | Minimum | Maximum | Number of Countries |
|---|--------|--------------------|----------|----------|--------|---------------------|---------|---------|---------------------|
| Real Income per capita                  | 9319   | 9509               | 1.318    | 4.083    | 5271   | 11843               | 359     | 48217   | 167                 |
| Real Income per worker                  | 20747  | 20227              | 1.325    | 4.747    | 13150  | 25496               | 885     | 114449  | 161                 |
| Average Real Income per capita          | 7854   | 7728               | 1.26     | 3.634    | 4827   | 10087               | 430     | 32486   | 167                 |
| Net Agric. Prod. per agric. population  | 2751   | 4934               | 2.79     | 10.401   | 784    | 2109                | 47      | 24004   | 171                 |
| Polity Democracy Measure (Normalized)   | 0.652  | 0.334              | -0.582   | 1.842    | 0.8    | 0.6                 | 0       | 1       | 150                 |
| Life Expectancy in years                | 67.03  | 10.32              | -0.826   | 2.65     | 70.3   | 14.41               | 41.99   | 81.08   | 170                 |
| Average Educational Attainment in years | 6.27   | 2.81               | 0.099    | 2.199    | 6.13   | 4.52                | 0.84    | 12.05   | 100                 |
| Malarial Risk                           | 0.344  | 0.429              | 0.654    | 1.623    | 0.002  | 0.894               | 0       | 1       | 156                 |
| Mean Temperature, 1970-1999             | 19.211 | 7.586              | -0.606   | 1.98     | 22.265 | 13.505              | -0.921  | 28.442  | 173                 |
| Mean Temperature, 1830-1859             | 18.893 | 7.716              | -0.646   | 2.055    | 21.891 | 13.619              | -2.732  | 27.633  | 173                 |
| Mean Temperature, 1730-1759             | 18.957 | 7.725              | -0.658   | 2.079    | 22.104 | 13.792              | -2.997  | 27.59   | 173                 |
| Absolute Latitude                       | 26.21  | 16.44              | 0.373    | 2        | 22.35  | 27.15               | 0.25    | 64.52   | 173                 |
| Mean Frost Days per year                | 8.54   | 9.95               | 0.784    | 2.029    | 2.7    | 17.91               | 0       | 29.88   | 159                 |

*Notes:* Income per capita/worker is for the year 2000. Average income per capita is calculated from the years 1980-2000. All income variables are from the Penn World table v. 6.2. Net agricultural productivity is for the year 2000, from the FAO Statistics database. The Polity Democracy measure takes the Polity 2 measure and maps it to the [0,1] interval, where 1 denotes complete democracy and 0 denotes complete autocracy. Life expectancy is for the year 2000, from the World Bank's World Development Indicators. Average education attainment is for the year 1999, from Barro and Lee (2000). Malarial incidence is the proportion of a country's population that is at high risk of malarial exposure for the year 1994. It ranges from 0 to 1 and is from Gallup, Mellinger, and Sachs (1998, 1999). The construction of the population-weighted climatological means for the 20th, 19th and 18th centuries is described in the main text. They are given in degrees Celsius. Absolute latitude is derived from the latitude of the country population centroid in 2000. Mean frost days per year is population-weighted and comes from Masters and McMillan (2001). Skewness is the 3rd central moment divided by the variance raised to the 1.5 power (symmetric distribution has a value of 0). Kurtosis is the 4th central moment divided by the square of the variance (normal distribution has a value of 3).

Table 2: Baseline Regression and Sub-sample Robustness Checks  
 Dependent variable is Logged Real GDP per capita in 2000

