Climate and Scale in Economic Growth

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Abstract: This paper introduces new data on climatic conditions to empirical tests of growth theories. We find that, since 1960, temperate countries have converged towards high levels of income while tropical nations have converged towards various income levels associated with economic scale and the extent of the market. These results hold for a wide range of tests. A plausible explanation is that temperate regions' growth was assisted by their climate, perhaps historically for their transition out of agriculture into sectors whose productivity converges across countries, while tropical countries' growth is relatively more dependent on gains from specialization and trade.

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CLIMATE AND SCALE IN ECONOMIC GROWTH

I. INTRODUCTION

The puzzle we address is illustrated by Figure 1. Per-capita incomes are consistently low from the equator to about 30 degrees of latitude, and are consistently high above about 50 degrees.[1] This correlation could have been caused by several different factors. For example, Hall and Jones [1999] interpret latitude to be a measure of distance from Western Europe, which might have affected income through the spread of market institutions. In contrast Gallup, Sachs and Mellinger [1999] see latitude as correlated with other factors affecting income, notably the difficulty of transport, the prevalence of disease and the productivity of agriculture.[2]

Nonlinearity in the correlation between latitude and growth provides an important clue as to how physical location might affect growth. In Figure 1, between zero and 30 degrees, and above the 50-degree line, the distributions appear to be flat. This suggests that location effects may not be a matter of degree: there may be no such thing as *very* tropical or *very* temperate. Between 30 and 50 degrees, income does rise with average latitude, but this could be due to the mix of latitudes in each country.

In this paper we introduce a new variable to help explain the tropical/temperate divide illustrated in Figure 1. We use newly available worldwide climate data to quantify the prevalence of seasonal frosts, hypothesizing that what the tropics have in common is an absence of winter frost, “the great executioner of nature” [Kamarck 1976, p. 17]. A hard frost that kills exposed organisms in nature could have a major influence on the productivity of human investment in agriculture and health, by reducing competition from pests, pathogens and parasites. Such differences could affect not only average growth rates but also the parameters of empirical growth models, due to differences in the degree to which different growth mechanisms depend on ecological conditions. For example, ecologically-favored regions might be able to grow through the reinvestment of savings from their own unskilled labor and agricultural land even in autarky, whereas regions with less favorable ecologies might be relatively more dependent on gains from specialization and trade.

A particularly important distinction among growth mechanisms is whether they involve scale effects. Growth in a Solow [1956] model is driven by savings and investment in exogenously determined technology, and can operate at any scale. In contrast, growth driven by endogenous technical change may be driven by the size of the human capital stock or the extent of the market [e.g. Romer 1990]. Scale effects are usually considered important in explaining the persistence of growth among industrialized economies, but these countries may all be sufficiently open to the rest of the world that they use global R&D and participate in a global growth process. Once they have industrialized, the productivity of even relatively small or isolated nations such as Finland may be determined on world markets, rather than by their home-market conditions. At the same time countries whose factor endowments have grown little beyond farmland and unskilled labor may have less use for world-market technologies, if those techniques are not useful for their land and their labor. As found by Bernard and Jones [1996], productivity in manufacturing and services tends to converge across countries, while productivity in agriculture does not. Thus countries which have lagged in accumulating resources might exhibit scale effects in cross-section, simply because their agriculture is not able to support high rates of savings and investment on its own. To generate savings and motivate investment such countries would be relatively more reliant on specialization and trade, compared with countries that are either industrialized or have rapid agricultural productivity growth.

Many different biophysical factors could affect the productivity of farmland and unskilled labor, and so influence the rate of factor accumulation in agriculture and the relative importance of various growth mechanisms. Countries differ in their rainfall and water balances, temperature and its fluctuation, daylength and many other dimensions of climate, all of which vary independently and continuously, forming an infinite number of possible classifications such as those of Thornthwaite [1933], Geiger and Pohl [1954], Holdridge [1971], Walter and Breckle [1985], or Bailey [1989]. Differences in climate can be measured directly or inferred from differences in biological activity – but soils and vegetation are heavily influenced by human investment to manage soil fertility and alter the landscape, even in prehistoric times [Simmons 1987].[3]

Ground frost is a particularly useful variable because it is unambiguously exogenous, has inherently dichotomous effects (either moisture freezes, or it does not), and is a plausible influence on economic conditions. Ground frost plays a role in human health, by selectively killing exposed organisms which helps people control the transmission of disease. This in turn reduces morbidity, mortality, and uncertainty, hence promoting the accumulation of human capital [Bloom and Sachs 1998]. Frost also plays an important role in agriculture, by helping people control plant and animal diseases [Kellman and Tackaberry 1997], and also facilitating the build-up of deeper and richer topsoils by controlling the organisms which mineralize soil organic matter [van Wambeke 1992]. This environmental input to temperate-zone agriculture could help explain why Bernard and Jones [1996] find agricultural productivity growth in temperate OECD countries to be relatively high,[4] while agricultural productivity in the tropics grows slowly or even declines [Gallup and Sachs 1999, Fulginiti and Perrin 1997].

The influence of biophysical conditions might or might not be of sufficient magnitude to offset other engines of growth. Does frost frequency really matter for growth at an economywide level? And if it does, what growth mechanisms can be exploited for countries with inhospitable climates to overcome that constraint?

II. EXPERIMENTAL DESIGN

The first step in our analysis is to ask whether frost is a significant determinant of economic behavior at all. If frost does indeed make it easier for people to control pests, pathogens and parasites, then we would expect people to choose to live and grow crops in areas with more frost – but perhaps not too much frost, if excessive levels of frost make it difficult to maintain desired kinds of biological activity such as crops or livestock. We therefore use a highly disaggregated dataset to test whether population density and cultivation intensity can be explained by the frequency of winter frost, in quadratic form, controlling for other factors and country fixed effects in the following framework:

$$x_{ij} = constant + \beta_1 frost_{ij} + \beta_2 frost_{ij}^2 + \gamma(other\ factors_{ij}) + \delta_i + \varepsilon_{ij} \qquad (1)$$

where x_{ij} is either population density (persons per square kilometer) or cultivation intensity (proportion of land under cultivation) at country i and location j. If population density and cropping intensity depended only on country characteristics, only the fixed-effects terms δ_i would be significant. A positive β_1 would confirm that places with more frost attract (or support) larger populations and more cropping intensity in a consistent way around the world. A negative β_2 would confirm that too much frost has the reverse effect.

Given the evidence on population location and agriculture from equation (1), we then ask how country-to-country differences in frost frequency might matter for economywide growth. We begin with a standard Barro and Sala-i-Martin [1992] growth-accounting regression,

$$g_i = \alpha + \beta \log y_{0i} + \gamma_1 z_{1i} + \gamma_2 z_{2i} + \gamma_3 z_{3i} + \varepsilon_i \qquad (2)$$

where g_i is observed average annual income growth in country i, y_{0i} is observed initial income in that country, and the three z_i terms are vectors of hypothesized determinants of the country's future steady-state income level (or growth rate). In this study we distinguish between variables that measure the scale of the economy (in z_{1i}), those that measure its exposure to seasonal frost (in z_{2i}), and all other variables used in previous studies (in z_{3i}).

In the simplest Solow [1956] model, only α and β would be significant, indicating convergence to a common steady-state income level at an estimated average speed of $\lambda = \log(1-\beta)$. In the presence of scale effects, γ_1 might also be significant. The significance of frost is given by whether $\gamma_2 \neq 0$, controlling for other variables.

Our z_{1i} vector represents three distinct dimensions of scale, capturing three different kinds of scale effects corresponding to the domestic population size (following Backus, Kehoe and Kehoe [1992] among others), the economy's exposure to the world as a whole, in the sense of total trade as a fraction of GDP (following Ades and Glaeser [1999] and Frankel and Romer [1999]), and also linguistic heterogeneity as a measure of communication barriers among people (following Easterly and Levine [1997]).

The z_{2i} vector of frost variables takes a variety of forms. Initially we use the country-average number of frost-days per month in winter, squared and also cubed, using that third-degree polynomial to identify a threshold level of frost above which additional frost-days do not contribute to growth. This permits us to consider a somewhat different measure, which is the proportion of a country's land where frost-frequency exceeds that threshold.

The z_{3i} vector of control variables captures variables that measure the country's rate of investment (I/GDP) and human-capital formation (school enrollment), following Mankiw, Romer and Weil [1992]. The vector also includes variables for trade policy (the Sachs and Warner [1997] index) and domestic institutional quality (the Gastil index, from Hall and Jones [1999]).

Having obtained a plausible threshold for frost effects, we use that criterion to subdivide the sample and test for parameter heterogeneity across the temperate-tropical divide:

$$g_{ik} = \alpha_k + \beta_k \log y_{0i} + \gamma_{1k} z_{1i} + \gamma_{2k} z_{2i} + \gamma_{3k} z_{3i} + \varepsilon \qquad (3)$$
$$k = 1 \text{ if } z_{2i} \geq \text{ threshold level of frost frequency, 0 otherwise}$$

To look for parameter heterogeneity, we use F-tests of the null hypothesis that each individual coefficient, and also the set of all coefficients together, are the same across the two subsamples. These parameter heterogeneity tests are done in both our own model specification, and in a replication of Mankiw, Romer and Weil [1992].

