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

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Abstract

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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Keywords: climate, temperature, economic performance, geography, history

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1 Introduction

The nature of the relationship between climate and economic outcomes has long fascinated philosophers and social scientists alike.[1] The canonical perspective is that climatic temperature (the long-run average temperature) has a negative effect upon economic performance, via a variety of channels.[2] 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.[3] 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-

[1] Inter alia, Montesquieu [1748], Huntington [1915], Myrdal [1968], Kamarck [1976], Lewis [1978], Landes [1998].

[2] Notable contributions include Gallup, Sachs, and Mellinger [1998, 1999], Masters and McMillan [2001], Sachs [2001], Nordhaus [2006].

[3] 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.[4] 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

[4]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].[5] 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.[6]

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

[5]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].

[6]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.[7] 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

[7]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.[8] 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.[9] 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

[8] 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.

[9] 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.[10] 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].[11] 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-

[10]See Maddison [2005] for a discussion of the economic history.

[11]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.[12] 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

[12] 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 *under*state 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, ε 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.[13]

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.

[13]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 temperature 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^2s 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.[14] 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

[14] 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.[15]

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.[16]

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

[15]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.

[16]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.[17] 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^2s 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.[18]

[17]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.

[18]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.[19] 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.

[19] 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.[20]

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.

[20]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.

References

Daron Acemoglu, Simon Johnson, and James A. Robinson. The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91(5):1369–1401, December 2001.

Daron Acemoglu, Simon Johnson, and James A. Robinson. Reversal Of Fortune: Geography And Institutions In The Making Of The Modern World Income Distribution. *The Quarterly Journal of Economics*, 117(4):1231–1294, November 2002.

Robert J. Barro and Jong-Wha Lee. International Data on Educational Attainment: Updates and Implications. *CID Working Paper*, (042), April 2000. URL http://www.cid.harvard.edu/ciddata/ciddata.html.

R. S. Bradley, K. R. Briffa, J. Cole, M. K. Hughes, and T. J. Osborn. *The Climate of the Last Millenium*, chapter 6, pages 105–141. Springer-Verlag, Berlin and Heidelberg, Germany, 2003. ISBN 3-540-42402-4.

P. Brohan, J. J. Kennedy, I. Harris, S.F.B. Tett, and P. D. Jones. Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. *Journal of Geophysical Research*, 11(D12106), 2006. doi:10.1029/2005JD006548.

Center for International Earth Science Information Network (CIESIN), Columbia University and Centro Internacional de Agricultura Tropical (CIAT). Gridded Population of the World Version 3 (GPWv3), 2005. URL http://sedac.ciesin.columbia.edu/gpw/.

University of East Anglia Climatic Research Unit. Temperature data, 2008. URL http://www.cru.uea.ac.uk/cru/data/temperature/. Accessed 2 February 2008.

Committee on Surface Temperature Reconstructions for the Last 2,000 Years. *Surface Temperature Reconstructions for the Last 2,000 Years*. National Academies Press, Washington, DC, USA, 2006. ISBN 0-309-10225-1. URL http://www.nap.edu/catalog/11676.html. Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, National Research Council of the National Academies.

Melissa Dell, Benjamin F. Jones, and Benjamin A. Olken. Climate Change and Economic Growth: Evidence from the Last Half Century. *NBER Working Paper*, (14312), June 2008.

Melissa Dell, Benjamin F. Jones, and Benjamin A. Olken. Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates. *American Economic Review*, 99(2):198–204, May 2009.

Olivier Deschênes and Michael Greenstone. The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather. *American Economic Review*, 97(1), March 2007.

Olivier Deschênes and Enrico Moretti. Extreme Weather Events, Mortality, and Migration. *NBER Working Paper*, (13227), July 2007.

Jared Diamond. *Guns, Germs, and Steel: The Fates of Human Societies*. W.W. Norton and Company, New York, NY, USA, 1997. ISBN 0393061310.

William Easterly and Ross Levine. Tropics, germs, and crops: How endowments influence economic development. *Journal of Monetary Economics*, 50(1):3–39, January 2003.

Stanley L. Engerman and Kenneth L. Sokoloff. Factor Endowments, Institutions, and Differential Paths of Growth Among New World Economies: A View from Economic Historians of the United States. *NBER Historical Working Paper*, (66), December 1994.