|     | <i>Sample</i>                        | <i>Regression 1</i> |       | <i>Regression 2</i> |                     |                    | <i>N</i> |       |
|-----|--------------------------------------|---------------------|-------|---------------------|---------------------|--------------------|----------|-------|
|     |                                      | Mean Temp.          | $R^2$ | Mean Temp.          | Mean Temp.          | Mean Temp.         |          |       |
|     |                                      | 1970-1999           |       | 1970-1999           | 1830-1859           | 1730-1759          |          | $R^2$ |
| (1) | Full Sample                          | -0.061**<br>(0.011) | 0.155 | 0.177*<br>(0.073)   | -2.1**<br>(0.315)   | 1.864**<br>(0.301) | 0.272    | 167   |
| (2) | Visual Outliers<br>Excluded          | -0.058**<br>(0.011) | 0.148 | 0.179<br>(0.18)     | -2.591**<br>(0.484) | 2.353**<br>(0.446) | 0.240    | 162   |
| (3) | Sub-Saharan Africa<br>Excluded       | -0.026*<br>(0.011)  | 0.044 | 0.126**<br>(0.047)  | -1.66**<br>(0.262)  | 1.505**<br>(0.257) | 0.162    | 128   |
| (4) | Neo-Europes<br>Excluded              | -0.057**<br>(0.011) | 0.140 | 0.169*<br>(0.068)   | -2.652**<br>(0.461) | 2.423**<br>(0.453) | 0.253    | 163   |
| (5) | WB Low and Middle<br>Income Excluded | -0.007<br>(0.008)   | 0.018 | 0.214**<br>(0.089)  | -0.677**<br>(0.208) | 0.463**<br>(0.13)  | 0.105    | 48    |
| (6) | WB High Income<br>Excluded           | -0.035**<br>(0.011) | 0.077 | 0.128<br>(0.072)    | -1.757**<br>(0.5)   | 1.582**<br>(0.487) | 0.168    | 119   |
| (7) | OPEC Members<br>Excluded             | -0.065**<br>(0.011) | 0.186 | 0.169*<br>(0.072)   | -2.147**<br>(0.321) | 1.914**<br>(0.309) | 0.314    | 158   |

*Notes:* Robust standard errors appear underneath coefficient estimates in parentheses. Significance levels are indicated by \*  $p < 0.05$  and \*\*  $p < 0.01$ . Visual outliers are Australia, Bolivia, Eritrea, Ethiopia, and the United States. Neo-Europes are Australia, Canada, New Zealand, and the United States. WB denotes the World Bank's income groupings. OPEC membership is determined by a country's status in 2000.  $N$  denotes the number of countries in the cross-sectional sample.

Table 3: Additional Geographic Controls  
 Dependent variable is Logged Real GDP per capita in 2000

| <i>Explanatory Variable</i>           | <i>Regression 3</i> | <i>Regression 4</i> | <i>Regression 5</i> | <i>Regression 6</i> | <i>Regression 7</i> |
|---------------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Mean Temperature 1970-1999            | 0.187*<br>(0.082)   | 0.143*<br>(0.067)   | 0.111<br>(0.084)    | 0.154**<br>(0.048)  | 0.114<br>(0.058)    |
| Mean Temperature 1830-1859            | -1.643**<br>(0.275) | -1.795**<br>(0.299) | -1.626**<br>(0.313) | -1.724**<br>(0.271) | -0.922**<br>(0.294) |
| Mean Temperature 1730-1759            | 1.512**<br>(0.239)  | 1.531**<br>(0.302)  | 1.444**<br>(0.284)  | 1.54**<br>(0.266)   | 0.763**<br>(0.268)  |
| Absolute Latitude                     | 0.058**<br>(0.014)  |                     |                     |                     | 0.035*<br>(0.016)   |
| Mean Frost Days per year              |                     | -0.048<br>(0.025)   |                     |                     | -0.057*<br>(0.023)  |
| Landlocked Indicator                  |                     |                     | -0.721**<br>(0.201) |                     | -0.384<br>(0.203)   |
| Latin America and Caribbean Indicator |                     |                     |                     | -0.091<br>(0.197)   | 0.031<br>(0.242)    |
| Sub-Saharan Africa Indicator          |                     |                     |                     | -1.235**<br>(0.228) | -0.924**<br>(0.271) |
| $R^2$                                 | 0.363               | 0.316               | 0.32                | 0.425               | 0.508               |
| $N$                                   | 167                 | 156                 | 167                 | 167                 | 156                 |

*Notes:* Robust standard errors appear underneath coefficient estimates in parentheses. Significance levels are indicated by \*  $p < 0.05$  and \*\*  $p < 0.01$ . Absolute latitude is derived from the latitude of the country population centroid in 2000. Mean frost days per year is population-weighted and comes from Masters and McMillan (2001).  $N$  denotes the number of countries in the cross-sectional sample.

