TRENDS IN RAINFALL AND ECONOMIC GROWTH IN AFRICA: A NEGLECTED CAUSE OF THE AFRICAN GROWTH TRAGEDY

Salvador Barrios, Luisito Bertinelli, and Eric Strobl*

Abstract—We examine the role of rainfall trends in poor growth performance of sub-Saharan African nations relative to other developing countries, using a new cross-country panel climatic data set in an empirical economic growth framework. Our results show that rainfall has been a significant determinant of poor economic growth for African nations but not for other countries. Depending on the benchmark measure of potential rainfall, we estimate that the direct impact under the scenario of no decline in rainfall would have resulted in a reduction of between around 15% and 40% of today's gap in African GDP per capita relative to the rest of the developing world.

I. Introduction

THE poor performance of sub-Saharan Africa during the second half of the twentieth century has had, and continues to receive, a considerable amount of attention in the economics literature (see Collier & Gunning, 1999a, 1999b; Artadi & Sala-i-Martin, 2004, for comprehensive reviews).[1] In the 1960s there was widespread optimism about its future: African countries' per capita GDP was higher than that of many Asian countries, and increasing political self-determination seemed to provide further scope for governments to cater to domestic needs. Indeed, until the early 1970s, there was little difference between the growth performance of African and other developing countries. By the second half of the 1970s, however, the outlook changed considerably as the average pace of growth of African economies began to slow, and by the 1980s even resulted in economic contraction. While Africa's growth rates have recently begun to normalize again, the disastrous performance over more than twenty years has left standards of living and income levels lagging well behind other developing countries.

A large number of theories have been put forward to explain this relatively poor economic performance, but the evidence for their importance, although abundant, is mixed (see Collier & Gunning, 1999a, 1999b). In essence the theories can be categorized into those arising from political causes and those due to exogenous factors. Political explanations usually refer to the poor policies or political institutions that are argued to have hindered growth in Africa (see Elbadawi & Ndulu, 1996; Knack & Keefer, 1995; Mauro, 1995). These range from poor fiscal, exchange rate, and trade policies and badly functioning financial and labor markets, to the lack of sufficient democracy and good governance (see Collier & Gunning, 1999b). Explanations of an exogenous nature have, in contrast, appealed to features of African economies outside of the immediate domestic political domain that may have negatively influenced growth. These include external aid allocation (Burnside & Dollar, 1997), the lack of diversification of Africa's exports (Sachs & Warner, 1997), and ethnolinguistic diversity (Easterly & Levine, 1997), as well as the landlocked geography and tropical climates predominant in many African nations (Bloom & Sachs, 1998).

One other aspect of Africa that is increasingly more frequently referred to, but has not yet been evaluated empirically as a potential determinant of Africa's poor performance, is the distinct change in rainfall trends that has taken place since the 1960s. In particular, while there is a general awareness of a number of severe droughts over the period, only relatively recently has it been noted that rainfall in Africa has also in general been on a decline since its relative peak in the 1960s (see Nicholson, 1994, 2001). Given the importance of agriculture for African countries and the dependence of this sector on rainfall, this decline, as suggested by Nicholson (1994), Collier and Gunning (1999b), O'Connell and Ndulu (2000), and Bloom and Sachs (1998), may have had potentially severe consequences for economic growth. Additionally, this decline has had a detrimental impact on energy supply since Africa is much more reliant than other developing countries on hydropower for electricity generation (Magadza, 1996).

In this paper, we explicitly investigate for the first time the role these trends in rainfall have had on Africa's relative economic performance.[2] In particular, we use a newly available climatic data set to construct a comparable rainfall measure across all developing countries. Trends in this variable confirm that in contrast to other developing countries, precipitation has been on a general decline in Africa since the 1960s.

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* Barrios: European Commission, Directorate General Joint Research Centre, Institute for Prospective Technological Studies; Bertinelli, CREA, Université du Luxembourg; Strobl: Ecole Polytechnique Paris.

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[1] As is conventional in essentially all of the literature on this topic, we focus on the relative growth performance of sub-Saharan Africa since the North African countries (Algeria, Egypt, Lybia, Morocco, and Tunisia) are considered to be part of the Middle East and thus of a different regional economy with other distinctive economic issues. In what follows, we interchangeably refer to "Africa" for sub-Saharan African countries (SSA) and to "non–sub-Saharan" (NSSA) countries for all other developing countries.

[2] A number of papers have already suggested the potential importance of rainfall for economic growth. For example, O'Connell and Ndulu (2000) include a measure of the number of dry years in a cross-country growth regression of African countries and find this variable to significantly negatively affect growth rates. Masters and Sachs (2001), in contrast, use IPCC climatic data to show how income levels have been affected by rainfall for a sample of developing and developed countries. In a somewhat different approach, Guillaumont et al. (1999) examine how climate, measured as instability in agricultural value added, has affected African growth rates.

TABLE 1.—MEAN CHARACTERISTICS FOR SSA AND NSSA

		1960	1970	1980	1990	1997
% of agriculture in GDP						
	NSSA	24.4	23.0	18.7	16.3	14.1
	SSA	39.2	33.9	32.0	29.9	29.7
% of arable land irrigated						
	NSSA	14.2	16.3	16.1	17.1	17.2
	SSA	6.4	7.2	7.7	8.3	8.4
% of power generation by hydropower						
	NSSA	35.0	39.4	37.6	39.6	34.1
	SSA	27.9	37.3	46.5	42.9	46.6

Notes: Where exact year was not available, information from the nearest year was used. The sample of countries may not correspond across the three variables as we included only countries in our sample for which we had observations for all five periods.
Sources: World Development Indicators (World Bank), FAO, and authors' computations.

More important, in a cross-country panel growth regression framework, results indicate that rainfall has had a significant impact on growth only in the African sample. Using these results, we show that the direct impact of the decline in rainfall has played an important role in the poor performance of African countries. Ceteris paribus, the gap in GDP per capita between African and non-African developing countries could have been between around 15% and 40% lower, depending on what level of rainfall is considered the benchmark.

The paper proceeds as follows. In the next section we discuss the importance of rainfall for Africa's economic performance and the channels through which rainfall affects it. Section III discusses our main data sources and provides summary statistics of our main variables. A discussion about the estimated specification is provided in section IV. The results of our econometric analysis are given in section V. Using these results, we explore hypothetical growth scenarios under more benevolent rainfall conditions in section VI. The last section provides concluding remarks.

II. Rainfall and Economic Growth in Sub-Saharan Africa

Rainfall could potentially have a wide array of economic implications anywhere in the developing world.[3] Historically, however, shortages in rainfall in Africa seem to have been associated with particularly damaging consequences. This particular sensitivity to rainfall seems to rest at least in part on features specific to Africa. We briefly describe the two main channels, agriculture and hydroenergy supply, through which rainfall is likely to have affected sub-Saharan Africa's (SSA) development.[4]

A. *Agricultural Production*

The most direct impact of rainfall on Africa is certainly on the agricultural sector, since water is an important input into agricultural production.[5] A large part of this is due to the significance of this sector for Africa's economy relative to those of most other developing nations. Table 1 shows, for example, that agriculture has traditionally had a higher share in GDP in Africa than in other non–sub-Saharan developing countries (NSSA)—nearly 40% in 1960. Although this share has since been steadily decreasing, it still represents almost a third of total GDP in 1997, compared to the average 14.1% in the rest of the developing world.

However, even apart from the importance of agriculture, other aspects of the SSA continent are likely to make the SSA agricultural sector highly susceptible to shortages in rainfall. In considering these, it is important to note that the availability of water in SSA differs widely as a consequence of the large diversity of geographic conditions across the continent. Parts of both West and the western part of Central Africa, mostly the tropics around the equator, are humid throughout the year. While there is substantial rainfall during the wet seasons in the subhumid regions located to the north and south of the tropics, there is almost no rain during the much longer dry seasons. Further pole-ward from these subhumid regions are the large semi-arid climates. These areas receive some water during the wet season but suffer from extreme unreliability of rainfall and few permanent water sources, whereas arid areas receive little direct water. Semi-arid and arid areas turn out to be most vulnerable to rainfall shortages.