Our core hypothesis of the paper is that parameters differ across the two subsamples, particularly in the sense that γ_1 may be zero for the temperate region, but nonzero for the tropical countries. This finding would be evidence for different growth mechanisms in the tropics, a result that would call for specific research and economic policies to address their distinct needs.

III. DATA

This section focuses on the original data used in our initial tests (Tables 1-4). The data used to replicate previous studies (Tables 5-6) are drawn directly from the original studies. Descriptive statistics for all variables are presented in the appendix. The raw data, along with Stata programs to generate our results, are available by email on request.

The main dependent variable we will ultimately seek to explain is income growth per capita over the 1960 to 1990 period, which we estimate directly by OLS regression from annual data on real income, drawn from the Penn World Tables version 5.6 (PWT).[5] This approach yields a GDP growth rate that gives equal weight to data observed in each year, and does not give particular importance to the initial or ending years.

Key explanatory variables include initial population size, initial income, and initial exposure to international trade, all of which we use in the form of three-year averages for the 1960-62 period, in an attempt to limit the influence of shocks occurring in specific years. Population and income are used in natural log form to be consistent with the Cobb-Douglas production structure that underlies many growth models [Jones 1999]. Exposure to trade in this context is total trade as a proportion of GDP, again from PWT 5.6, as in Ades and Glaeser [1999] and Frankel and Romer [1999]. Our objective here follows Rodríguez and Rodrik [1999] in looking for a measure of trade *exposure* rather than trade policy, to ask what proportion of the economy is in direct contact with the rest of the world as opposed to relying on the domestic population for its market size. Government policy towards external trade is captured separately, where relevant, using the Sachs and Warner [1997] index measuring the proportion of years in which policies meet five criteria.[6]

To capture heterogeneity we note that there are many crosscutting dimensions along which a given country could be subdivided [Peterson 1997]. Here we use what is perhaps the most fundamental communication barrier between people, namely the use of a common language. From Easterly and Levine [1997], we draw the probability of two randomly selected people speaking different languages. Easterly and Levine [1997] report two different datasets for this concept, with slightly different samples—to expand the sample size while weighting the two measures equally we have combined them into one measure, using whichever is available or their average if both are reported.

The climate data we use are derived from values compiled by the Climatic Research Unit of the University of East Anglia, and are distributed by them for the International Panel on Climate Change (IPCC). In recent years a huge amount of information on global climate has become available, and the combinations of different variables form a multitude of biophysical environments. Our central insight is to focus on frost, particularly seasonal ground frosts, in the sense of the number of days with below-freezing ground temperatures in a winter season that follows a frost-free summer.[7]

Figure 2 presents the data on frequency of winter frosts. It turns out that in most places winter frosts are either very rare (0-1 days per month) or very common (10-30 days/month), with a relatively narrow intermediate range. That transition line is closely but not perfectly correlated with latitude. Most of the geographic tropics is frost-free, but for a given latitude there is relatively frequent frost in Mexico, Chile and Southern Africa, and relatively little frost in South Asia and the Middle East.

To test the link between frost frequency and economic behavior we conduct some tests at a local level (in section IV below). With ArcView GIS software [ESRI 1996] we match the IPCC frost maps to data compiled by Gallup, Mellinger and Sachs [2000] covering population density [Tobler et al. 1996] and cultivation intensity [Matthews 1983], plus precipitation levels, temperature, elevation and latitude [ESRI, 1995], distance to a seacoast or navigable river [Gallup, Sachs and Mellinger 1999], and also the Köppen-Geiger climate zones used to classify ecosystems [Geiger and Pohl 1954]. The result is a database of about 12,500 cells covering almost all of the world's surface. The cells are one degree of longitude by one degree of latitude. Such cells vary in size from about 12,000 square kilometers at the equator to nearly zero at the poles, so regressions using these data are weighted by the land area in each cell.

To test for links between frost frequency and economic growth (in section V), we must aggregate the frost data up to country scale. We consider two mappings: one is the average number of frost-days within the country's borders, and the other is the proportion of the country's land that receives five or more frost-days per month. Our motivation for this particular threshold is derived from the empirical results reported below.

IV. RESULTS: SIGNIFICANCE OF FROST FREQUENCY AT THE CELL LEVEL

We begin our analysis at the level of individual cells, to ask whether frost frequency is a significant correlate of people's choice of where to live (and hence population density) or grow crops (and hence cultivation intensity). Using the framework of equation (1), we control directly for biophysical factors (precipitation levels, temperature, elevation and latitude, distance to a seacoast or navigable river, and Köppen-Geiger climate zones), and also exploit the spatial variation in these factors to control for unobserved socioeconomic and other factors that vary across countries (using country fixed effects).

Our hypothesis is that, when controlling for other factors, both population density and cultivation intensity will be *positively* correlated with frost frequency, but *negatively* correlated with frost-frequency squared: that is, people tend to choose to live and grow crops where there is some frost, but not too much. A similar logic applies to precipitation. A cell's distance to a coast or navigable river is expected to be negatively correlated with population density and cultivation intensity, as more isolated locations might be less attractive due to higher transaction costs with the rest of the world.

Table 1 presents six tests, three for population density and three for cultivation intensity. The first regression for each dependent variable (columns 1 and 4) controls only for biophysical factors unrelated to frost, namely precipitation and distance. The second regression (columns 2 and 5) adds controls for factors that are correlated with frost, namely temperature, elevation, latitude and the interaction of elevation and latitude. The third (columns 3 and 6) replaces these with the Köppen-Geiger climate zones digitized from Strahler and Strahler [1992] in Gallup, Mellinger and Sachs [2000].

In the regressions, both frost-frequency terms enter as predicted, and they survive controls for other biophysical factors with little change in coefficients or standard errors. The magnitudes of the two frost terms are such that moving from zero to one day of frost per month in winter is associated with an increase of between two and three people per square kilometer, and an increase of between one-third and one percent of land area under cultivation. The other variables also enter as predicted, as the coefficients on precipitation and precipitation squared are significantly positive and negative (there are more people and more cultivated area) in locations with more rainfall, but not too much more, and the coefficient on distance to the coast or a navigable river is strongly negative.[8] The country fixed effects also matter: an F-test clearly rejects the hypothesis that all country fixed effects are jointly zero ($p<0.0000$). From this we conclude that frost frequency does have remarkable significance for economic behavior, independently of many other factors for which data are available.

V. RESULTS: SIGNIFICANCE OF FROST FREQUENCY FOR ECONOMIC GROWTH

To test whether frost frequency plays a role in aggregate economic performance, we begin by characterizing the correlates of growth in a worldwide sample using the framework of equation (2), and then test for parameter heterogeneity across climate zones in the framework of equation (3).

Table 2 serves to characterize the worldwide dataset in terms of scale effects and convergence, and then establish useful threshold values of frost frequency when controlling for scale and initial income. The first four columns describe the scale effects we observe. Column (1) makes the perhaps obvious point that there is no unconditional correlation with population alone, but column (2) shows that conditioning on trade intensity is sufficient to reveal a partial correlation between population and growth. Column (3) reveals that language heterogeneity is independently significant in this context, and column (4) finds evidence for conditional convergence controlling only for the three dimensions of scale. In this context, however, the coefficient on log of initial income implies a convergence rate of less than one-third the rate of those found in growth accounting studies such as Mankiw, Romer and Weil [1992]. Omitted variables can account for the difference: including frost as a regressor brings the implied convergence rate (which here is $\lambda = \log[1-\beta/100]$) up to around one percent per year, similar to rates obtained using MRW approaches.

Evidence for a nonlinear threshold effect of frost is shown in column (6). With a third-degree polynomial, the significance and magnitude of the coefficients is such that, holding all else constant, growth increases sharply with frost at low levels, and then remains unaffected by higher levels of frost up to about 25 days per month. The possibility of a threshold effect of frost is consistent with a mechanism whereby frost helps growth by regulating biological competition. Once past the first few hard frosts of winter, there may be few exposed pests, pathogens or parasites left to kill.

The specific number of frost-days we might choose as a threshold is investigated further in a scatter plot (Figure 3) showing actual growth rates against the frequency of frost. A natural breakpoint in the data occurs at around five days of frost per year, with a wide range of experience up to that level, and consistently high growth rates above it. We can test the robustness of this specific threshold by replacing our three frost variables with a dummy (set to 1 for more than five frost-days) and separate variables for the number of frost-days above and below the threshold. Regression results (not shown) indicate that the dummy is significantly positive and the number of frost-days below the threshold is significantly negative, while the number of frost-days above it has no significance. Thus we retain a threshold of five frost-days per month in winter, and in subsequent models we use a new measure to capture this concept in a single continuous variable, namely the proportion of land receiving more than five frost-days per month.