Stanley L. Engerman and Kenneth L. Sokoloff. Institutional and Non-Institutional Explanations of Economic Differences. *NBER Working Paper*, (9989), September 2003.

Stanley L. Engerman and Kenneth L. Sokoloff. Colonialism, Inequality, and Long-Run Paths of Development. *NBER Working Paper*, (11057), January 2005.

Food and Agricultural Organization of the United Nations (FAO). ProdSTAT, Production Statistics, June 2009. URL http://faostat.fao.org/.

John Luke Gallup, Jeffrey D. Sachs, and Andrew D. Mellinger. Geography and Economic Development. *NBER Working Paper*, (6849), 1998.

John Luke Gallup, Jeffrey D. Sachs, and Andrew D. Mellinger. Geography and Economic Development. *International Regional Science Review*, 22(2):179–232, 1999.

Oded Galor. 2008 Lawrence R. Klein Lecture – Comparative Economic Development: Insights from Unified Growth Theory. *Brown University, Department of Economics, Working Papers*, (2009-10), 2009.

Alan Heston, Robert Summers, and Bettina Aten. Penn World Table Version 6.2, September 2006. URL http://pwt.econ.upenn.edu/.

John K. Horowitz. The income-temperature relationship in a cross-section of countries and its implications for predicting the effects of global warming. *Environmental and Resource Economics*, forthcoming. URL http://dx.doi.org/10.1007/s10640-009-9296-2.

Ellsworth Huntington. *Civilization and climate*. Yale University Press, New Haven, CT, USA, 1915.

P. D. Jones and M. E. Mann. Climate over past millenia. *Review of Geophysics*, 42, 2004. URL http://dx.doi.org/10.1029/2003RG000143.

P. D. Jones, T. J. Osborn, and K. R. Briffa. The Evolution of Climate Over the Last Millenium. *Science*, 292(5517):662–667, April 2001.

P.D. Jones, M. New, D.E. Parker, S. Martin, and I.G. Rigor. Surface air temperature and its variations over the last 150 years. *Reviews of Geophysics*, 37(2):173–199, May 1999.

Andrew M. Kamarck. *The Tropics and Economic Development*. Johns Hopkins University Press, Baltimore, MD, USA, 1976. ISBN 0801818915. Published for the World Bank.

K. Klein Goldewijk and G. van Drecht. HYDE 3.1: Current and historical population and land cover, 2006. URL http://www.mnp.nl/en/themasites/hyde/index.html. Netherlands Environmental Assessment Agency (MNP), Bilthoven, Netherlands.

K. Klein Goldewijk, R. de Man, J. Meijer, and S. Wonink. The Environmental Assessment Agency 2004: World Regions and Subregions, Global Sustainability and Climate. Technical Report KMD-M001/04, Netherlands Environmental Assessment Agency (MNP), Amsterdam, NLD, 2004.

Kees Klein Goldewijk. Three Centuries of Global Population Growth: A Spatial Referenced Population (Density) Database for 1700-2000. *Population and Environment*, 26 (4), March 2005.

David S. Landes. *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor*. W. W. Norton and Company, New York, NY, USA, 1998. ISBN 0393040178.

W. Arthur Lewis. *The Evolution of the International Economic Order*. Eliot Janeway Lectures on Historical Economics in honor of Joseph Schumpeter. Princeton University Press, Princeton, NJ, USA, 1978.

Bo Li, Douglas W. Nychka, and Caspar M. Ammann. The 'hockey stick' and the 1990s: a statistical perspective on reconstructing hemispheric temperatures. *Tellus - Series A, Dynamic Meteorology and Oceanography*, 59(5):591–598, 2007.

Angus Maddison. *Monitoring the World Economy, 1820-1992*. Development Centre of the OECD, Paris, France, 1995. ISBN 9264145494.

Angus Maddison. Measuring and interpreting world economic performance 1500-2001. *Review of Income and Wealth*, 51(1):1–35, March 2005.

Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes. Global-scale temperature patterns and climate forcing over the past six centuries. *Nature*, 392:779–787, 23 April 1998a.

Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes. Global Six Century Temperature Patterns. *IGBP PAGES/World Data Center-A for Paleoclimatology*, 1998b. URL http://picasso.ngdc.noaa.gov/paleo/data/mann/. Data Contribution Series No. 1998-016, NOAA/NGDC Paleoclimatology Progam, Boulder, CO, USA. Corrected 2004.

Michael E. Mann, Ed Gille, Raymond S. Bradley, Malcolm K. Hughes, Jonathan Overpeck, Frank T. Keimig, and Wendy Gross. Global Temperature Patterns in Past Centuries: An Interactive Presentations. *Earth Interactions*, 4(4):1–29, 2000. URL http://www.ncdc.noaa.gov/paleo/ei/ei_cover.html.

Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes. Corrigendum: Global-scale temperature patterns and climate forcing over the past six centuries. *Nature*, 430: 105, 1 July 2004.

Michael E. Mann, Scott Rutherford, Eugene Wahl, and Caspar Ammann. Testing the Fidelity of Methods Used in Proxy-Based Reconstructions of Past Climate. *Journal of Climate*, 18:4097–4107, October 2005.

Michael E. Mann, Scott Rutherford, Eugene Wahl, and Caspar Ammann. Robustness of proxy-based climate field reconstruction methods. *Journal of Geophysical Research*, 112:4097–4107, October 2007. URL http://dx.doi.org/10.1029/2006JD008272.

Monty G. Marshall, Keith Jaggers, and Ted Gurr. Polity IV Project: Political Regime Characteristics and Transitions, 1800-2002, 2007.

William A. Masters and Margaret S. McMillan. Climate and Scale in Economic Growth. *Journal of Economic Growth*, 6(3):167–86, September 2001.

Brian R. Mitchell. *International Historical Statistics 1750-2005*. Palgrave Macmillan, New York, NY, USA, 6th edition, 2007. 5 volumes, covering Africa, Americas, Asia, Europe, and Oceania.

Charles de Secondat, Baron de Montesquieu. *The Spirit of the Laws*. Cambridge Texts in the History of Political Thought. Cambridge University Press, Cambridge, UK, 1989 edition, 1748. ISBN 0521369746.

Gunnar Myrdal. *Asian Drama: An Inquiry into the Poverty of Nations*. Pantheon, New York, NY, USA, 1968. 3 volumes, sponsored by the Twentieth Century Fund.

William D. Nordhaus. Geography and macroeconomics: New data and new findings. *Proceedings of the National Academy of Science*, 103(10):3510–3517, March 7 2006.

Nathan Nunn. The Importance of History for Economic Development. *Annual Review of Economics*, 1(1):65–92, September 2009.

Nathan Nunn and Diego Puga. Ruggedness: The Blessing of Bad Geography in Africa. *CEPR Discussion Paper*, (6253), April 2007.

Ola Olsson and Douglas A. Hibbs, Jr. Biogeography and Long-Run Economic Development. *European Economic Review*, 49(4):909–938, May 2005.

Louis Putterman. Agriculture, Diffusion and Development: Ripple Effects of the Neolithic Revolution. *Economica*, 75(300):729–748, November 2008.

Dani Rodrik, Arvind Subramanian, and Francesco Trebbi. Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development. *Journal of Economic Growth*, 9(2):131–165, June 2004.

Jeffrey D. Sachs. Tropical Underdevelopment. *NBER Working Paper*, (8119), February 2001.

Jeffrey D. Sachs. Institutions Don't Rule: Direct Effects of Geography on Per Capita Income. *NBER Working Paper*, (9490), February 2003.

Kenneth L. Sokoloff and Stanley L. Engerman. History Lessons: Institutions, Factors Endowments, and Paths of Development in the New World. *Journal of Economic Perspectives*, 14(3):217–232, Summer 2000.

Waldo Tobler, Uwe Deichmann, Jon Gottsegen, and Kelly Maloy. The Global Demography Project. Technical Report TR-95-6, National Center for Geographic Information and Analysis, Dept. of Geography, University of California, Santa Barbera, CA, USA, April 1995.

U.S. Census Bureau . Centers of Population Computation. Technical report, U.S. Department of Commerce, Washington, DC, USA, April 2001. URL http://www.census.gov/geo/www/cenpop/calculate2k.pdf.

U.S. Geological Survey. Global GIS Global Coverage. DVD-ROM, 2003. URL http://webgis.wr.usgs.gov/globalgis/index.html.