It is also important to point out that while the African continent has several large water basins and rivers and heavy rainfall in some areas, the runoff from these water sources to the arid and semi-arid areas is particularly low. This is exacerbated by the year-round high temperatures in SSA. Additionally, within the arid and semi-arid areas, there is little water runoff as drier soil absorbs more moisture. In fact, the average runoff of about 15% is lower than on any other continent and very sensitive to changes in rainfall. Reibsame (1989), for example, estimates that in southern Africa, a reduction of 10% in precipitation would lead to a

[3] Unless stated otherwise, information from this section is taken from IPCC (2001).

[4] Our choice of these two channels does not preclude the prominence of other channels, some of which have been documented in Christiansen, Demery, and Paternosto (2002), Rosenzweig and Binswanger (1993), Masters and McMillan (2001), and Barrios, Bertinelli, and Strobl (2005).

[5] Masters and Wiebe (2000) have already shown evidence of the importance of rainfall for agriculture, using the same climatic data source as we do in this paper, for developing countries in general.

fall of more than 50% in runoff. Moreover, compared to other developing areas in the world, a much smaller proportion of arable land in SSA is irrigated. For instance, figures in table 1 show that still less than 10% of arable land in SSA is irrigated, compared to nearly a fifth in other developing countries, thus increasing the vulnerability of African agriculture to precipitation shortages.

As becomes apparent, the areas outside the tropics are extremely reliant on rainfall for moisture. The availability of water from rainfall depends in turn on the rate of evapotranspiration—the share of water that is evaporated and transpired by plants as a part of their metabolic processes. This rate is particularly high in SSA, in part because high temperatures increase the water-holding capacity of the air. Moreover, recent trends in desertification may have affected the extent of rainfall in the semi-arid areas as a reduction of vegetative cover can also translate into the absence of interannual soil water storage and hence negatively affect agricultural productivity. It has been estimated, for example, that desertification has reduced the potential vegetative productivity by 25% for nearly a quarter of Africa's land area (see UNEP, 1997).

The geographical variation of availability of water can be considered in terms of its implications for agricultural production in SSA. More precisely, despite the abundance of water, the tropical humid regions are generally not suitable for crop or animal production. For crops, the combination of high temperatures and abundant rainfall fosters high rates of chemical weathering and the production of leached clay soils of low inherent fertility. Hence, much crop production is located in the semi-arid regions, making it susceptible to rainfall shortages. In terms of animal production, domestic livestock in Africa other than pigs are also generally concentrated in the arid and semi-arid regions because the relatively more humid areas provide greater exposure to animal diseases and are characterized by grasses of low digestibility. Since livestock are directly dependent on grass quantity, rainfall variations in the semi-arid and arid areas have direct consequences on livestock production.[6]

B. *Energy Production*

Rainfall can also significantly affect the energy sector in SSA, and hence affect other industries indirectly, since energy supply in many SSA countries now relies heavily on water as both a direct and an indirect input (see Magadza, 1996).[7] Over the past fifty years, African countries have invested heavily in hydroelectric power. This is evidenced by the figures provided in table 1, which show that hydropower energy now represents about 47% of total power generation in Africa compared to the relatively stable average of 34% in other developing countries. Additionally, water serves as an important secondary input for thermal power generation as a cooling device and is needed in large quantities for this purpose.

Importantly, hydroelectric and other energy production that uses water as a secondary input in SSA tend to be heavily reliant on rivers as their source of water. River flows in African regions are in turn sensitive to changes in precipitation. One of the reasons is that apart from the Zambezi and Congo rivers, major African rivers like the Nile, Niger, Senegal, Senqu/Orange, and Rufiji are located in arid or semi-arid regions. In fact, some evidence shows that the performance of Africa's major rivers is significantly lower than that of other areas in the world.[8] In addition, these rivers originate in tropical areas where high temperatures increase evaporation losses. Moreover, lakes and reservoirs, the other sources of water for hydropower, are also greatly exposed to decreases in rainfall. For example, declines in precipitation led to a loss of as much as 30% of total hydropower energy from the Kariba dam, which supplies power to Zambia and Zimbabwe (see Magadza, 1996).

III. Data and Summary Statistics

A. *Rainfall*

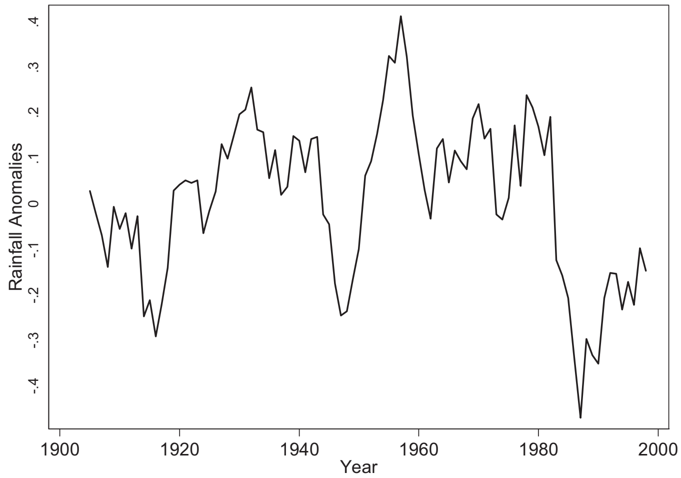
The data used in this paper are derived from a number of sources, and we describe these and the definitions of all our variables in greater detail in the appendixes. Our main variable of interest, the measure of rainfall, is taken from the Inter-Governmental Panel on Climate Change (IPCC) data set, which provides, among other things, time-series data on the annual rainfall for 289 "countries" (comprising 188 states and 101 islands and territories) from 1901 to 2000 (see Mitchell, Hulme, & New, 2002, for a complete description of the data set). The underlying methodology used to derive these country-level series consists essentially of three steps (see New, Hulme, & Jones, 1999). First, a high-resolution 0.5 degree latitude by 0.5 longitude gridded climatology of the world's land surface area is constructed. This grid is then subsequently used to derive gridded time series of rainfall over the desired period. Finally, the individual gridded values are assigned to individual countries to arrive at country-wide time series. Since the spatial area of each grid box can vary with latitude, a mean measure of rainfall within each country for each year was calculated by using the cosine of the grid box's latitude as weight. For a country-specific proxy of rainfall, we follow the climatology literature and use anomalies, defined as the deviations from the country's long-term mean, divided by its long-run standard deviation, where the long run is taken to be the

[6] Apart from animal products, domestic livestock often also serve as source of draft power in SSA.

[7] See Harrison and Whittington (2001, 2002a, 2002b) for studies of climate variability on hydropower generation.

[8] For example, the total runoff as a percentage of precipitation in African rivers is estimated to be around 20% for Africa, while it oscillates around 40% in Asia, North America, and Europe (see IPCC, 2001).

FIGURE 1.—RAINFALL IN SUB-SAHARAN AFRICAN COUNTRIES: LONG-TERM TRENDS



1901–2000 period.[9] Using anomalies allows one to eliminate possible scale effects and take account of the likelihood that for the more arid countries, variability is large compared to the mean (see Nicholson, 1986, and Muñoz-Diaz & Rodrigo, 2004).

One other aspect with regard to our rainfall measure that deserves discussion since it has plagued many studies examining other potential determinants of Africa's poor growth performance is the question of exogeneity. In terms of rainfall, we can argue fairly confidently that it is a strictly exogenous factor given that it measures an aspect of climate. While one could in theory also hypothesize that perhaps economic activity itself can affect aspects such as environmental degradation and desertification, and thereby possibly rainfall, Nicholson (1994) finds no evidence suggesting such, at least in the case of Africa. Moreover, as just noted, earlier historical data from other studies suggest that rainfall naturally moves through long cycles of relative troughs and peaks and that a cycle similar to the one over the twentieth century seems to have also occurred in the nineteenth century.