Table 3 presents complete tests of equation (2) using the threshold variable, asking whether its estimated coefficient is robust to controls for additional growth accounting variables found in the literature. We note from column (1) that this new frost variable captures more of the variance in growth than the simple area-weighted measure (which is used in the same model in column (4) of the Table 2). Column (2) is a conventional growth-accounting regression without a frost-frequency variable, showing that it matches the data reasonably well using as regressors the (possibly endogenous) levels of gross investment (the log of I/GDP) and human capital formation (the log of school enrollment rates) from the augmented-Solow model of Mankiw, Romer and Weil [1992], plus the Sachs and Warner [1997] index of trade policy and the Gastil index of institutional quality from Hall and Jones [1999]. But column (3) shows that in this context frost is independently significant, and column (4) shows that the frost variable survives controls for latitude.

The regression results in Tables 2 and 3 are based on global data. These show significant scale effects in Table 2, but one or more dimensions of scale lose their significance in Table 3. Our hypothesis is that those regressions are misspecified, in that the two subsamples have different coefficients on key variables. To test this hypothesis using the framework of equation (3), we segment the data into those countries with an average of at least five days per month of frost in winter (n=35), and those with fewer than five (n=57). We will refer to these as the temperate and tropical subsamples, noting from the frost map on Figure 2 that this definition is quite different from previous usage of these terms.

Table 4 presents results of our parameter-heterogeneity tests. Columns (1) and (2) compare the simple growth model controlling only for scale and initial income, and (3) and (4) control also for the four growth-accounting variables. An F-test rejects the hypothesis of common parameter values for the population variable (p=0.004) and all variables except the constant (p=0.03) across equations (1) and (2). The same F-tests are not conclusive across equations (3) and (4). But more importantly, in both cases, the scale variables lose their significance in the temperate (with-frost) zone, but retain significance in the tropical (no-frost) zone. This remarkable mirror-image effect, whereby growth in the tropics is slower and is associated with scale effects, whereas growth in temperate zones is rapid and convergent, is consistent with the presence of some common engine of growth in the temperate countries raising their factor productivity and accumulation rates independently of scale. The effect could have been historical, accelerating their transition out of agriculture, but it contrasts sharply with the tropical countries whose growth remains dependent on mechanisms associated with scale such as specialization and gains from trade.

The finding presented in Table 4 that scale effects are significant for the tropical but not the temperate subsamples is the main result of this paper. We therefore test this result for robustness to variations in the sample. First we omit countries that are expected to be exceptional for structural reasons, specifically China and India, and Hong Kong and Singapore. (USSR. or Russia are already omitted from the sample for lack of data.). Doing so has no effect on the signs and significance levels of the coefficients. Taking a data-driven approach, we also omit observations judged to be exceptional on the DFITS and DFBETA criteria and cutoff levels recommended by Belsley, Kuh and Welsch (1980).[9]

The DFITS criterion measures the influence of each observation on the regression's predicted value of the dependent variable, scaled by that observation's residual. Omitting the small number (between 2 and 5) of such high-influence, high-residual observations changes none of the signs and significance levels reported in Table 4, except for small changes in column (4).[10]

The DFBETA criterion measures the influence of each observation on the regression coefficient for a specific independent variable, scaled by the estimated standard error of that coefficient. Here we drop observations that have high DFBETA values for *any* of the three scale-effect variables (population, trade or heterogeneity). This is a large number of observations (between 7 and 12) but dropping them has no impact on the broad conclusion that scale effects are insignificant in the temperate sample, and significant in the tropical one.[11] The conclusion is strengthened in that significance of the heterogeneity variable is reduced (from significant at the 10 percent level to no significance) in column 1, and weakened in that significance of the trade variable is reduced in columns 2 and 4 (from significant at the 1 percent level to no significance).

The core result of Table 4, which we find is robust to changing the sample, is that temperate countries are converging towards income levels that are conditional only on their policy choices (the Sachs-Warner openness index), while tropical countries's convergence is conditional on their ability to achieve economies of scale, either through a larger and more homogeneous domestic population, or through greater integration with the world economy. Investment, schooling and institutional quality variables are also more significant in the tropical sample.

To investigate further the nature of this parameter heterogeneity, we can test whether dividing the sample into tropical and temperate countries affects the main results of two frequently-cited empirical growth models: Mankiw, Romer and Weil [1992] and Hall and Jones [1999].

Table 5 presents regressions using the original dataset of Mankiw, Romer and Weil [1992], replicating their main results over all countries and then testing for parameter heterogeneity across the temperate-tropical divide. For brevity we suppress any motivation of their model and data, and use the exact same notation to make our table directly comparable with theirs. Column (1) replicates the MRW results. Column (2) controls for frost frequency, which is itself significant (shifting the constant) and also reduces the magnitude of each parameter estimate (except the constant). Columns (3) and (4) perform the split-sample test. Here an F-test for parameter heterogeneity rejects the hypothesis of common parameter values for $\ln(n+g+\delta)$, the variable which captures labor-force growth, technical change and depreciation. This result suggests that investment in human capital (captured here by SCHOOL) or physical capital (I/GDP) may be little affected by climate, but that climate acts to suppress growth rates only for other resources that are captured in $\ln(n+g+\delta)$.

Replication and extension of the main results from Hall and Jones [1999] is provided in Table 6. Their "social infrastructure" variable is the average of the two policy variables used by us in Table 3, that is the Sachs-Warner index of trade policy and the Gastil index of institutional quality. The HJ model treats these policies as the endogenous result of socio-cultural history, captured by four instruments: geographic distance from the equator, the Frankel and Romer [1996] predicted trade share derived from a gravity model, and two measures of Western language use. They run their regressions with two samples, one that includes some imputed data. We split both the complete and restricted samples into temperate and tropical climate zones, and find that the estimated coefficients are much lower in the temperate zone and much higher in the tropics—although in the tropics the standard errors and root mean squared error of the equation are also much higher. We conclude from this that the original HJ results were driven largely by the gap between temperate and tropical conditions, and that the model performs much less well in explaining differences in performance within these two zones.

VI. CONCLUSIONS

Our central finding is that temperate countries have been on growth paths that converge towards a common high level of income, while tropical countries' growth paths converge towards income levels that depend on their economic scale or the extent of their markets. In this context scale is defined over three distinct dimensions: the country's population size, population heterogeneity, and exposure to the world as a whole. Each of the three dimensions is independently significant in most of our tests.

Climate is defined in terms of the frequency of frost in winter, after a frost-free summer. A threshold of five such days was chosen to define climate zones and split the sample, in a way that is clearly exogenous and has plausible economic effects. One major channel for these effects could be that seasonal frosts kill exposed organisms, raising the productivity of investment in human capital and in agriculture by selectively reducing competition from pests, parasites and disease vectors.

For temperate zones, the benefits of seasonal frosts may have been economically important only in the past, when people were more dependent on nature for agriculture and health. Thus the income convergence that we observe in this region over our 1960-1990 data could be an indirect echo of the historical effects of climate, rather than a contemporaneous effect. It may be that their climate fostered a historical accumulation of man-made capital, whose productivity grows towards similar levels anywhere in the world.

Climate could have helped determine where industrialization would first take place, facilitating the accumulation of human capital and savings from agriculture in temperate zones, without limiting to where it could spread. Today's tropical countries, lacking the benefits of seasonal frost that support productivity growth in a way which is independent of scale, must rely on growth mechanisms involving specialization and trade. They may also be able to accelerate their productivity growth in agriculture and public health by directly addressing their climate-specific constraints, with specific institutional changes to improve control of pests, parasites and disease vectors.

The unprecedented availability of detailed global data makes it possible to take climate and other biophysical constraints explicitly into account when testing economic models and drawing policy conclusions. This paper demonstrates the potential value of this approach, showing in particular the greater importance of economic scale for low-income tropical countries than for high-income temperate regions. As with other kinds of constraints on economic activity, understanding and acting on climate differences is a crucial first step in escaping their influence.

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Notes

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[1]. The limit of the geographic tropics, where the sun passes directly overhead, is 23°45' degrees North and South of the equator.

[2]. In fact the influence of climate on society has been debated since antiquity. Early observers suggested a direct link between European climate and European culture, well before modern economic growth. In about 350 BC, Aristotle wrote "those who live in a cold climate… are full of spirit" [*The Politics* Book 7, part VII]. A particularly influential writer on this theme was Montesquieu, who wrote "People are more vigorous in cold climates" [*Spirit of Laws* (1753), Book XIV]. But contemporary anthropology finds that "humans are remarkably well adapted to tolerate heat whether derived from environmental or from metabolic sources. This adaptation apparently developed early in hominid evolution and permitted successful colonization of savanna and other hot environments… with high levels of physical activity" (Hanna and Brown 1983, pp. 279-280). The key physiological adaptations (specialized sweat glands and variable blood flow) are closely linked to human culture (controlling supplies of drinking water as well as work rhythms, clothing and housing), and involve a high degree of plasticity and acclimatization over time. Thus we may well experience heatstroke and fatigue seasonally or when travelling, but this effect is temporary and cannot reliably explain cross-country differences in economic growth. We must turn instead to indirect influences on incentives to explain the correlations we observe.