Table 4: Climatic Temperature Channels

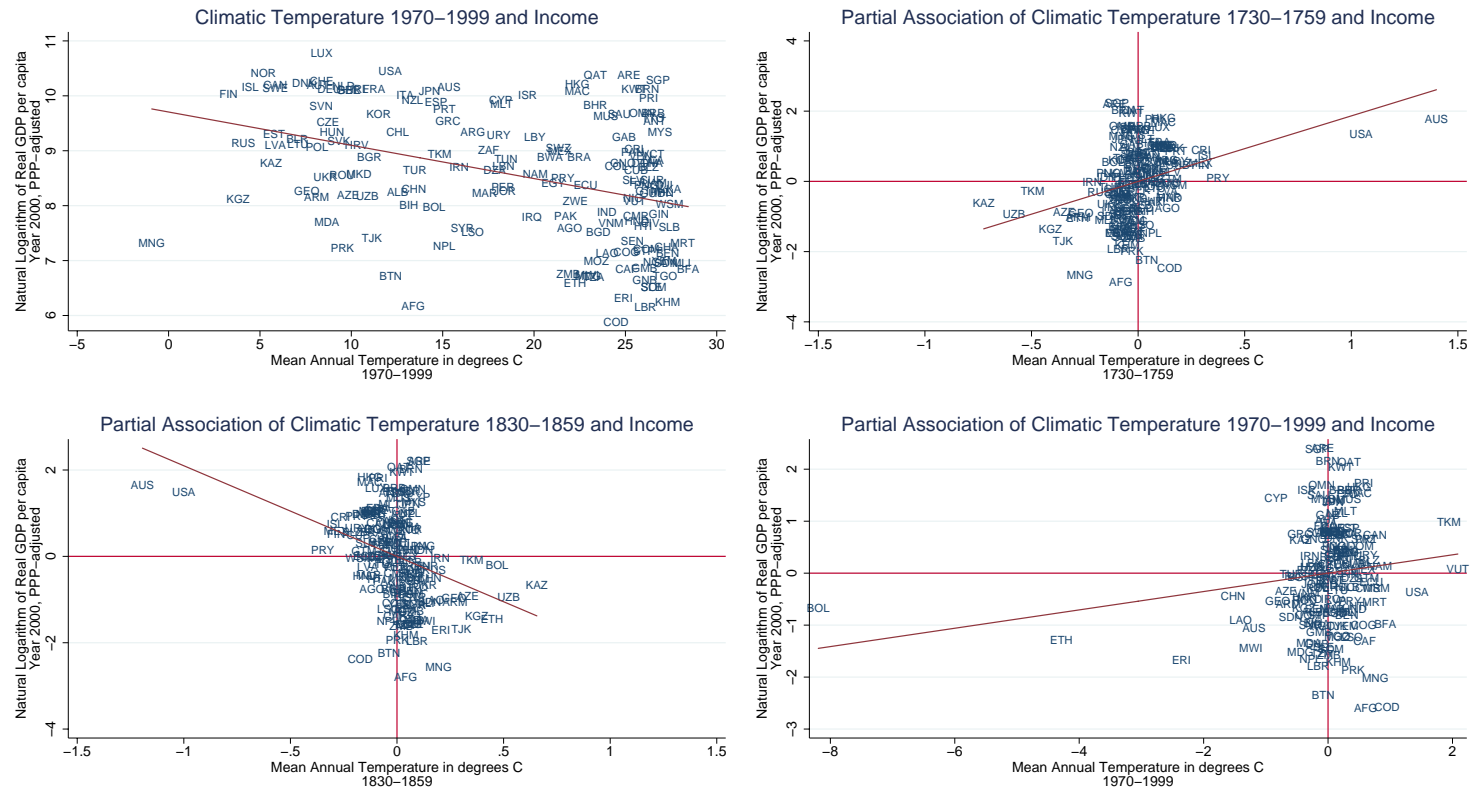
| <i>Dependent Variable</i>                                 | <i>Regression 8</i>     |       | <i>Regression 9</i>     |                         |                         |       |     |
|---|-------------------------|-------|-------------------------|-------------------------|-------------------------|-------|-----|
|   | Mean Temp.<br>1970-1999 | $R^2$ | Mean Temp.<br>1970-1999 | Mean Temp.<br>1830-1859 | Mean Temp.<br>1730-1759 | $R^2$ | $N$ |
| Log Net Real Agric. Productivity<br>per agric. population | -0.111**<br>(0.012)     | 0.308 | 0.139<br>(0.079)        | -2.757**<br>(0.304)     | 2.509**<br>(0.277)      | 0.422 | 171 |
| Polity Democracy Measure<br>(Normalized)                  | -0.013**<br>(0.003)     | 0.086 | 0.002<br>(0.024)        | -0.574**<br>(0.146)     | 0.56**<br>(0.144)       | 0.206 | 150 |
| Life Expectancy in years                                  | -0.535**<br>(0.082)     | 0.155 | 0.828<br>(0.501)        | -15.917**<br>(3.009)    | 14.562**<br>(2.884)     | 0.238 | 170 |
| Average Educational Attainment in<br>years                | -0.27**<br>(0.028)      | 0.436 | 0.089<br>(0.101)        | -3.348**<br>(0.586)     | 3.013**<br>(0.573)      | 0.488 | 100 |
| Malarial Risk   | 0.036**<br>(0.003)      | 0.411 | 0.018<br>(0.023)        | 0.271**<br>(0.088)      | -0.253**<br>(0.081)     | 0.426 | 156 |