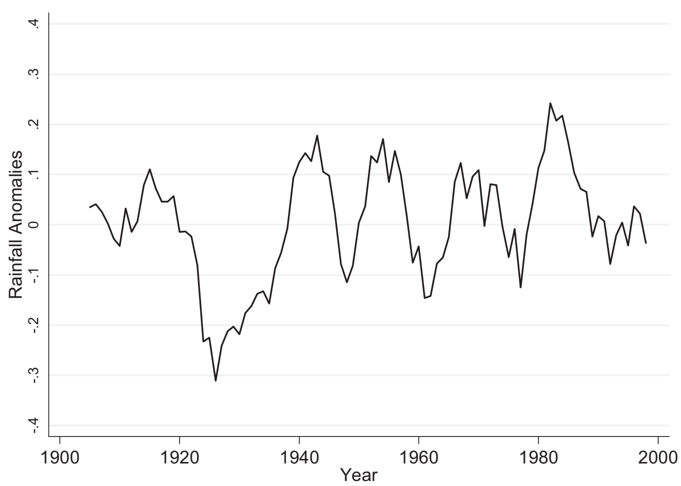
Figures 1 and 2 depict the mean long-term trends in our rainfall anomalies for SSA and NSSA, shown as five-year moving averages.[10] As can be seen, the mean rainfall anomalies in SSA were fairly variable in the first part of the century, peaking in the late 1950s. However, since this peak, rainfall appears to have been on a downward trend, at least until the 1990s. More precisely, mean rainfall anomalies experienced a considerable drop in the 1960s and then an even more severe one in the early 1980s, reaching an all-time low for the century. Figure 2 shows, in contrast, that average annual rainfall anomalies in NSSA are less variable than in SSA. Moreover, there are no comparatively large downward trends in the latter half of the twentieth century.

Given the continent's diverse geographic and climatic conditions, it is unlikely that the mean trends over time just described are completely homogeneous across all countries in SSA. In order to investigate this further, we follow the general approach in the climatology literature and take our individual national annual rainfall anamolies over the 100 available years and perform a principal component analysis to identify climatic groups.[11] More specifically, this involves running a principal component analysis of all series, selecting the number of significant components, rotating their principal component loadings,[12] and then identifying climatic groups according to the rotated loadings. Important in this regard is determining the significant components and what cut-off factor to use to identify groups among the rotated loadings of these components. With regard to the former we implemented Horn's test and also verified our results visually using a scree plot. In terms of the latter we chose a cut-off value of 0.2.[13]

The procedure just described resulted in identifying four climatic groups, as shown in map 1, where the countries

[9] We also experimented with using the mean and standard deviation of the data prior to our econometric analysis (before 1960). This made no qualitative and little quantitative difference to our results.

FIGURE 2.—RAINFALL IN NON–SUB-SAHARAN AFRICAN COUNTRIES: LONG-TERM TRENDS



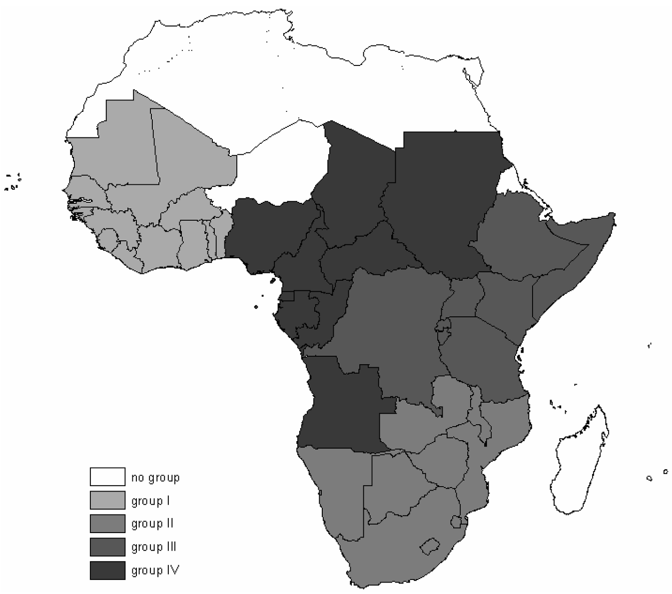
[10] For all graphical depictions and all other tabulations, we included more developing countries than we used for our econometric specification where the use of control variable restricted our sample. This allowed the graphs to be more representative of the entire population of developing countries. However, we did restrict this sample to those for which, over the years depicted, there was a full set of observations, so as to avoid trends being pushed by sample entry and exit.

[11] See, for instance, Singh and Singh (1996) and Muñoz-Diaz and Rodrigo (2004). Importantly, note that much of the analysis in the climatology literature has dealt with monthly data and hence captured seasonal covariability across geographical units. Since we use as a measure of rainfall a moving average of annual series in our econometric analysis, we restricted our regionalization exercise to annual data.

[12] The rotation of loadings facilitates interpretation of the principal components (see Richman, 1986). We use an oblimin (oblique) rotation.

[13] The choice of cut-off is inevitably subjective, as researchers tend to choose a value that results in reasonable groupings. For instance, in their subnational study of 90 rainfall stations in Nepal, Singh and Singh (1996) experiment with cut-off points ranging between 0.2 and 0.5. Using lower cut-off points will tend to result in larger, not necessarily mutually exclusive, groups. At our chosen value, no countries fell into more than one group.

Map 1.—Rainfall Climatic Groups: Sub-Saharan Africa



Map 2.—Temperature Climatic Groups: Sub-Saharan Africa

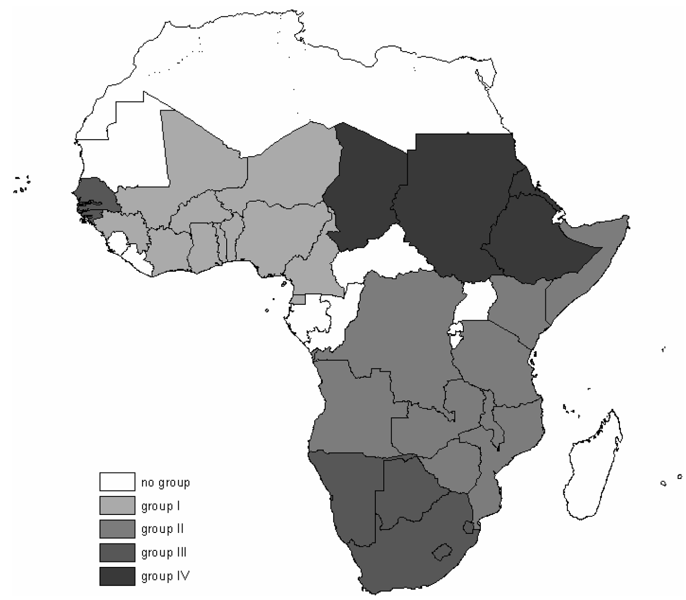
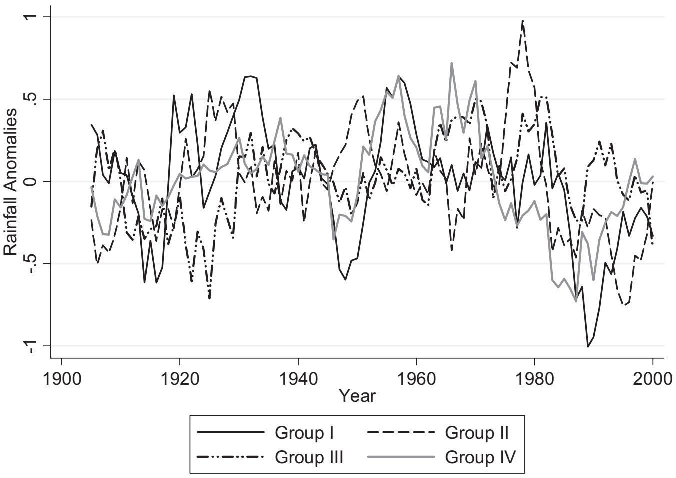