[3]. Among the most vast literature on interactions between climate, soils and agriculture, some particularly relevant sources not cited elsewhere are Weischet and Caviedes [1993] on the tropics in general, and Voortman, Sonneveld and Keyzer [2000] on Africa in particular. Scoones *et al.* [1996] is a remarkably insightful, detailed study of how farmers adapt to harsh conditions.

[4]. Over the 1970-87 period, for 14 OECD economies, average annual TFP growth was found to be 0.03 in agriculture, 0.02 in manufacturing, and 0.012 in total industry [Bernard and Jones 1996, Table 1].

[5]. The specific income variable we use is real GDP per capita at PPP-adjusted prices, chain indexed (RGDPC). The growth rate reported is 100 times the antilog minus one of the coefficient on time estimated in a regression of the log of GDP on the year with a constant.

[6]. The Sachs-Warner criteria is empirically relevant in this context in part because it takes account of policies' duration as well as magnitude, and of substitutability between policy instruments. In the SW index, a country is open to trade in any one year if nontariff barriers apply to less than 40% of trade, average tariffs are less than 40%, the black market foreign exchange premium was less than 20%, the country is not classified as socialist and major exports are not subject to monopoly trading.

[7]. In the IPCC dataset, frost-days are defined as those where the estimated temperature of ground-level grasses falls below 0 degrees centigrade. The data used here are the average number of such days per month in winter, defined as December through February in the Northern hemisphere and June through August in the Southern

hemisphere, for locations with negligible frost in the summer (June-August in the North, December-February in the South). Values are averages for 1961 through 1990, computed over 0.5-degree cells for all land mass except Antartica. Values for each cell are interpolated from station observations. For stations not reporting frost observations, values are estimated from observed temperature level, temperature variation, and precipitation. Details on the data are at http://ipcc-ddc.cru.uea.ac.uk.

[8]. Interestingly, isolation has a somewhat greater effect on population density than on cultivation intensity: moving 100 km away from the coast or navigable river is associated with a decrease of 1 person per square kilometer (an elasticity of 34.6 percent at the variable means), and a decrease of about 0.2 percent of land under cultivation (an elasticity of 25.0 percent). This is consistent with an "agricultural hinterlands" effect in which more remote areas attract less nonfarm investment, and so have a comparative advantage in agriculture (more cultivated land per person).

[9]. The Belsley, Kuh and Welsch (1980) recommendation is to examine observations for which abs(DFITS) exceeds 2*sqrt(k/n), and observations for which abs (DFBETA) exceeds 2/sqrt(n), where k is the number of regressors and n the number of observations.

[10]. By the DFITS criterion countries with frost that are dropped from the sample are Botswana, Japan, Malta and Myanmar (in column 1) and the same plus Chile (column 3). Countries without frost that are dropped are Cyprus and Venezuela (column 2) and Rwanda, Chad, Trinidad and Tobago, and Zambia (column 4). Dropping these observations has no effect on sign and significance except for the regression in column (4) where there is a stronger significance of trade (from ** to ***) and a lower significance of heterogeneity (from * to none).

[11]. By the DFBETA criterion countries with frost that are dropped from the sample are Argentina, Botswana, Chile, Japan, Malta, Myanmar, Netherlands, Nepal, Romania, and South Africa (in column 1), and Botswana, Chile, Japan, Malta, Myanmar, Netherlands, and Tunisia (in column 3). Countries without frost that are dropped are Cyprus, Hong Kong, Indonesia, India, Madagascar, Mozambique and Singapore (in column 2) and Hong Kong, Indonesia, India, Israel, Madagascar, Nigeria, Nicaragua, Paraguay, Rwanda, Singapore, Trinidad & Tobago and Zambia (in column 4). The wide variety of countries on these lists is further evidence that no one category of nations is driving our results.

Table 1. Cell-Level Determinants of Population Density and Cultivation Intensity

Dependent variables:	*population density* (pers. per sq. km.)			*cultivation intensity* (% of land area cultivated)		
	(1)	(2)	(3)	(4)	(5)	(6)
Frost days/mo. in winter	2.308***	3.319***	2.996***	0.520***	1.378***	0.396**
	(0.767)	(0.825)	(0.808)	(0.198)	(0.202)	(0.199)
Frost-days squared	-0.239***	-0.253***	-0.266***	-0.034***	-0.028***	-0.028***
	(0.023)	(0.023)	(0.025)	(0.006)	(0.006)	(0.006)
Precipitation (mm)	0.874***	0.806***	0.582***	0.262***	0.204***	0.115***
	(0.097)	(0.099)	(0.100)	(0.025)	(0.024)	(0.023)
Precipitation squared	-0.003***	-0.003***	-0.002***	-0.001***	-0.001***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Dist. to coast/river (km)	-0.012***	-0.014***	-0.013***	-0.003***	-0.002***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Temperature avg ann (C)		-1.272***			0.058	
		(0.177)			(0.063)	
Elevation in meters		-0.010*			-0.001	
		(0.005)			(0.001)	
Absolute Latitude		0.562***			-0.378***	
		(0.170)			(0.055)	
Abs.Lat. x Elevation		0.000***			0.000***	
		(0.000)			(0.000)	
K-G Subzones			X			X
Country effects	X	X	X	X	X	X
Observations	12442	12440	12302	12408	12406	12290
Adj. R-squared	0.42	0.44	0.44	0.27	0.31	0.30

Notes: Huber-White standard errors in parentheses. Significance levels are 99% (***), 95% (**), and 90 (*). Data sources are detailed in the text. All observations are weighted by land area in each cell, and all specifications control for country fixed effects. Columns (3) and (6) also include dummy variables for the 12 Koppen-Geiger subzones. F-tests find country fixed effects to be jointly significantly different from zero at p<0.000.

Table 2. Scale, Convergence and Frost Frequency Threshold Effects

Dependent variable: Average annual growth in real GDP, 1960-90

	(1)	(2)	(3)	(4)	(5)	(6)
ln(Pop)1960-62	0.096	0.337***	0.389**	0.418***	0.367**	0.370**
	(0.094)	(0.117)	(0.150)	(0.147)	(0.144)	(0.142)
X+M/GDP 1960-62		0.020***	0.022***	0.024***	0.025***	0.026***
		(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Language heterogeneity			-0.026***	-0.033***	-0.030***	-0.029***
			(0.006)	(0.007)	(0.007)	(0.007)
ln(GDP)1960-62				-0.395*	-0.787***	-0.826***
				(0.206)	(0.183)	(0.179)
Area-weighted frostdays					0.087***	0.390**
					(0.020)	(0.160)
Frost-days squared						-0.027*
						(0.014)
Frost-days cubed						0.001*
						(0.000)
Constant	1.895***	0.434	1.137**	4.140**	6.308***	6.210***
	(0.249)	(0.426)	(0.556)	(1.823)	(1.504)	(1.435)
Observations	125	125	92	92	89	89
Adjusted R-squared	0.00	0.11	0.26	0.27	0.37	0.38
Root MSE	1.9459	1.8359	1.7435	1.5877	1.5716	1.5128

Notes: Huber-White standard errors in parentheses. Significance levels are 99% (***), 95% (**), and 90 (*). Data sources are detailed in the text. Units are percentage points (for the dependent variable), log of millions of persons (initial population), and percentage points (for initial trade as a proportion of GDP). The language heterogeneity measure is the probability that two people will speak different languages. Robustness tests are detailed in the text.