*Notes:* Robust standard errors appear underneath coefficient estimates in parentheses. Significance levels are indicated by \*  $p < 0.05$  and \*\*  $p < 0.01$ . Net agricultural productivity is for the year 2000, from the FAO Statistics database. The Polity Democracy measure takes the Polity 2 measure and maps it to the [0,1] interval, where 1 denotes complete democracy and 0 denotes complete autocracy. Life expectancy is for the year 2000, from the World Bank's World Development Indicators. Average education attainment is for the year 1999, from Barro and Lee (2000). Malarial incidence is the proportion of a country's population that is at high risk of malarial exposure for the year 1994. It ranges from 0 to 1 and is from Gallup, Mellinger, and Sachs (1998, 1999).  $N$  denotes the number of countries in the cross-sectional sample.



Figure 1

## Climatic Temperature and Income Partial Associations



The upper-left panel is a scatterplot of the raw data on current climatic temperature and log income. The remaining panels depict the partial associations (residual scatterplots) between the listed variables under the specification in regression 2. All plots reflect the full sample.

Table A.1: Data Sources

| <i>Data Source</i>  | <i>Access Location</i>  | <i>Component/Variable</i>  |
|---|---|--|
| Barro and Lee (2000) International Educational Attainment Dataset                       | URL:<br><a href="http://www.cid.harvard.edu/ciddata/barrolee/appendix_data_tables_in_panel_set_format.xls">http://www.cid.harvard.edu/ciddata/barrolee/appendix_data_tables_in_panel_set_format.xls</a> . Downloaded on 20 January 2009. Version from February 2000.  | TYR: Average years of total schooling in a country based upon the entire population in 1999.   |
| Food and Agricultural Organization of the United Nations Statistics (FAOSTAT)           | Production (PRODSTAT) URL:<br><a href="http://faostat.fao.org/site/612/default.aspx">http://faostat.fao.org/site/612/default.aspx</a> . Downloaded on 28 July 2009. Version from 19 June 2009.<br><br>Population (PopSTAT) URL: <a href="http://faostat.fao.org/site/452/default.aspx">http://faostat.fao.org/site/452/default.aspx</a> . Downloaded on 28 July 2009. UN Revision 2008. | FAO Series Code 154, Country Net Real Agricultural Production in 2000 by country (thousands of 1999-2001 constant international dollars).<br><br>FAO Series Code 3010, Country agricultural population in 2000 (thousands of individuals). |
| Gallup, Sachs, and Mellinger (1999) Geography and Development Dataset                   | URL: <a href="http://www.cid.harvard.edu/ciddata/geodata.dta">http://www.cid.harvard.edu/ciddata/geodata.dta</a> . Downloaded on 6 October 2009.  | LANDLOCK: Indicator for whether or not a country is landlocked (no direct access to the sea) in 2000.  |
| History Database of the Global Environment (HYDE), v. 3.1                               | URL: <a href="ftp://ftp.mnp.nl/hyde/hyde31final/*_pop.zip">ftp://ftp.mnp.nl/hyde/hyde31final/*_pop.zip</a> . Downloaded on 6 August 2009. Version from 26 June 2009.  | Global 5 minute gridded population counts (raster) for 1730, 1830, 1970, and 2000. Each year is a separate ASCII file.   |
| ISO 3166 Country Codes  | URL: <a href="http://www.iso.org/iso/country_codes.htm">http://www.iso.org/iso/country_codes.htm</a> . Accessed on 15 October 2008.   | 2 and 3 letter country codes, used in harmonization of datasets.   |
| Kiszewski, Mellinger, Spielman, Malaney, and Sachs (2004) Malaria Transmission Database | URL:<br><a href="http://www.earth.columbia.edu/sitefiles/file/about/director/data/Malaria_vars_Oct2103.dta">http://www.earth.columbia.edu/sitefiles/file/about/director/data/Malaria_vars_Oct2103.dta</a> . Downloaded on 6 October 2009.   | MAL94P: Percent of country population at high risk of malaria in 1994.   |
| Mann, Bradley, and Hughes (1998, 2004) Global Gridded Temperature Anomalies, 1730-1993  | URL: <a href="http://picasso.ngdc.noaa.gov/paleo/data/mann/mann*.dat">http://picasso.ngdc.noaa.gov/paleo/data/mann/mann*.dat</a> . Downloaded on 18 January 2008. Version from 2004.  | Global 5 degree gridded annual temperature anomalies raster file (degrees Celsius). Each year is a separate ASCII file.  |
| Marshall, Jagers, and Gurr (2007) Polity IV Database                                    | URL: <a href="http://www.systemicpeace.org/inscr/p4v2007.xls">http://www.systemicpeace.org/inscr/p4v2007.xls</a> . Downloaded on 27 July 2009.  | POLITY2: Revised, combined Polity score for a country (democracy minus autocracy) in 2000.   |
| Masters and McMillan (2001) Country Frost Frequency                                     | URL:<br><a href="http://www.agecon.purdue.edu/staff/masters/countrydata/countrydata_frost.htm">http://www.agecon.purdue.edu/staff/masters/countrydata/countrydata_frost.htm</a> (file WillMastersDataOnFrostFrequency.xls). Downloaded on 28 July 2009.   | POPWEIGH: Country average number of frost days per unit of population.   |