Figure 3.—Long-Term Trends in Rainfall for SSA Climatic Groups



Map 3.—Rainfall Climatic Groups: Latin American and Caribbean

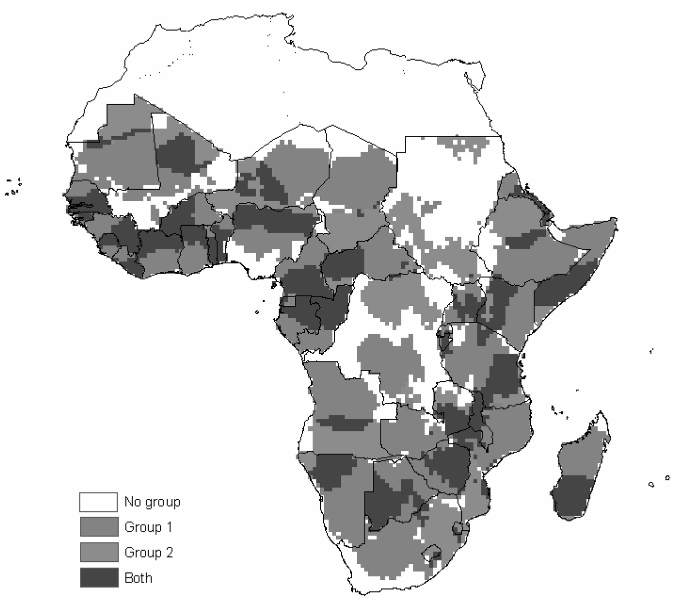
depicted in white did not fall in any group. Accordingly, using the national series results in groups that are fairly geographically distinct. The mean long-term anomalies depiction in figure 3 show nevertheless that all four groups have experienced a declining trend in rainfall at least at some stage since the early 1960s. Applying the same classification methodology to national annual series of temperature anomalies, also taken from the IPCC data, similarly isolates four distinct climatic regions, but also left more countries unclassified, and, at least for one group, resulted in greater geographical scope (see map 2). As a comparison group we undertook parallel analyses for Latin American and Caribbean countries (LAC), the results of which for rainfall and temperature are shown in maps 3 and 4. As is apparent, for LAC, there are fewer groups using the same cut-off point, and these cover only a small part of the continent in terms of both rainfall and temperature anomalies.

Thus far we have implicitly assumed, and as will be necessary for the econometric analysis, that climate is homogeneous within national borders. To examine this in greater detail we ran a principal component analysis of the 0.5 by 0.5 degree cells separately for each country,[14] retained the two components with the highest eigenvalues if these were deemed to be significant according to Horn's

[14] For instance, there were 8,129 cells for SSA, with an average of 170 cells per country.

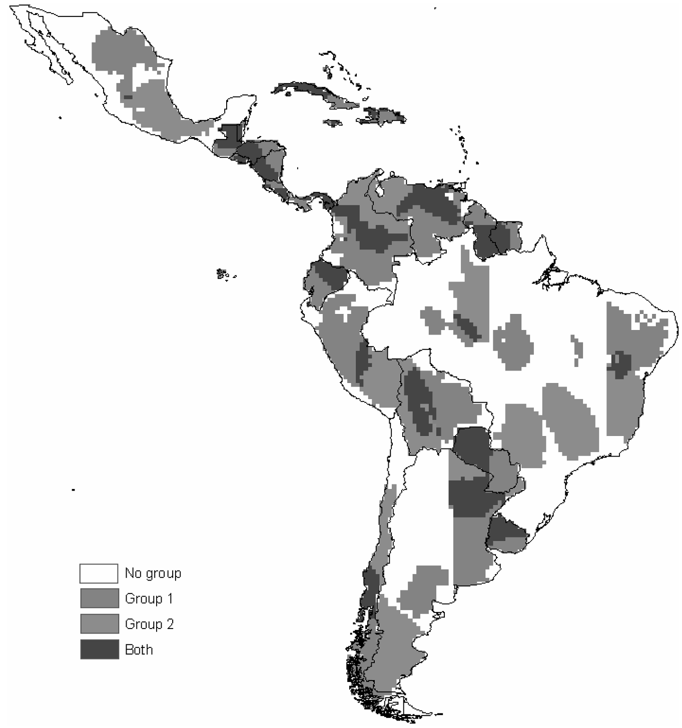
Map 4.—Temperature Climatic Groups: Latin American and Caribbean

Map 5.—Rainfall within Country Homogeneity: Sub-Saharan Africa



test, rotated their loadings, and then identified those cells within each country that had a loading greater than 0.05. The results of this for SSA are shown in map 5, where shaded cells identify cells that belong in the first, second, or both components, and white cells were unclassified.[15] As

Map 6.—Rainfall within Country Homogeneity: Latin American and Caribbean



can be seen, most countries have a substantial amount of their area following some common annual movement in rainfall, except notably Sudan and, to a lesser extent, the Democratic Republic of Congo, which, unsurprisingly are two of the larger countries on the continent. In contrast, as shown in map 6, in LAC particularly in large countries, there appears to be somewhat less homogeneity defined according to the same criteria.[16]

B. *Real Income*

The main purpose of this paper is to link trends in rainfall to growth of real income. As a measure of real income in a country, we use GDP per capita and for this, we take data directly from the 2001 World Penn Tables for all developing countries, as defined by World Bank criteria according to their 1960 status.[17] We graph the mean series of GDP per capita, taking 1960 as the base year for normalization, for sub-Saharan African and other non–sub-Saharan developing countries in figure 4.[18] The picture that emerges is one that is well known in the literature: the gap remained roughly constant during the early 1960s and slightly increased up to

[15] In several island economies, there was only one rainfall series observation at the 0.5 × 0.5 degree level, and hence the analysis could not be done. These were Cape Verde, Seychelles, São Tome, Comoros, and Mauritius. In the other countries the number of cells ranged from 3 (Gambia) to 833 (Sudan).

[16] We undertook a similar exercise with temperature and found similar patterns within countries and differences across these.

[17] See appendix B for further details on the groups as well as the definitional criteria.

[18] The mean real GDP per capita in 1996 $US was $1,457 and $2,611 for Sub-Saharan African and other developing countries, respectively.

FIGURE 4.—GDP PER CAPITA TRENDS

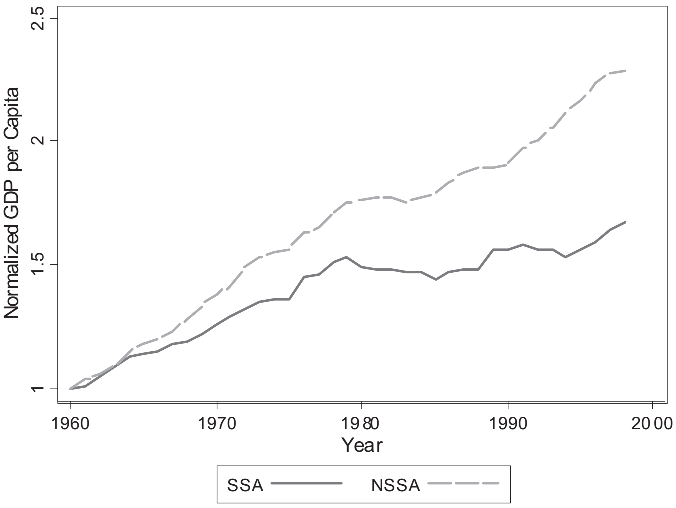
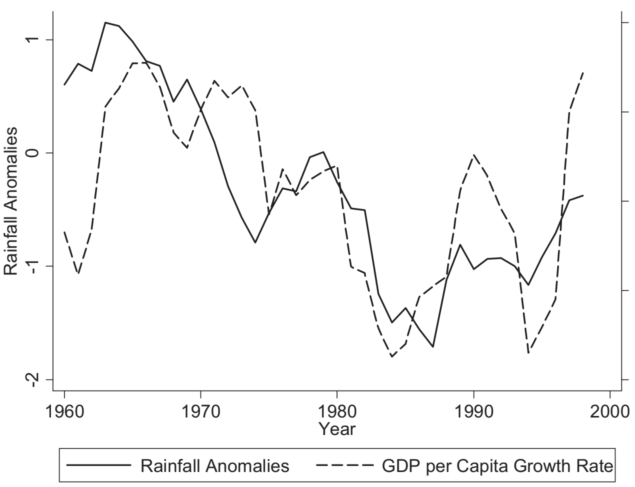