Table 3. Robustness of Frost Effects Controlling for Investment and Policy

Dependent variable: Average annual growth in real GDP, 1960-90

	(1)	(2)	(3)	(4)
ln(Pop)1960-62	0.243	0.094	-0.015	-0.019
	(0.166)	(0.097)	(0.118)	(0.119)
X+M/GDP 1960-62	0.010	0.008**	-0.011	-0.011
	(0.008)	(0.003)	(0.007)	(0.007)
Language heterogeneity	-0.021***	-0.014**	-0.009	-0.009
	(0.007)	(2.11)	(1.35)	(1.35)
ln(GDP)1960-62	-0.812***	-1.987***	-2.070***	-2.048***
	(0.177)	(0.237)	(0.226)	(0.235)
Frostdays>5 (% of land)	2.483***		0.884**	1.052*
	(0.462)		(2.28)	(1.77)
ln(I/GDP)		1.272**	1.266***	1.259***
		(0.531)	(0.450)	(0.451)
ln(SCHOOL)		0.862***	0.944***	0.937***
		(0.281)	(0.279)	(0.286)
Openness (Sachs-Warner)		1.772***	1.502***	1.504***
		(0.478)	(0.466)	(0.472)
Instit. qual. (GADP)		3.790***	3.358**	3.436**
		(1.227)	(1.324)	(1.352)
Absol. latitude (ave.)				-0.006
				(0.016)
Constant	6.650***	18.605***	20.308***	20.129***
	(1.473)	(1.994)	(2.068)	(2.194)
Observations	82	83	76	76
Adjusted R-squared	0.37	0.69	0.68	0.68
Root MSE	1.5128	1.1058	1.0194	1.0264

Notes: Huber-White standard errors in parentheses. Significance levels are 99% (***), 95% (**), and 90 (*). Data sources are detailed in the text. “Investment” and “schooling” variables are *ln(I/GDP)* and *ln(SCHOOL)* from Mankiw, Romer and Weil (1992), and “Sachs-Warner” and “Institutional Quality” are the indexes of external and domestic policy respectively from Sachs and Warner (1997) and used in Hall and Jones (1999). Results are robust to outliers and influential observations. Using Belsley, Kuh and Welsch (1980, p. 28) criteria, countries that are exceptional by the DFITS measure are Botswana, Chad, Madagascar, Nicaragua, Rwanda and Zambia, and countries that influence the frost-days coefficient by the DFBETA measure are Brazil, Chile, Nicaragua and Syria. But these countries' influence oppose each other, and dropping either set of observations has little influence on the coefficients or their significance levels.

Table 4. Parameter Heterogeneity Across Climate Zones

Dependent variable: Average annual growth in real GDP, 1960-90

	(1) Temperate	(2) Tropical	(3) Temperate	(4) Tropical
ln(Pop)1960-62	-0.047	0.722***	-0.057	0.293*
	(0.208)	(0.185)	(0.157)	(0.173)
X+M/GDP 1960-62	0.018	0.025***	0.006	0.009**
	(0.014)	(0.003)	(0.011)	(0.004)
Language heterogeneity	-0.020*	-0.027***	-0.004	-0.014*
	(0.011)	(0.008)	(0.009)	(0.008)
ln(GDP)1960-62	-0.766***	-0.183	-1.832***	-1.489***
	(0.240)	(0.368)	(0.399)	(0.359)
ln(I/GDP)			1.386	1.134*
			(0.885)	(0.635)
ln(SCHOOL)			0.790	0.609*
			(0.475)	(0.358)
Openness (Sachs-Warner)			1.967***	2.018***
			(0.498)	(0.615)
Instit. qual. (GADP)			1.629	3.549*
			(2.059)	(1.890)
Constant	8.823***	1.326	19.286***	13.541***
	(1.886)	(2.752)	(3.614)	(2.867)
Observations	35	57	30	53
Adjusted R-squared	0.29	0.34	0.60	0.65
Root MSE	1.0264	1.7129	.86185	1.2151

Notes: Huber-White standard errors in parentheses. Significance levels are 99% (***), 95% (**), and 90 (*). Data sources are detailed in the text. "Temperate" subsample has more than half of the country's land received five or more frost-days in winter; "tropical" subsample is the remainder. F-tests reject the hypothesis that coefficients are equal in columns (1) and (2) on the variables for population (p=0.004) and for all variables together (p=0.03). Robustness tests for variation in the sample using DFITS and DFBETA criteria are reported in the text.

Table 5. Replication of MRW Augmented-Solow Model with Frost Effects

Dependent variable: log of real GDP per working-age person in 1985

	(1)	(2)	(3) Temperate	(4) Tropical
Unrestricted regression				
Constant	6.84***	8.11***	7.62***	10.15***
	(1.18)	(1.17)	(1.81)	(1.80)
ln(I/GDP)	0.70***	0.55***	0.89***	0.54***
	(0.13)	(0.12)	(0.25)	(0.15)
ln($n+g+\delta$)	-1.75***	-0.94**	-1.61***	-0.24
	(0.42)	(0.45)	(0.57)	(0.70)
ln(SCHOOL)	0.65***	0.55***	0.63***	0.59***
	(0.07)	(0.07)	(0.19)	(0.08)
Frostdays>5 (% of land)		0.66***		
		(0.17)		
N	98	91	32	66
AdjRSqrd	0.78	0.83	0.74	0.66
Root MSE	0.51	0.45	0.40	0.52
Restricted regression				
Constant	7.85***	7.72***	7.83***	7.85***
	(0.14)	(0.13)	(0.27)	(0.16)
ln(I/GDP)-ln($n+g+\delta$)	0.74***	0.54***	0.91***	0.51***
	(0.12)	(0.12)	(0.22)	(0.15)
ln(SCHOOL)-ln($n+g+\delta$)	0.66***	0.55***	0.64***	0.61***
	(0.07)	(0.07)	(0.18)	(0.08)
Frostdays>5 (% of land)		0.64***		
		(0.13)		
N	98	91	32	66
AdjRSqrd	0.78	0.83	0.75	0.66
Root MSE	0.51	0.44	0.39	0.52
Test of restric. (p > F)	0.39	0.74	0.90	0.21

Notes: Huber-White standard errors in parentheses. Significance levels are 99% (***), 95% (**), and 90 (*). Data sources are detailed in the text. All variables and tests are as in Mankiw, Romer and Weil (1992) Table 2, using our frost variables as a regressor (column 2) and to split the sample. Across the split-sample regressions, an F-test rejects the hypothesis of equal coefficients for the ln($n+g+\delta$) variable (p=0.017), and for all variables together (p=0.0078).

Table 6. Replication of Hall & Jones with Frost Effects

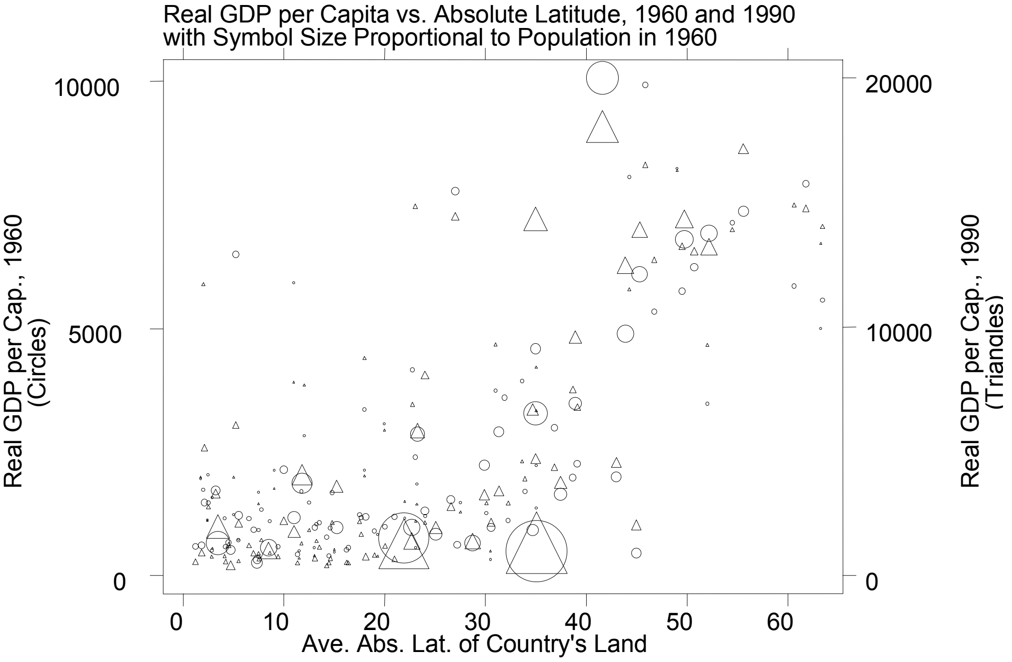
Dependent variable: log of real output per worker, in 1988

Estimating equation: log Y/L = a + bS + e

	Replication of Hall & Jones		**Temperate (>=5 frost-days/yr)**		**Tropical (<5 frost-days/yr)**	
	coef. on soc.infr.	rmse of equation	coef. on soc.infr.	rmse of equation	coef. on soc.infr.	rmse of equation
Main specification	5.142	0.840	3.574	0.620	7.997	1.22
	(0.469)	*n=127*	(0.557)	*n=45*	(1.821)	*n=82*
No imputed data	5.323	0.889	3.598	0.577	11.539	2.03
	(0.683)	*n=79*	(0.635)	*n=35*	(8.245)	*n=44*

Notes: Standard errors in parentheses, no. of obs. in italics. The “replication” columns follow Hall and Jones (1999). *S* is “social infrastructure”, defined as the average of the Sachs-Warner trade policy index and the GADP domestic policy index, estimated by 2SLS using as instruments for S the distance from equator, Frankel-Romer trade shares, fraction of population speaking English and fraction speaking a major European language. The “Tropical” and “Temperate” columns subdivide the sample.