| <i>Data Source</i>   | <i>Access Location</i>   | <i>Component/Variable</i>   |
|--|--|---|
| Organization of the Petroleum Exporting Countries (OPEC) Website                       | URL: <a href="http://www.opec.org/library/faqs/aboutopec/q3.htm">http://www.opec.org/library/faqs/aboutopec/q3.htm</a> . Accessed on 5 August 2009.  | Country OPEC Membership in 2000.  |
| Penn World Table v.6.2   | URL: <a href="http://pwt.econ.upenn.edu/php/site/pwt62/pwt62_form.php">http://pwt.econ.upenn.edu/php/site/pwt62/pwt62_form.php</a> . Downloaded on 27 July 2009. Version from September 2006.  | RGDPL: Country Real GDP (Income) per capita, in constant 2000 international dollars (Laspeyres), in 2000 and over 1980-2000.<br>RGDPWOK: Country Real GDP (Income) per worker, in constant 2000 international dollars (Chained), in 2000. |
| United States Geological Survey (USGS) Global GIS Global Coverage DVD-ROM, 2003        | Distributed by the American Geological Institute (AGI). Described at URL: <a href="http://webgis.wr.usgs.gov/globalgis/index.html">http://webgis.wr.usgs.gov/globalgis/index.html</a> .  | Country boundaries vector file (admin02.shp), with WGS1984 datum and geographic projection.<br>Global 5 degree latitude-longitude grid vector file (latlong.shp), with WGS1984 datum and geographic projection.                           |
| University of East Anglia Climatic Research Unit Global Gridded Temperature, 1850-2009 | URL: <a href="http://hadobs.metoffice.com/crutem3/data/CRUTEM3.nc">http://hadobs.metoffice.com/crutem3/data/CRUTEM3.nc</a> . Downloaded on 2 February 2008.<br>URL: <a href="http://www.cru.uea.ac.uk/cru/data/temperature/ftpdata/absolute.nc">http://www.cru.uea.ac.uk/cru/data/temperature/ftpdata/absolute.nc</a> . Downloaded on 2 February 2008. | Global 5 degree gridded monthly temperature anomalies raster-NetCDF file (degrees Celsius).<br>Global 5 degree gridded monthly average temperature level over 1961-1990, raster-NetCDF file (degrees Celsius).                            |
| World Bank Country Classification  | URL: <a href="http://www.worldbank.org/data/countryclass/classgroups.htm">http://www.worldbank.org/data/countryclass/classgroups.htm</a> . Accessed on 5 August 2009.  | Country income groups (high, medium, low).<br>Country geographic regions (Sub-Saharan Africa, Latin America and the Caribbean).   |
| World Development Indicators   | URL: <a href="http://www.esds.ac.uk/International/access/dataset_overview.asp#desc_WBWDI">http://www.esds.ac.uk/International/access/dataset_overview.asp#desc_WBWDI</a> . Downloaded on 11 October 2009. April 2009 Revision.   | SP.DYN.LE00.IN: Life expectancy in country at birth (total, years) in 2000.   |