FIGURE 5.—TRENDS IN REAL GDP PER CAPITA GROWTH RATES AND RAINFALL IN SUB-SAHARAN AFRICAN COUNTRIES

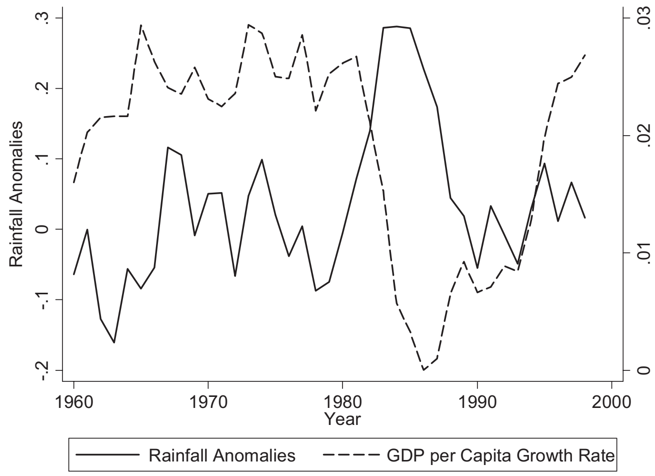


the early 1970s. It then rose significantly in the late 1970s and particularly in the 1980s, but appears to have stabilized in the latter half of the 1990s.

In order to give some graphical indication of how the observed rainfall trends in SSA may be related to its poor growth performance, we depicted a five-year moving average of real GDP per capita growth rates and rainfall, appropriately rescaled, from 1960 onward simultaneously in figure 5 for SSA countries for which we have a complete series of growth rates over the period.[19] This reveals that the two series seem to move remarkably closely together, except during the drop in rainfall in the early 1970s. A similar pattern is, in contrast, not apparent for other developing countries, as shown in figure 6.

[19] This constitutes 22 out of a possible 46 SSA countries for which we have rainfall series, and hence explains the slight difference in trends compared to figure 1.

FIGURE 6.—TRENDS IN REAL GDP PER CAPITA GROWTH RATES AND RAINFALL IN OTHER DEVELOPING COUNTRIES



IV. Econometric Specification

The graphical trends just depicted seem to suggest that SSA's relatively poor growth performance has gone hand in hand with some of the trends in mean precipitation. In contrast, no such relationship is apparent for other developing countries. In order to investigate this econometrically, we follow the standard empirical cross-country economic growth literature and assume that economies follow the extended neoclassical growth model with conditional convergence first proposed by Barro (1991). Accordingly, economies have unique steady-state growth rate values to which they will tend to converge to over time, the rate of which will depend on the current distance from the steady-state value. The steady state of each economy itself will depend on cross-country differences in postulated factors:[20]

$$GR_{i,t-j \to t} = \beta_1 + \beta_2 \log(Y_{i,t-j}) + \beta_3 X_{i,t} + \gamma_t + \mu_i + \varepsilon_{it}, \tag{1}$$

where GR is the GDP per capita growth rate for country i over the period $t - j$ to t, Y is the level of GDP per capita of country i at time $t - j$, X is a vector of hypothesized determinants of future steady-state income growth rates that will vary over countries or regions and possibly over time, γ are time-specific effects common to all countries, μ are country-specific effects that are unobservable to the econometrician, ε is an independent and identically distributed (i.i.d.) random term, and the β's are the coefficients to be estimated. The coefficient on $\log(Y)$ determines the speed at which economies converge toward their steady state and is expected to be negative.

[20] Also see Barro and Sala-i-Martin (1995) for further details. This framework underlies much of the empirical growth literature on what determines differences in growth rates of countries. See also, just to name a few, Islam (1995), Lee, Pesaran, and Smith (1997), Barro (1997), Easterly and Levine (1997), and Masters and McMillan (2001).

TABLE 2.—OLS RESULTS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RAIN	0.003	−0.004	−0.004	0.011**	−0.007	−0.007	0.016**
	(0.003)	(0.005)	(0.004)	(0.006)	(0.005)	(0.005)	(0.008)
SSA	−0.013***	−0.012***			−0.006		
	(0.004)	(0.004)			(0.008)		
RAIN × SSA		0.014**			0.018***		
		(0.007)			(0.007)		
log(GDP/CA)	−0.006**	−0.006**	−0.009***	0.001	−0.014***	−0.016**	−0.037***
	(0.003)	(0.003)	(0.003)	(0.005)	(0.004)	(0.007)	(0.009)
Constant	0.068***	0.065***	0.094***	0.007	0.137***	0.155***	−0.215
	(0.022)	(0.022)	(0.026)	(0.037)	(0.034)	(0.051)	(0.177)
Sample	All	All	NSSA	SSA	All	NSSA	SSA
Controls	No	No	No	NO	Yes	Yes	Yes
Observations	393	393	254	139	393	254	139
Countries	60	60	38	22	60	38	22
F-test	3.58***	3.82***	4.57***	2.02***	4.63***	5.10***	3.05***
R^2	0.03	0.04	0.04	0.03	0.21	0.30	0.39

Notes: Robust standard errors in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels. Controls include time dummies, openness (OPEN), population size (POP), schooling (ED), civil war incidence (CIVWAR), civil war incidence in surrounding countries (CIVWAR_S), investment (INV/GDP), government expenditure (G/GDP), urbanization (URB), landlockedness (LANDLOCK), ethnic diversity (ETHNIC), and tropical area dummy (TROP).

In terms of showing what since Easterly and Levine's (1997) seminal paper has become known as the African growth tragedy, generally X includes a 0-1 type dummy that takes on the value of 1 when a country is located in the SSA region, the coefficient of which has consistently been found to be negative. For purposes of this paper, we postulate the following specification for the pooled sample of all developing countries:

$$\begin{aligned} GR_{i,t-j\rightarrow t} = \beta_1 + \beta_2 \log(Y_{i,t-j}) + \beta_3 X_{i,t} + \beta_4 SSA_i \\ + \beta_5 RAIN_{i,t} + \beta_6 SSA_i \times RAIN_{i,t} \\ + \gamma_t + \mu_i + \varepsilon_{it}, \end{aligned} \tag{2}$$

where *SSA* is the sub-Saharan African dummy variable and *RAIN* is a country-level measure of precipitation. Our working hypothesis is that the coefficient on the interaction term *SSA* × *RAIN* is positive and significant (and, possibly, the coefficient on *RAIN* insignificant), implying that trends in rainfall have affected growth in SSA more than that of NSSA. Alternatively, we also estimate equation (2) separately for the SSA and NSSA sample, excluding the *SSA* dummy and its interaction with rain, where we then compare their coefficients on *RAIN*.