Hans von Storch, Eduardo Zorita, and Fidel González-Rouco. Assessment of three temperature reconstruction methods in the virtual reality of a climate simulation. *International Journal of Earth Sciences*, 98(1):67–82, February 2009. URL http://dx.doi.org/10.1007/s00531-008-0349-5/.

Eugene R. Wahl and Caspar M. Ammann. Robustness of the mann, bradley, hughes reconstruction of northern hemisphere surface temperatures: Examination of criticisms based on the nature and processing of proxy climate evidence. *Climatic Change*, 85 (1-2):33–69, November 2007.

World Meteorological Organization. Climate FAQs, 2008. URL http://www.wmo.ch/pages/prog/wcp/ccl/faqs.html. Accessed 4 February 2008.

World Bank . Country Classification, July 2009a. URL http://www.worldbank.org/data/countryclass/classgroups.htm. Accessed 5 August 2009.

World Bank . World Development Indicators, July 2009b. URL http://www.esds.ac.uk/international/. Accessed 11 October 2009.

Table 1: Summary Statistics

Variable	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

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

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

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

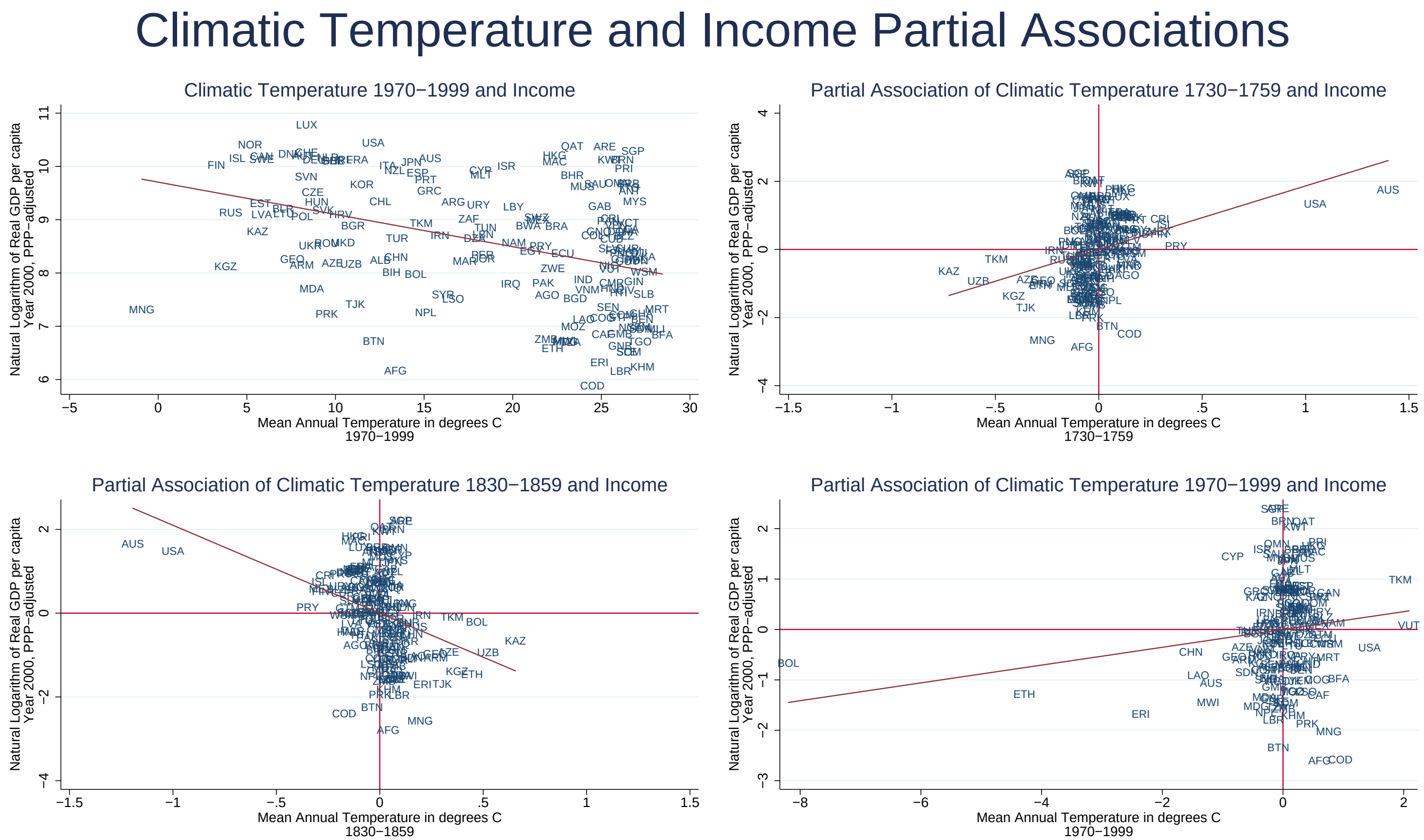
Notes: Robust standard errors appear underneath coefficient estimates in parentheses. Significance levels are indicated by * $p < 0.05$ and ** $p < 0.01$. Absolute latitude is derived from the latitude of the country population centroid in 2000. Mean frost days per year is population-weighted and comes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