Table A.2: Full Sample Country List

| <i>Country Name</i>        | <i>ISO 3166-1 2-Letter Code</i> | <i>ISO 3166-1 3-Letter Code</i> | <i>World Bank Income Group</i> |
|----------------------------|---------------------------------|---------------------------------|--------------------------------|
| Afghanistan                | AF                              | AFG                             | Low income                     |
| Albania                    | AL                              | ALB                             | Lower middle income            |
| Algeria                    | DZ                              | DZA                             | Upper middle income            |
| Angola                     | AO                              | AGO                             | Lower middle income            |
| Argentina                  | AR                              | ARG                             | Upper middle income            |
| Armenia                    | AM                              | ARM                             | Lower middle income            |
| Australia                  | AU                              | AUS                             | High income: OECD              |
| Austria                    | AT                              | AUT                             | High income: OECD              |
| Azerbaijan                 | AZ                              | AZE                             | Lower middle income            |
| Bahrain                    | BH                              | BHR                             | High income: nonOECD           |
| Bangladesh                 | BD                              | BGD                             | Low income                     |
| Barbados                   | BB                              | BRB                             | High income: nonOECD           |
| Belarus                    | BY                              | BLR                             | Upper middle income            |
| Belgium                    | BE                              | BEL                             | High income: OECD              |
| Belize                     | BZ                              | BLZ                             | Lower middle income            |
| Benin                      | BJ                              | BEN                             | Low income                     |
| Bhutan                     | BT                              | BTN                             | Lower middle income            |
| Bolivia                    | BO                              | BOL                             | Lower middle income            |
| Bosnia and Herzegovina     | BA                              | BIH                             | Upper middle income            |
| Botswana                   | BW                              | BWA                             | Upper middle income            |
| Brazil                     | BR                              | BRA                             | Upper middle income            |
| Brunei Darussalam          | BN                              | BRN                             | High income: nonOECD           |
| Bulgaria                   | BG                              | BGR                             | Upper middle income            |
| Burkina Faso               | BF                              | BFA                             | Low income                     |
| Cambodia                   | KH                              | KHM                             | Low income                     |
| Cameroon                   | CM                              | CMR                             | Lower middle income            |
| Canada                     | CA                              | CAN                             | High income: OECD              |
| Central African Republic   | CF                              | CAF                             | Low income                     |
| Chile                      | CL                              | CHL                             | Upper middle income            |
| China                      | CN                              | CHN                             | Lower middle income            |
| Colombia                   | CO                              | COL                             | Upper middle income            |
| Comoros                    | KM                              | COM                             | Low income                     |
| Congo                      | CG                              | COG                             | Lower middle income            |
| Costa Rica                 | CR                              | CRI                             | Upper middle income            |
| Côte d'Ivoire              | CI                              | CIV                             | Lower middle income            |
| Croatia                    | HR                              | HRV                             | High income: nonOECD           |
| Cuba                       | CU                              | CUB                             | Upper middle income            |
| Cyprus                     | CY                              | CYP                             | High income: nonOECD           |
| Czech Republic             | CZ                              | CZE                             | High income: OECD              |
| Dem. Republic of the Congo | CD                              | COD                             | Low income                     |
| Denmark                    | DK                              | DNK                             | High income: OECD              |
| Djibouti                   | DJ                              | DJI                             | Lower middle income            |
| Dominican Republic         | DO                              | DOM                             | Upper middle income            |
| Ecuador                    | EC                              | ECU                             | Lower middle income            |
| Egypt                      | EG                              | EGY                             | Lower middle income            |
| El Salvador                | SV                              | SLV                             | Lower middle income            |
| Equatorial Guinea          | GQ                              | GNQ                             | High income: nonOECD           |
| Eritrea                    | ER                              | ERI                             | Low income                     |
| Estonia                    | EE                              | EST                             | High income: nonOECD           |
| Ethiopia                   | ET                              | ETH                             | Low income                     |
| Fiji                       | FJ                              | FJI                             | Upper middle income            |
| Finland                    | FI                              | FIN                             | High income: OECD              |
| France                     | FR                              | FRA                             | High income: OECD              |
| Gabon                      | GA                              | GAB                             | Upper middle income            |
| Gambia                     | GM                              | GMB                             | Low income                     |
| Georgia                    | GE                              | GEO                             | Lower middle income            |
| Germany                    | DE                              | DEU                             | High income: OECD              |
| Ghana                      | GH                              | GHA                             | Low income                     |