In estimating equation (2) and other variants of this specification, we generally resorted to estimating the determinants of average GDP per capita growth over five-year intervals. This was done for a number of reasons. First, the underlying conditional convergence framework is more concerned with longer-term growth patterns than with annual short-term fluctuations in GDP per capita. In fact, abstracting from annual movements in GDP per capita is an approach taken essentially by all of the empirical literature using this framework.[21] Moreover, researchers of the African growth tragedy have similarly been more interested in long-term divergence from the economic growth patterns of other developing countries.[22] Within this five-year average economic growth rate empirical framework, our proxy of rainfall, *RAIN*, is then the average anomalies over any five-year interval $t - 5$ to t.[23]

In terms of choosing other control variables, X, we took into consideration both what is commonly used in the literature to look at conditional convergence and what has been used in the past to investigate the African growth tragedy. A complete list of all control variables, their definitions, and their sources is given in the appendix. One should note in this regard that while there have clearly been a sizable number of other time-varying and time-invariant variables that have been used to explain cross-country differences in growth rates, inclusion of these, where available, would have put severe restrictions on the number of countries and extent of time span for each in our sample. Use of the ones listed in the appendix provided us the five-year interval growth rate regressions with a sample of 60 countries, of which 22 were sub-Saharan African, covering the period 1960 to 1990.[24] One should note that our base sample consists of an unbalanced panel data set in the sense that not all time periods are available for all countries, although for most, the number of observations across time is complete.[25]

V. Econometric Results

A. Main Results

Using standard OLS, we first estimate equation (2) without any interaction term between *RAIN* and *SSA* or other control variables X, as shown in the first column of table 2.[26] Accord-

[21] See Dobson, Ramalogan, and Strobl (2006) for a review.

[22] We also tried our base specification with ten-year intervals with an obviously much reduced sample size. Reassuringly our main results were qualitatively the same.

[23] We also experimented with using the growth rate of rainfall anomalies over the five-year period, but this proved never to be significant. This may not be surprising since rainfall is generally viewed as a flow variable of the input in the water stock in the hydrology literature (see Dingman, 2001).

[24] Our time period was limited to 1990 in the base specification because a number of our main and auxiliary explanatory variables are limited to this period: urbanization growth, education, civil wars, and hydropower growth.

[25] The mean number of observations for each country (from a possible 6) is 5.87.

[26] Given that countries appear many times in the data, we tested for serial correlation within panels with the test suggested by Wooldridge (2002) but found no evidence of this.

TABLE 3.—FIXED-EFFECTS RESULTS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RAIN	−0.004	−0.004	0.011*	−0.003	−0.003	0.022***	−0.004
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.008)	(0.004)
RAIN × SSA	0.015***			0.014*			0.015**
	(0.007)			(0.007)			(0.007)
log(Y)	−0.043***	−0.041***	−0.046***	−0.056***	−0.065***	−0.054***	−0.039***
	(0.007)	(0.008)	(0.014)	(0.009)	(0.012)	(0.015)	(0.004)
Sample	All	NSSA	SSA	NSSA	SSA	SSA	All
Controls	No	No	No	Yes	Yes	Yes	No
Observations	393	254	139	393	254	139	393
Countries	60	38	22	60	38	22	60
F-test	14.70***	14.58***	7.66***	6.56***	6.21***	2.43***	—
R^2	0.15	0.15	0.15	0.26	0.33	0.28	—

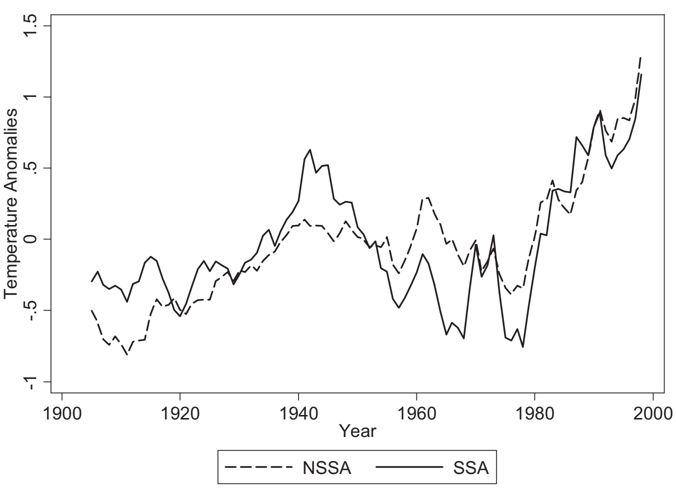
Notes: Standard errors in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels. Controls include time dummies, openness (OPEN), population size (POP), schooling (ED), civil war incidence (CIVWAR), civil war incidence in surrounding countries (CIVWAR_S), investment (INV/GDP), government expenditure (G/GDP), and urbanization (URB). Coefficients in column 7 are corrected using the Kiviet (1995); standard errors are generated by bootstrapping.

ingly, the SSA dummy is negative and significant, indicating that SSA countries had on average lower growth rates, thus supporting the idea of an African growth tragedy, whereas the coefficient on *RAIN* is insignificant. In order to determine whether the lack of significance of the latter may be due to different effects across SSA and NSSA countries, we included an interaction term of the *SSA* dummy and rainfall in the second column. As can be seen, while the coefficient on *RAIN* remains insignificant, one finds a positive effect of the interaction term. Put differently, lower rainfall will have a negative effect on growth only in SSA countries. As shown in the third and fourth columns, this result—a significant positive relationship only in SSA countries but no effect in their NSSA counterparts—is robust to regressing growth on rainfall for the two samples separately.

We next included our full set of control variables, including time dummies. Given that our focus here is not on disentangling the effects of the other theories that have been put forward in the literature trying to explain SSA's poor performance, but rather on isolating the impact of rainfall, the full set of results on all control variables is not discussed but is reported in the appendix. The estimated coefficients on our main variable of interest, rainfall, for the full sample and the subsamples are provided in columns 5 to 7 of table 2. In line with our simple specification, they similarly indicate that rainfall has only had a significant impact in SSA countries.

In table 3, columns 1 to 6, we reran the specifications of columns 2 through 7 of table 2 using a fixed-effects estimator, which allows us to purge not only the effect of our time-invariant controls but all other nonincluded time-invariant factors from the model. Accordingly, taking account of fixed effects in the specification without (time-varying) controls changes little relative to the OLS results: rainfall influences economic growth only in SSA nations and gives similar coefficients. The results are also robust to including our set of time-varying explanatory variables, although the coefficient for the separate SSA sample regression is somewhat higher in the fixed-effects specification.

FIGURE 7.—LONG-TERM TRENDS IN TEMPERATURE: SSA AND NSSA COUNTRIES



B. Temperature and Main Channel Effects

As indicated in section II, temperature may also play an important role in SSA. Feasibly the effect of rainfall on growth in SSA found above may simply be capturing the effect of temperature trends. For example, previous studies have argued and found evidence for some industrialized countries that temperature can have a negative impact on agriculture (see Mendelsohn, Nordhaus, & Shaw, 1994). We hence constructed an anomalies measure of temperature similar to our rainfall proxy for SSA and NSSA, depicted in figure 7.[27] As can be seen, the trend in average temperature followed a similar pattern in both country groups, first rising until the 1940s, then embarking on a long decline until the late 1970s, and since then, they have been on a steep ascent.

To investigate whether the temperature trends may have affected growth rates or the effect of rainfall on growth in SSA (or both) may simply be capturing the effect of temperature changes, we included temperature in our fixed-effects specification for our two subsamples in columns 1 and 2 of table 4. Accordingly, in neither case is temperature

[27] The data on temperature were also taken from the IPCC database and constructed in a similar manner.