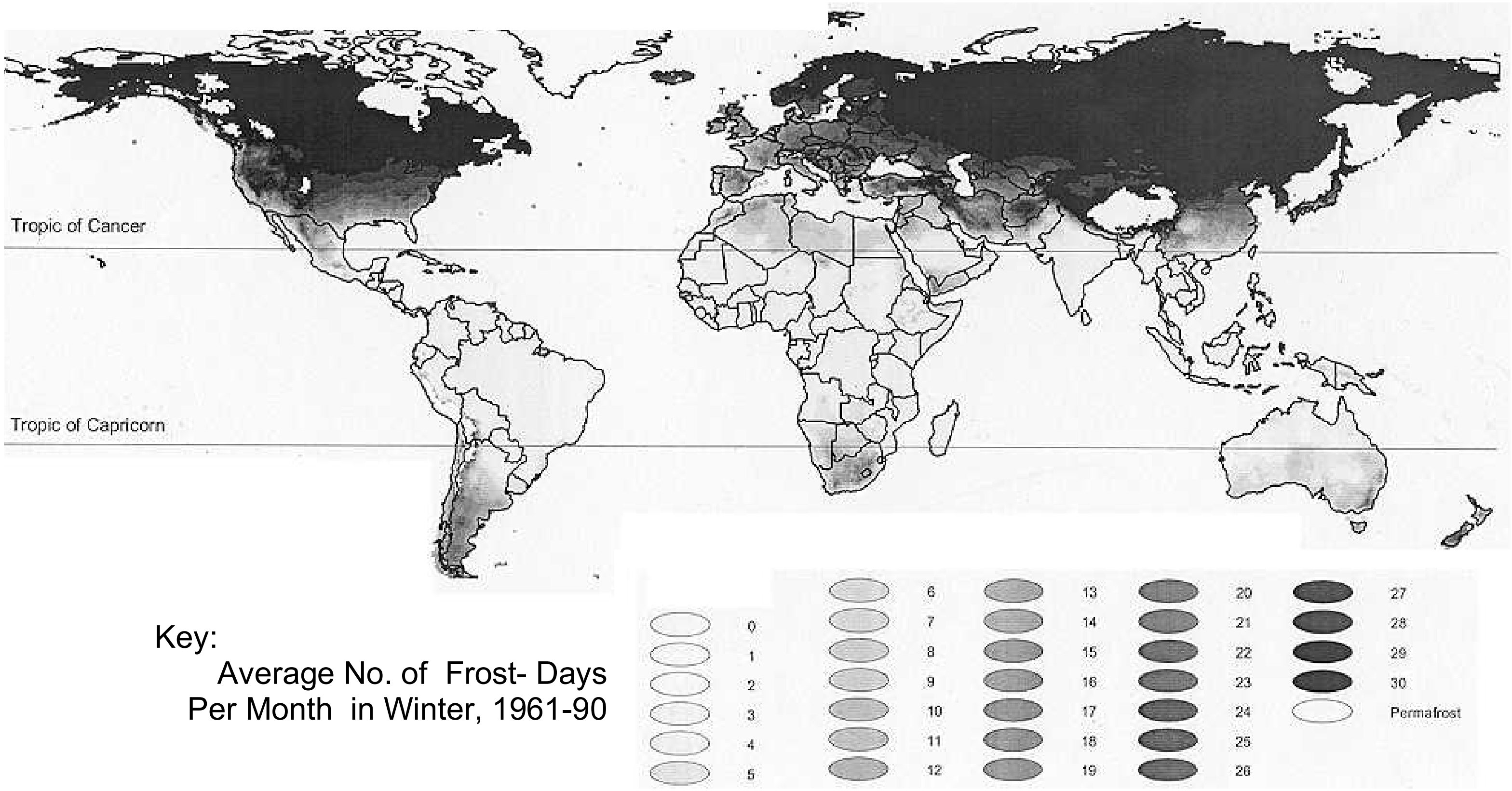
Figure 1.



Notes: Symbol sizes are proportional to initial income (in 1960), and latitude is fixed, so same-sized observations at a given latitude represent the same country's income level in 1960 (using a circle, and values on the left-hand axis) and in 1990 (using a triangle, and values on the right-hand side. Income levels are from Penn World Tables 5.6 (series RGDPC). Average latitudes are weighted by land area, from Tobler (1995) in ESRI (1996). High-income outliers (above $5000 in 1960 or $10000 in 1990) at 0-10 degrees of latitude are Venezuela and Trinidad & Tobago (1960 incomes only), and Singapore (1990 income only), and at 20-30 degrees they are Hong Kong (1990 income only) and Australia. Low-income outliers (below $5000 in 1960 or $10000 in 1990) are Yugoslavia and Romania (both 1960 and 1990) at 40-50 degrees, Ireland above 50 and Iceland above 60.

Figure 2.

Prevalence of Seasonal Frost



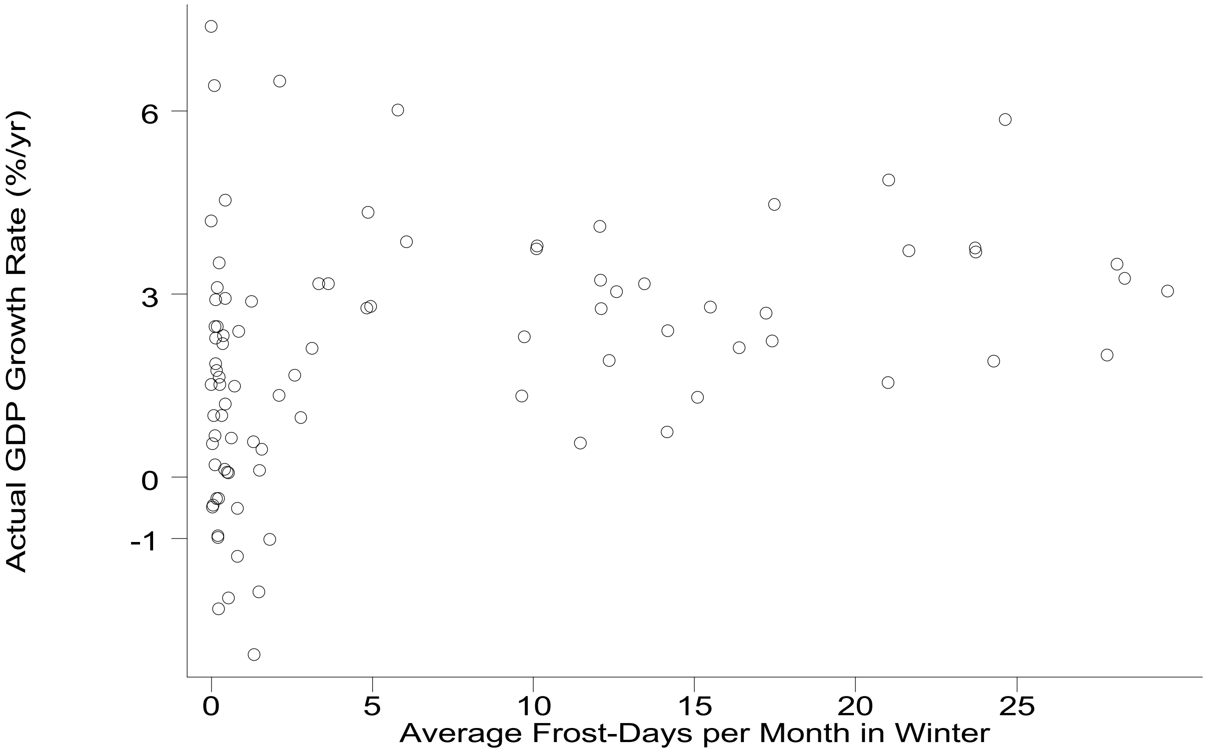
Key:
Average No. of Frost- Days
Per Month in Winter, 1961-90

Source: Mapped from data in IPCC (1999) data, in *International Panel on Climate Change, Data Distribution Centre CD-ROM*. (Norwich, UK: Climatic Research Unit, Univ. of East Anglia).

Note: for higher resolution use FrostMap.pdf (9.5 MB)

Figure 3.