| <i>Country Name</i>                            | <i>ISO 3166-1 2-<br/>Letter Code</i> | <i>ISO 3166-1 3-<br/>Letter Code</i> | <i>World Bank Income<br/>Group</i> |
|--|--------------------------------------|--------------------------------------|------------------------------------|
| Greece   | GR                                   | GRC                                  | High income: OECD                  |
| Guatemala                                      | GT                                   | GTM                                  | Lower middle income                |
| Guinea   | GN                                   | GIN                                  | Low income                         |
| Guinea-Bissau                                  | GW                                   | GNB                                  | Low income                         |
| Guyana   | GY                                   | GUY                                  | Lower middle income                |
| Haiti  | HT                                   | HTI                                  | Low income                         |
| Honduras                                       | HN                                   | HND                                  | Lower middle income                |
| Hong Kong                                      | HK                                   | HKG                                  | High income: nonOECD               |
| Hungary  | HU                                   | HUN                                  | High income: OECD                  |
| Iceland  | IS                                   | ISL                                  | High income: OECD                  |
| India  | IN                                   | IND                                  | Lower middle income                |
| Indonesia                                      | ID                                   | IDN                                  | Lower middle income                |
| Iran, Islamic Republic of                      | IR                                   | IRN                                  | Lower middle income                |
| Iraq   | IQ                                   | IRQ                                  | Lower middle income                |
| Ireland  | IE                                   | IRL                                  | High income: OECD                  |
| Israel   | IL                                   | ISR                                  | High income: nonOECD               |
| Italy  | IT                                   | ITA                                  | High income: OECD                  |
| Jamaica  | JM                                   | JAM                                  | Upper middle income                |
| Japan  | JP                                   | JPN                                  | High income: OECD                  |
| Jordan   | JO                                   | JOR                                  | Lower middle income                |
| Kazakhstan                                     | KZ                                   | KAZ                                  | Upper middle income                |
| Korea, Dem. People's Republic of (North Korea) | KP                                   | PRK                                  | Low income                         |
| Korea, Republic of (South Korea)               | KR                                   | KOR                                  | High income: OECD                  |
| Kuwait   | KW                                   | KWT                                  | High income: nonOECD               |
| Kyrgyzstan                                     | KG                                   | KGZ                                  | Low income                         |
| Lao People's Dem. Republic                     | LA                                   | LAO                                  | Low income                         |
| Latvia   | LV                                   | LVA                                  | Upper middle income                |
| Lebanon  | LB                                   | LBN                                  | Upper middle income                |
| Lesotho  | LS                                   | LSO                                  | Lower middle income                |
| Liberia  | LR                                   | LBR                                  | Low income                         |
| Libyan Arab Jamahiriya                         | LY                                   | LBY                                  | Upper middle income                |
| Lithuania                                      | LT                                   | LTU                                  | Upper middle income                |
| Luxembourg                                     | LU                                   | LUX                                  | High income: OECD                  |
| Macao  | MO                                   | MAC                                  | High income: nonOECD               |
| Macedonia, the former Yugoslav Republic of     | MK                                   | MKD                                  | Upper middle income                |
| Madagascar                                     | MG                                   | MDG                                  | Low income                         |
| Malawi   | MW                                   | MWI                                  | Low income                         |
| Malaysia                                       | MY                                   | MYS                                  | Upper middle income                |
| Mali   | ML                                   | MLI                                  | Low income                         |
| Malta  | MT                                   | MLT                                  | High income: nonOECD               |
| Mauritania                                     | MR                                   | MRT                                  | Low income                         |
| Mauritius                                      | MU                                   | MUS                                  | Upper middle income                |
| Mexico   | MX                                   | MEX                                  | Upper middle income                |
| Moldova  | MD                                   | MDA                                  | Lower middle income                |
| Mongolia                                       | MN                                   | MNG                                  | Lower middle income                |
| Morocco  | MA                                   | MAR                                  | Lower middle income                |
| Mozambique                                     | MZ                                   | MOZ                                  | Low income                         |
| Namibia  | NA                                   | NAM                                  | Upper middle income                |
| Nepal  | NP                                   | NPL                                  | Low income                         |
| Netherlands                                    | NL                                   | NLD                                  | High income: OECD                  |
| Netherlands Antilles                           | AN                                   | ANT                                  | High income: nonOECD               |
| New Zealand                                    | NZ                                   | NZL                                  | High income: OECD                  |
| Nicaragua                                      | NI                                   | NIC                                  | Lower middle income                |
| Nigeria  | NG                                   | NGA                                  | Lower middle income                |
| Norway   | NO                                   | NOR                                  | High income: OECD                  |
| Oman   | OM                                   | OMN                                  | High income: nonOECD               |
| Pakistan                                       | PK                                   | PAK                                  | Lower middle income                |
| Panama   | PA                                   | PAN                                  | Upper middle income                |