TABLE 4.—TEMPERATURE AND CHANNEL EFFECTS

	(1)	(2)	(3)	(4)	(5)	(6)
RAIN	−0.005	0.014**	−0.004	0.014**	−0.009	−0.008
	(0.004)	(0.006)	(0.004)	(0.006)	(0.007)	(0.010)
Log(Y)	−0.052***	−0.048***	−0.053***	−0.048***	−0.051***	−0.098***
	(0.010)	(0.014)	(0.010)	(0.014)	(0.018)	(0.023)
TEMP	−0.002	0.000	−0.003	0.000		
	(0.03)	(0.005)	(0.003)	(0.005)		
RAIN × TEMP			−0.008	−0.001		
			(0.007)	(0.007)		
RAIN × $\overline{AGR}$					0.021	0.704***
					(0.031)	(0.200)
RAIN × $\overline{HYDRO}$					0.392	0.728*
					(0.363)	(0.375)
log(Y) × $\overline{AGR}$					−0.015	−0.024
					(0.030)	(0.041)
log(Y) = $\overline{HYDRO}$					−0.030	1.099***
					(0.074)	(0.287)
Sample	NSSA	SSA	NSSA	SSA	NSSA	SSA
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	254	139	254	139	254	124
Countries	38	22	38	22	38	20
F-test	7.91***	3.25***	7.30***	2.93***	6.00***	4.62***
R^2	0.28	0.23	0.28	0.23	0.24	0.40

Notes: Standard errors are in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels.

a significant determinant of growth, nor does its conclusion change the coefficient on rainfall. We subsequently then also experimented interacting temperature with rainfall, given that the rate of evapotranspiration of water depends on both aspects of climate. As can be seen, the interaction terms also are insignificant, with no apparent change in the coefficient on rainfall.

Our discussion in section II also suggested that the two key impact sectors through which rainfall in SSA affected the economy are agriculture and hydropower. One would thus expect that countries for which these sectors are more important parts of the economy to be more vulnerable to trends in rainfall. In order to proxy the importance of these channels nationally, we calculated the average agriculture production share of GDP, $\overline{AGR}$, and the average hydropower production share of GDP, $\overline{HYDRO}$, over the sample period for each country. We used the average measure of these over the period rather than their time-varying values for two reasons. First, the data on both proxies are comparatively poor, with many missing values for most countries in our data set; including these with our control variables would have further reduced the sample size considerably and made it difficult to compare any results with our base specification.[28] Second, the use of time-invariant averages at least partially allows us to circumvent likely endogeneity and misspecification issues since both sectors are components of GDP and are also affected by rainfall itself.

We hence proceeded to interact $\overline{AGR}$ and $\overline{HYDRO}$ with the rainfall anomalies in our fixed-effects specification. These interaction terms can thus be interpreted to capture the potentially different effects of rainfall on GDP growth for countries that had on average greater agricultural and hydropower sectors. Additionally, we controlled for different convergence rates in this regard by interacting $\overline{AGR}$ and $\overline{HYDRO}$ with initial GDP per capita. Our results of this exercise are reported in the final two columns of table 4. As can be seen, controlling for either the size of the agricultural sector or for the importance of hydropower does not change our finding of a nonsignificant impact of rainfall on growth in NSSA. In contrast, these interaction terms are positive and statistically significant for the SSA sample, while rendering rainfall anomalies coefficients insignificant. This indicates that countries with a larger agricultural sector or greater hydropower production are indeed more vulnerable to trends in rainfall in terms of economic growth. Moreover, these two channels appear to explain most of the impact of rainfall trends on growth.

C. *Extended SSA Sample and Further Robustness Checks*

The inclusion of other control variables has meant that for our SSA sample, we were restricted to less than half (22) of all SSA nations and to a sample period that ended in 1990. In order to ensure that these data were a representative sample of SSA, we also reran our base specification with fixed effects without any controls for SSA, allowing us to include 42 countries over the 1960 to 2000 period, as shown in the first column of table 5. Accordingly, despite being able to cover almost all SSA nations and more than doubling our sample size, the essential result of a positive effect of rainfall on growth holds.[29] Moreover, the size of the coefficient is similar.

While rainfall measured in terms of anomalies is the most widely used proxy for rainfall in the climatology literature, we also experimented with other indicators of precipitation.

[28] For example, the number of SSA countries would have been reduced by nearly half.

[29] Extending the NSSA sample in a similar manner continued to produce an insignificant effect for rainfall.

TABLE 5.—EXTENDED SSA SAMPLE AND FURTHER ROBUSTNESS CHECKS

	(1)	(2)	(3)	(4)	(5)	(6)
log(Y),	−0.047***	−0.046***	−0.047***	−0.047***	−0.049***	−0.045***
	(0.008)	(0.008)	(0.007)	(0.008)	(0.008)	(0.008)
RAIN	0.013***					
	(0.004)					
RAIN_FAO		0.059**				
		(0.023)				
RAIN × NON_SAHEL			0.014			
			(0.001)			
RAIN × SAHEL			0.009**			
			(0.000)			
RAIN_FAO × NON_SAHEL				0.043		
				(0.028)		
RAIN_FAO × SAHEL				0.091		
				(0.040)		
RAIN_POP					0.016**	
					(0.007)	
SST_1						−0.008*
						(0.005)
SST_2						0.013***
						(0.003)
Observations	301	301	301	301	301	301
Number of countries	42	42	42	42	42	42
F-test	23.68***	22.22***	39.06***	15.12***	21.30***	18.63***
R^2	0.16	0.15	0.16	0.15	0.14	0.18

Notes: Standard errors in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels.

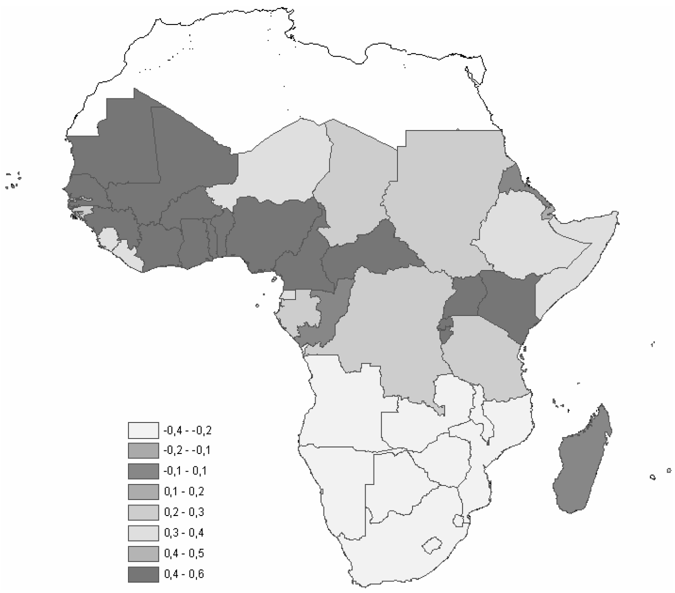
For instance, in the past, the FAO has used the level of rainfall divided by its long-term mean (see Gommes & Petrassi, 1996). As the estimates in the second column demonstrate, the significant positive effect is robust to employing this alternative proxy. Arguably one of the advantages of the anomalies relative to the FAO measure of rainfall is that the former can better take account of the fact that in countries where mean rainfall is low, the coefficient of variation tends to be high, which would amplify the effect of droughts. One good example is the Sahel region, which tends to have very low levels of rainfall by SSA standards but also experiences severe droughts over our sample period. To investigate this, we created 0-1 type dummies for the Sahel (SAHEL) and non-Sahel (NON_SAHEL) regions and interacted these with the two rainfall measures; the results of including these are given in the third and fourth columns of table 5. Accordingly, while both interaction terms are significant for the anomalies proxy, the non-Sahel interaction term is now marginally insignificant for the FAO proxy specification, thus indeed confirming the suspicion that the latter may in some cases be inappropriate.

As noted in section III, the countrywide measure of rainfall is an average of the individual cell values, weighted by the latitude in order to control for the area of the cell. It may, however, be the case that the falling trends in rainfall are mostly occurring in sparsely populated areas that generate little economic activity, hence attributing too much weight to these in terms of the impact of rainfall on economic growth. For example, Masters and McMillan (2001), using the same climatic data set as here, show that local population density is related to precipitation. To see whether our results are robust to taking account of this, we resorted to information from the African population database, which provides population estimates in a raster format for the years 1960, 1970, 1980, 1990, and 2000. Since these raster grids did not correspond to the format for which the precipitation data were available (0.5 by 0.5 degrees), we had to impose this latter format on the population data. In order to derive annual population shares from the decadal data, we linearly interpolated the shares between decades and used the 1960 weights for all years prior to 1960. Rather than weighting these by the latitude of the area as before, we instead used the population shares of the grids as weights. The population-weighted rainfall anomalies were then averaged at the country level to obtain annual country-level series. Reassuringly, using this measure, RAIN_POP, produces the same positive and significant effect on growth as our benchmark measure, as is shown in the fifth column of table 5.