Threshold effect of frost frequency



Annex Table 1. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
growth	125	2.04752	1.944998	-2.91	7.38
ln(pop)	125	1.587544	1.714966	-3.218876	6.498869
X+M/GDP	125	53.392	38.67876	5	309
lang.het.	92	35.3913	26.68249	0	84
ln(GDP)	125	7.343993	.8918287	5.56452	9.216919
ln(I/GDP)	121	-1.815126	.4954514	-3.194183	-.9969586
ln(SCHOOL)	118	-3.203601	.9107757	-5.521461	-2.111965
S-W Index	130	.3357231	.342799	0	1
GADP Index	133	.5968496	.2007285	.197	1
Frost-Days	180	8.19167	10.15892	0	29.79718
Frost>5(%)	152	.4815918	.4614823	0	1

Annex Table 2. Correlation matrix (obs=76)

	growth	ln(pop)	X+M/GDP	lang.het.	ln(GDP)	ln(I/GDP)	ln(SCH.)	S-W In.	GADPInd	Frost-Days
growth	1.0000									
ln(pop)	0.1651	1.0000								
X+M/GDP	0.0323	-0.5492	1.0000							
lang.het.	-0.3644	-0.0192	0.0344	1.0000						
ln(GDP)	0.1949	0.1553	0.0994	-0.5518	1.0000					
ln(I/GDP)	0.5651	0.0615	0.2487	-0.4392	0.6221	1.0000				
ln(SCHOOL)	0.5340	0.2274	0.1599	-0.5249	0.6975	0.6425	1.0000			
S-W Index	0.5164	0.1405	0.0807	-0.4870	0.6843	0.5346	0.6494	1.0000		
GADP Indx	0.4624	0.1610	0.1599	-0.4310	0.8020	0.6944	0.5834	0.7126	1.0000	
Frost-Day	0.4343	0.1286	0.1149	-0.4212	0.6898	0.5848	0.5295	0.6654	0.7989	1.00
Frst>5(%)	0.5183	0.1611	0.1030	-0.4750	0.6579	0.5859	0.5686	0.6295	0.7696	0.90

Annex Table 3. Country Codes, Names and Data Used in Estimation

WB code	Country Name (& alt.code)	Growth 1960-1990	Pop. 1960-1962	GDP 1960-1962	X+M/GDP 1960-1962	Lang. Het.	Area > 5 Frost-Days /Mo. in Winter	Ave. No. of Frost-Days	Hall& Jones Lat.	Ave. Lat.
AGO	Angola	-1.89	4.92	964	37	76	0.000	1.48	-8.8	13.1
ARG	Argentina	0.55	20.94	4589	17	27	0.622	11.46	-36.7	35.0
AUS	Australia	2.11	10.50	7778	31	1	0.190	3.13	-32.2	27.0
AUT	Austria	3.02	7.09	5337	47	.	1.000	24.55	48.2	46.7
BDI	Burundi	0.43	2.97	589	24	.	0.000	0.35	-3.4	4.2
BEL	Belgium	2.78	9.17	5753	80	46	1.000	15.50	50.8	49.5
BEN	Benin	-0.50	2.10	1098	20	66	0.000	0.03	6.4	8.6
BFA	Burkina Faso	1.01	4.48	432	14	52	0.000	0.08	12.0	11.4
BGD	Bangladesh	0.76	53.50	963	25	.	0.075	0.02	23.9	22.7
BOL	Bolivia	1.34	3.51	1172	51	60	0.104	2.11	-15.2	17.7
BRA	Brazil	3.51	74.82	1860	12	9	0.000	0.26	-19.6	11.8
BRB	Barbados	3.52	0.23	2828	107	.	.	.	13.2	12.0
BUR	Burma/Myanmar (=MMR)	1.86	22.26	334	42	39	.	.	17.7	.
BWA	Botswana	6.01	0.49	559	56	50	0.302	5.79	-21.5	23.1
CAF	Central African Rep	-0.55	1.63	706	64	.	0.000	0.79	4.3	5.5
CAN	Canada	3.05	18.26	7375	37	33	0.881	29.68	43.7	55.6
CHE	Switzerland	1.55	5.46	9936	60	33	1.000	21.01	47.4	45.8
CHL	Chile	0.74	7.88	2988	28	6	0.768	14.16	-33.6	36.9
CHN	China	3.69	664.39	496	8	40	0.840	23.73	29.6	35.1
CIV	Ivory Coast	0.67	3.96	1152	66	76	0.000	0.12	5.5	6.5
CMR	Cameroon	3.10	5.43	666	50	70	0.000	0.18	10.7	4.5
COG	Congo	3.28	0.97	1125	104	.	0.000	0.15	-3.7	2.4
COL	Colombia	2.46	16.28	1729	27	13	0.000	0.18	4.8	3.2
COM	Comoros	-0.18	0.20	551	53	.	.	1.20	-11.7	.
CPV	Cape Verde	3.40	0.20	469	135	.	.	1.05	15.1	15.0
CRI	Costa Rica	1.63	1.30	2128	48	14	0.000	0.25	9.9	9.0
CSK	Czechoslovakia (=CZE)	3.53	13.75	1691	28	36	.	.	49.2	.
CYP	Cyprus	4.34	0.58	2223	78	25	.	4.88	35.1	35.0
DEU	Germany	2.51	56.15	6803	34	.	1.000	19.60	48.2	49.7
DNK	Denmark	2.23	4.61	7138	63	6	1.000	17.42	55.7	54.5
DOM	Dominican Republic	2.38	3.42	1231	40	0	.	0.86	18.6	.
DZA	Algeria	2.79	11.02	1532	65	37	0.558	4.96	36.7	26.6
ECU	Ecuador	2.88	4.70	1460	34	20	0.050	1.25	-2.1	2.5
EGY	Egypt	3.17	26.55	829	40	2	0.356	3.64	30.0	25.1
ESP	Spain	3.03	30.76	3479	19	26	1.000	12.59	37.4	38.9
ETH	Ethiopia	0.58	23.09	261	21	69	0.047	1.32	9.0	7.3
FIN	Finland	3.26	4.46	5569	44	20	1.000	28.35	60.2	63.5
FJI	Fiji	2.18	0.41	2133	64	.	.	0.10	-17.8	18.0
FRA	France	2.76	46.28	6104	26	9	1.000	12.11	48.9	45.3
GAB	Gabon	2.31	0.46	1960	78	.	0.000	0.05	0.4	1.7
GBR	United Kingdom	2.12	52.97	6924	42	2	1.000	16.40	51.5	52.2
GHA	Ghana	-0.46	7.01	921	49	58	0.000	0.06	6.7	7.0
GIN	Guinea	1.49	3.91	583	32	72	0.000	0.74	11.7	9.4
GMB	Gambia, The	1.18	0.38	567	68	.	.	0.05	13.3	13.0
GNB	Guinea-Bissau	0.38	0.54	497	36	.	.	0.03	12.3	.
GRC	Greece	3.79	8.39	2249	26	11	1.000	10.12	38.1	39.1

Annex Table 3. Country Codes, Names and Data Used in Estimation

WB code	Country Name (& alt.code)	Growth 1960-1990	Pop. 1960-1962	GDP 1960-1962	X+M/GDP 1960-1962	Lang. Het.	Area > 5 Frost-Days /Mo. in Winter	Ave. No. of Frost-Days	Hall& Jones Lat.	Ave. Lat.
GTM	Guatemala	1.00	4.01	1680	28	60	0.000	0.34	14.6	14.8
GUY	Guyana	-0.74	0.55	1575	103	.	0.000	0.07	5.8	2.9
HKG	Hong Kong	6.41	3.17	2388	180	8	.	0.10	22.7	23.0
HND	Honduras	1.19	2.00	1039	45	5	0.000	0.45	14.2	13.3
HTI	Haiti	0.07	3.92	904	39	20	0.000	0.55	18.9	19.0
IDN	Indonesia	4.54	96.52	652	19	64	0.000	0.44	-6.6	3.5
IND	India	1.67	444.37	759	12	70	0.178	2.60	25.3	21.9
IRL	Ireland	3.17	2.83	3468	71	32	1.000	13.45	54.6	52.0
IRN	Iran	0.36	21.01	2907	35	.	0.964	16.41	35.4	31.3
IRQ	Iraq	0.13	7.06	3594	65	.	0.785	6.86	33.3	31.9
ISL	Iceland	3.75	0.18	4995	90	35	1.000	23.71	63.9	63.3
ISR	Israel	3.17	2.20	3744	44	38	0.504	3.36	32.1	31.0
ITA	Italy	3.22	50.52	4897	26	5	0.782	12.09	45.4	43.8
JOR	Jordan	4.11	1.75	1259	57	5	1.000	12.07	31.6	30.1
JPN	Japan	4.87	94.96	3286	20	1	1.000	21.04	35.7	35.0
KEN	Kenya	1.51	8.34	604	58	75	0.000	0.27	-0.5	1.8
KOR	South Korea	7.05	25.42	917	19	.	1.000	25.47	37.6	34.7
LBR	Liberia	0.12	1.08	730	80	69	0.000	0.42	6.4	5.5
LKA	Sri Lanka	2.27	10.14	1222	89	34	0.000	0.15	6.9	5.5
LSO	Lesotho	4.47	0.89	328	68	29	1.000	17.47	-29.6	30.5
LUX	Luxembourg	2.38	0.32	8239	162	.	.	18.30	49.8	49.0
MAR	Morocco	2.77	12.22	973	43	36	0.592	4.83	33.6	30.6
MDG	Madagascar	-1.99	5.46	1185	36	13	0.000	0.53	-19.0	21.0
MEX	Mexico	2.57	39.48	2866	19	.	0.618	5.98	16.8	23.3
MLI	Mali	0.64	4.28	518	24	79	0.000	0.62	12.5	16.2
MLT	Malta	6.14	0.33	1361	122	33	.	.	35.9	35.0
MOZ	Mozambique	-2.16	7.72	1178	49	74	0.000	0.23	-18.5	18.1
MRT	Mauritania	0.08	1.00	817	70	25	0.000	0.50	17.9	19.3
MUS	Mauritius	2.22	0.68	3067	71	.	.	0.00	-20.2	20.0
MWI	Malawi	1.01	3.61	393	59	.	0.000	0.55	-15.8	14.5
MYS	Malaysia	4.56	8.45	1479	86	.	0.000	0.04	3.3	2.1
NAM	Namibia	1.34	0.79	1852	75	.	0.419	4.69	-18.0	23.2
NER	Niger	-0.52	3.32	566	22	72	0.030	0.81	13.9	16.4
NGA	Nigeria	2.90	52.93	557	20	81	0.000	0.14	6.5	8.5
NIC	Nicaragua	-0.96	1.63	1705	49	6	0.000	0.20	12.2	11.8
NLD	Netherlands	2.39	11.64	6235	88	2	1.000	14.18	51.9	50.7
NOR	Norway	3.49	3.61	5847	85	10	1.000	28.12	60.0	60.6
NPL	Nepal	1.91	9.59	620	16	30	0.846	12.35	27.7	27.2
NZL	New Zealand	1.30	2.43	8060	47	4	1.000	15.09	-36.9	44.3
PAK	Pakistan	2.29	47.19	656	28	53	0.635	9.72	31.2	28.7
PAN	Panama	2.32	1.18	1682	71	8	0.000	0.38	9.2	7.5
PER	Peru	0.45	10.24	2143	41	50	0.093	1.56	-11.8	10.0
PHL	Philippines	1.51	28.76	1168	28	70	0.000	0.01	13.9	11.0
PNG	Papua New Guinea	0.11	1.98	1327	44	84	0.066	1.50	-6.6	7.8
PRI	Puerto Rico	2.92	2.43	3356	104	8	.	0.43	18.2	18.0
PRT	Portugal	4.19	8.97	1980	42	.	0.906	4.65	38.8	38.7
PRY	Paraguay	2.46	1.87	1207	31	44	0.000	0.13	-25.6	24.0