| <i>Country Name</i>              | <i>ISO 3166-1 2-Letter Code</i> | <i>ISO 3166-1 3-Letter Code</i> | <i>World Bank Income Group</i> |
|----------------------------------|---------------------------------|---------------------------------|--------------------------------|
| Papua New Guinea                 | PG                              | PNG                             | Lower middle income            |
| Paraguay                         | PY                              | PRY                             | Lower middle income            |
| Peru                             | PE                              | PER                             | Upper middle income            |
| Philippines                      | PH                              | PHL                             | Lower middle income            |
| Poland                           | PL                              | POL                             | Upper middle income            |
| Portugal                         | PT                              | PRT                             | High income: OECD              |
| Puerto Rico                      | PR                              | PRI                             | High income: nonOECD           |
| Qatar                            | QA                              | QAT                             | High income: nonOECD           |
| Romania                          | RO                              | ROU                             | Upper middle income            |
| Russian Federation               | RU                              | RUS                             | Upper middle income            |
| Saint Lucia                      | LC                              | LCA                             | Upper middle income            |
| Saint Vincent and the Grenadines | VC                              | VCT                             | Upper middle income            |
| Samoa                            | WS                              | WSM                             | Lower middle income            |
| Sao Tome and Principe            | ST                              | STP                             | Lower middle income            |
| Saudi Arabia                     | SA                              | SAU                             | High income: nonOECD           |
| Senegal                          | SN                              | SEN                             | Low income                     |
| Sierra Leone                     | SL                              | SLE                             | Low income                     |
| Singapore                        | SG                              | SGP                             | High income: nonOECD           |
| Slovakia                         | SK                              | SVK                             | High income: OECD              |
| Slovenia                         | SI                              | SVN                             | High income: nonOECD           |
| Solomon Islands                  | SB                              | SLB                             | Lower middle income            |
| Somalia                          | SO                              | SOM                             | Low income                     |
| South Africa                     | ZA                              | ZAF                             | Upper middle income            |
| Spain                            | ES                              | ESP                             | High income: OECD              |
| Sri Lanka                        | LK                              | LKA                             | Lower middle income            |
| Sudan                            | SD                              | SDN                             | Lower middle income            |
| Suriname                         | SR                              | SUR                             | Upper middle income            |
| Swaziland                        | SZ                              | SWZ                             | Lower middle income            |
| Sweden                           | SE                              | SWE                             | High income: OECD              |
| Switzerland                      | CH                              | CHE                             | High income: OECD              |
| Syrian Arab Republic             | SY                              | SYR                             | Lower middle income            |
| Tajikistan                       | TJ                              | TJK                             | Low income                     |
| Tanzania, United Republic of     | TZ                              | TZA                             | Low income                     |
| Thailand                         | TH                              | THA                             | Lower middle income            |
| Togo                             | TG                              | TGO                             | Low income                     |
| Trinidad and Tobago              | TT                              | TTO                             | High income: nonOECD           |
| Tunisia                          | TN                              | TUN                             | Lower middle income            |
| Turkey                           | TR                              | TUR                             | Upper middle income            |
| Turkmenistan                     | TM                              | TKM                             | Lower middle income            |
| Ukraine                          | UA                              | UKR                             | Lower middle income            |
| United Arab Emirates             | AE                              | ARE                             | High income: nonOECD           |
| United Kingdom                   | GB                              | GBR                             | High income: OECD              |
| United States                    | US                              | USA                             | High income: OECD              |
| Uruguay                          | UY                              | URY                             | Upper middle income            |
| Uzbekistan                       | UZ                              | UZB                             | Low income                     |
| Vanuatu                          | VU                              | VUT                             | Lower middle income            |
| Venezuela                        | VE                              | VEN                             | Upper middle income            |
| Viet Nam                         | VN                              | VNM                             | Low income                     |
| Yemen                            | YE                              | YEM                             | Low income                     |
| Zambia                           | ZM                              | ZMB                             | Low income                     |
| Zimbabwe                         | ZW                              | ZWE                             | Low income                     |

*Notes:* These countries constitute the sample underlying the baseline regressions. They are countries for which real income per capita in 2000 from the Penn World v. 6.2 exists and for which current and historic, climatic temperatures can be calculated. The ISO 3166-1 country codes have been adapted in some cases to accommodate the availability of income data in the Penn World table (e.g., Hong Kong is available separately). The World Bank income groups are from July 2009 (historic income groupings for 2000 were not available). Countries classified as low and middle income are commonly referred to as developing, which countries classified as high income are commonly referred to as developed.