Table 4: Climatic Temperature Channels

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

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:



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

Data Source	*Access Location*	*Component/Variable*
Barro and Lee (2000) International Educational Attainment Dataset	URL: http://www.cid.harvard.edu/ciddata/barrolee/appendix_data_tables_in_panel_set_format.xls. 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: http://faostat.fao.org/site/612/default.aspx. Downloaded on 28 July 2009. Version from 19 June 2009. Population (PopSTAT) URL: http://faostat.fao.org/site/452/default.aspx. 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). FAO Series Code 3010, Country agricultural population in 2000 (thousands of individuals).
Gallup, Sachs, and Mellinger (1999) Geography and Development Dataset	URL: http://www.cid.harvard.edu/ciddata/geodata.dta. 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: ftp://ftp.mnp.nl/hyde/hyde31˙final/*_pop.zip. 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: http://www.iso.org/iso/country˙codes.htm. 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: http://www.earth.columbia.edu/sitefiles/file/about/director/data/Malaria_vars_Oct2103.dta. 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: http://picasso.ngdc.noaa.gov/paleo/data/mann/mann*.dat. 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, Jaggers, and Gurr (2007) Polity IV Database	URL: http://www.systemicpeace.org/inscr/p4v2007.xls. 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: http://www.agecon.purdue.edu/staff/masters/countrydata/countrydata_frost.htm (file WillMastersDataOnFrostFrequency.xls). Downloaded on 28 July 2009.	POPWEIGH: Country average number of frost days per unit of population.

Data Source	*Access Location*	*Component/Variable*
Organization of the Petroleum Exporting Countries (OPEC) Website	URL: http://www.opec.org/library/faqs/aboutopec/q3.htm. Accessed on 5 August 2009.	Country OPEC Membership in 2000.
Penn World Table v.6.2	URL: http://pwt.econ.upenn.edu/php`site/pwt62/pwt62_form.php. 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. 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: http://webgis.wr.usgs.gov/globalgis/index.html.	Country boundaries vector file (admin02.shp), with WGS1984 datum and geographic projection. 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: http://hadobs.metoffice.com/crutem3/data/CRUTEM3.nc. Downloaded on 2 February 2008. URL: http://www.cru.uea.ac.uk/cru/data/temperature/ftpdata/absolute.nc. Downloaded on 2 February 2008.	Global 5 degree gridded monthly temperature anomalies raster-NetCDF file (degrees Celsius). Global 5 degree gridded monthly average temperature level over 1961-1990, raster-NetCDF file (degrees Celsius).
World Bank Country Classification	URL: http://www.worldbank.org/data/countryclass/classgroups.htm. Accessed on 5 August 2009.	Country income groups (high, medium, low). Country geographic regions (Sub-Saharan Africa, Latin America and the Caribbean).
World Development Indicators	URL: http://www.esds.ac.uk/International/access/dataset_overview.asp#desc_WBWDI. 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

Country Name	*ISO 3166-1 2-Letter Code*	*ISO 3166-1 3-Letter Code*	*World Bank Income Group*
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

Country Name	*ISO 3166-1 2-Letter Code*	*ISO 3166-1 3-Letter Code*	*World Bank Income Group*
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

Country Name	*ISO 3166-1 2-Letter Code*	*ISO 3166-1 3-Letter Code*	*World Bank Income Group*
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.