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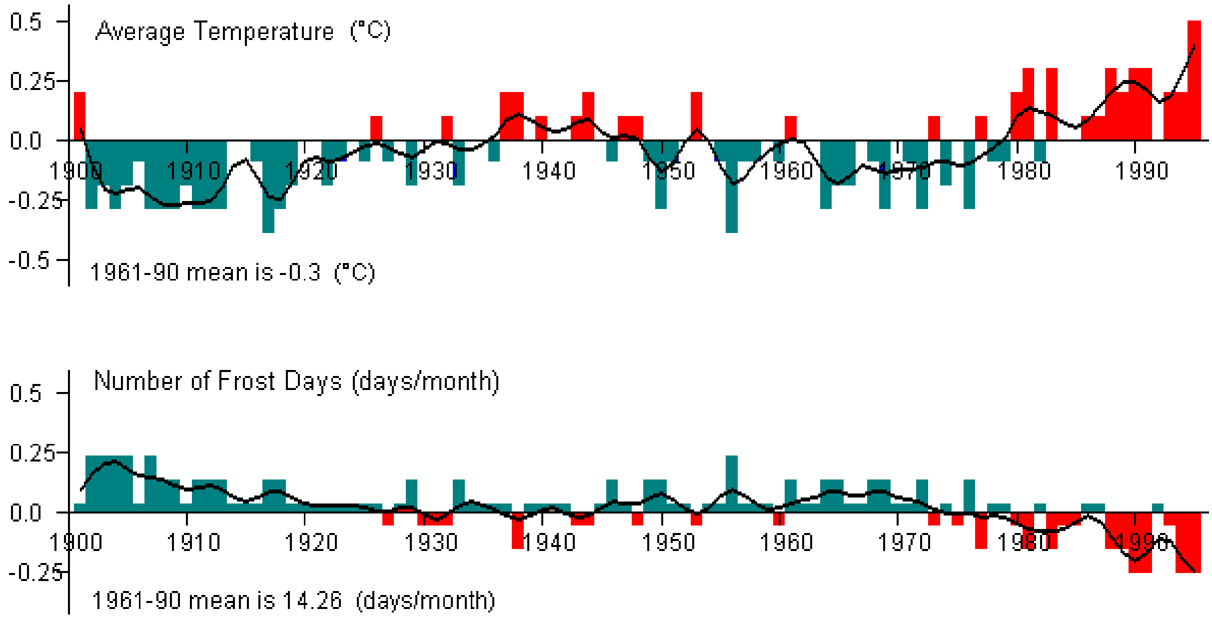
WB code	Country Name (& alt.code)	Growth 1960-1990	Pop. 1960-1962	GDP 1960-1962	X+M/GDP 1960-1962	Lang. Het.	Area > 5 Frost-Days /Mo. in Winter	Ave. No. of Frost-Days	Hall& Jones Lat.	Ave. Lat.
REU	Reunion	3.68	0.35	1162	71	.	.	0.90	-21.0	22.0
ROM	Romania	5.86	18.54	455	25	11	1.000	24.65	44.5	44.9
RWA	Rwanda	2.18	2.84	503	24	10	0.000	0.36	-2.0	2.8
SAU	Saudi Arabia	2.18	4.21	4158	71	.	0.221	2.87	23.1	22.8
SEN	Senegal	0.20	3.58	1074	60	77	0.000	0.14	14.8	13.5
SGP	Singapore	7.38	1.70	1733	309	42	.	0.00	1.4	2.0
SLE	Sierra Leone	-0.35	2.36	923	88	76	0.000	0.23	8.7	7.5
SLV	El Salvador	0.54	2.66	1471	45	4	0.000	0.04	13.8	12.5
SOM	Somalia	-1.30	2.63	1156	30	16	0.027	0.81	10.6	4.1
SUN	USSR	4.16	217.92	2532	5	.	.	.	55.7	.
SUR	Suriname	1.47	0.30	2042	101	.	0.000	0.09	5.6	2.5
SWE	Sweden	2.00	7.52	7927	44	6	1.000	27.81	59.3	61.7
SWZ	Swaziland	1.87	0.32	1473	84	.	0.000	1.88	-26.5	27.5
SYC	Seychelles	4.17	0.04	1233	46	.	.	0.00	-4.7	5.0
SYR	Syria	3.74	4.71	1705	48	9	1.000	10.10	33.5	33.9
TCD	Chad	-2.91	3.12	772	35	55	0.083	1.34	10.4	14.2
TGO	Togo	1.85	1.56	368	67	63	0.000	0.14	6.2	7.5
THA	Thailand	4.19	27.22	966	37	29	0.000	0.01	13.8	15.2
TTO	Trinidad & Tobago	1.74	0.81	5915	121	22	.	0.17	10.4	11.0
TUN	Tunisia	3.85	4.30	1116	50	10	0.611	6.06	36.8	32.2
TUR	Turkey	2.68	28.21	1641	16	15	1.000	17.23	41.2	37.5
TWN	Taiwan	6.49	11.15	1303	32	30	0.591	2.12	25.3	24.0
TZA	Tanzania	1.63	10.33	316	60	.	0.000	0.42	-2.2	7.4
UGA	Uganda	-0.09	6.84	585	23	.	0.000	0.31	0.2	1.2
URY	Uruguay	0.73	2.57	3929	30	.	0.000	2.80	-34.8	33.6
USA	United States	1.90	183.63	10066	9	14	0.962	24.29	34.4	41.6
VEN	Venezuela	-0.35	7.60	6491	46	10	0.000	0.18	9.8	5.2
YUG	Former Yugoslavia	3.71	18.61	1990	34	25	.	21.66	43.8	43.0
ZAF	South Africa	1.32	18.44	2232	54	82	0.801	9.65	-29.1	29.9
ZAR	Zaire	-0.99	16.29	513	18	84	0.000	0.21	-0.6	4.7
ZMB	Zambia	-1.02	3.23	956	95	80	0.000	1.81	-12.9	14.6
ZWE	Zimbabwe	0.97	3.75	979	86	50	0.000	2.79	-17.9	20.0

Note: 1960 value set to 1961 for Sierra Leone, 1990 set to 1989 for Angola, Barbados, Botswana, Ethiopia, Haiti, Iraq, Liberia, Malta, Nepal, Niger, Puerto Rico, Reunion, Romania, SaudiArabia, Somalia, Surinam, Swanziland, Tanzania, USSR and Zaire.

Sources: Detailed in text.

Appendix Figure 1. Temperature and frost frequency, worldwide, 1901-95



Source: Drawn from data supplied by the International Panel on Climate Change, Data Distribution Centre (Climatic Research Unit, University of East Anglia, UK), April 1999: http://ipcc-ddc.cru.uea.ac.uk.

Notes: Frost-days are those when estimated grass temperature falls below 0° C.
Data shown are means of 1961-90 values, computed over 0.5 degree cells for all land mass except Antartica. Values for each cell are interpolated from station observations. For stations not reporting frost observations, values are estimated from observed temperature level, temperature variation, and precipitation.