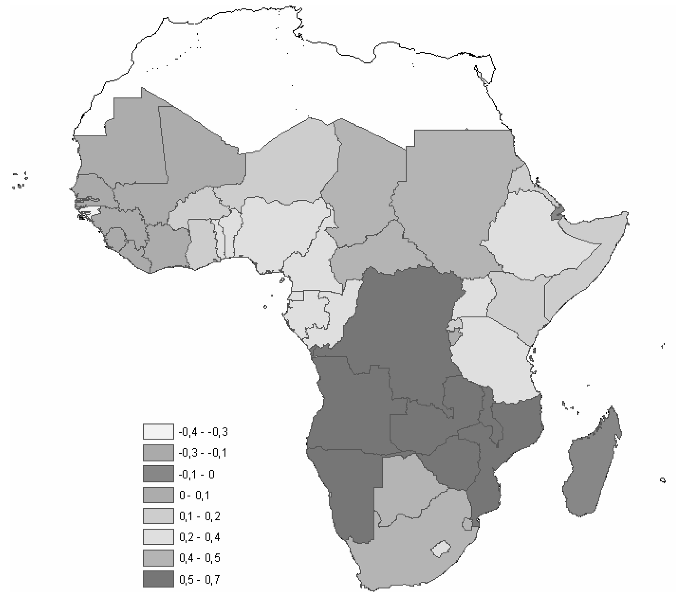
D. *Oceanic Factors*

An extensive literature now demonstrates the link between oceanic factors and precipitation patterns over large distances, commonly known as teleconnections. For instance, the El Niño–Southern oscillation (ENSO) has been shown to have a diapole association with rainfall anomalies in Africa, where eastern African rainfall is in phase, whereas southern African precipitation moves negatively with warm ENSO events (see Nicholson & Kim, 1997). In contrast, for northern Africa, the North Atlantic oscillation appears to be the main factor behind climatic interannual variability, while for the western part of the continent, the Atlantic Ocean as well as the rest of the world oceans appear to play a major role (see IPCC, 2001). It thus may be of interest to determine whether SSA growth itself can ultimately be statistically linked to movements in such oceanic factors.

Map 7.—Correlation between Sea Surface Temperature and Rainfall: First Linear Combination, Sub-Saharan Africa



Map 8.—Correlation between Sea Surface Temperature and Rainfall: Second Linear Combination, Sub-Saharan Africa



The primary approach to modeling the link between oceanic variables and rainfall has been to employ canonical correlation analysis (CCA) on precipitation and sea surface temperature (SST) data sets (see, for example, Barnston & Smith, 1996; Giannini, Kushnir, & Cane, 2000).[30] We similarly follow this approach here to determine whether our annual SSA rainfall anomalies can be related to movements in SSTs. In this regard we first use data on measures of SST anomalies of 2×2 degree cells covering all the world's oceans from the Comprehensive Ocean Atmosphere Data Set (ERSST v.2), aggregate these to 6×6 degree cell measures,[31] and then reduce the series to a much smaller set of summary fields using principal component analysis. More specifically, a Horn's test indicated the existence of seven components from the 290 SST 6×6 degree cells, and we used the complete set of loadings of these components to generate seven summary series. For the country-level rainfall anomalies data, we used the complete set of loadings on the previously isolated four components to similarly create summary series of the data. The reduced set of fields of the predictor (SST) and predictand (rainfall) were then subjected to a CCA, which produced various sets of linear combinations of the two input sets that maximized the correlation between these. The derived linear combinations (modes) of the predictor can then be used to examine how SST anomalies are linked to local rainfall anomalies by calculating the temporal correlation (also known as the skill) of the CCA predictions of original data with the observed country-level rainfall series in the manner proposed by Barnston (1994).

Map 7 provides a graphical depiction of the skills derived from the first (i.e., the one with the greatest explanatory power) set of linear combinations. As can be seen, there is much variation in the manner and the degree to which this first mode can explain rainfall anomalies in SSA. More precisely, some parts of Africa are positively correlated, while others are characterized by negative comovements with SST, whereas many other nations appear to be nearly unrelated to SST movements. Also noteworthy is that, as has been shown in some of the studies previously cited, correlation patterns are not necessarily local phenomena; instead very distant parts of the continent can move similarly in response to SST changes. The depiction of the skills derived from the second mode, shown in map 8, demonstrates how inherently complex the relationship between SST and rainfall anomalies is in SSA, however, where a largely different pattern evolves.[32]

To examine whether the SST anomalies can also be econometrically linked to growth, we used the first two modes of predictors instead of rainfall as explanatory variables in our base econometric specification of the SSA sample, as shown in the last column of table 5. Accordingly, both components are significantly related to growth, although with opposing signs. This provides some evidence that growth patterns in SSA are at least partially linked to movements in SST.

VI. Simulations

Our results clearly indicate that trends in rainfall have had a significant impact only in SSA countries. Given the trends in

[30] For a given two sets of variables, CCA involves finding the linear combinations of these so that the correlation of these combinations is as high as possible.

[31] Barnston and Smith (1996) find in an analysis linking monthly SST anamolies to climatic variables that results from these more aggregated data produced virtually identical results to the 2×2 degree cells.

[32] The first set of linear combination of predictand and predictor variables was found to be correlated at 0.95 while the second set had a correlation of 0.89. Further linear combinations fell drastically in their covariability, and hence we do not report on these.

the growth rates and rainfall outlined in section III, this finding suggests that perhaps rainfall may have played a considerable role in explaining the diverging performance in economic growth of SSA countries relative to the rest of the developing world, as shown in figure 1. A simple manner of investigating this is to calculate the trend that GDP per capita in SSA countries would have followed if rainfall had remained at some previous level using our estimated coefficients.

In considering how rainfall would affect GDP per capita within our conditional convergence framework, one must realize that it will do so directly through the growth rate and by influencing the following period's initial level of GDP per capita and thus the convergence to the steady state. Consequently, given a benchmark level of rainfall, $RAIN^B$, one can construct the hypothetical GDP per capita series at any time T for a country i by:

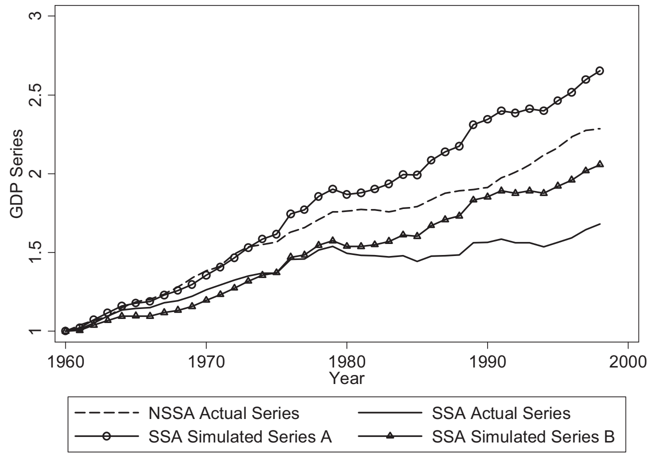
$$\log(Y^H_{i,T}) = \log(Y_{i,1960}) + \sum_{t=1}^{t=T} [GR_{i,t-5\to t} - \beta_2(\log(Y_{i,t-5}) - \log(Y^H_{i,t-5})) - \beta_5(RAIN_{i,t-5\to t} - RAIN^B)] \times Y^H_{i,t-5}, \quad (3)$$

where the superscript H indicates the simulated hypothetical series. In essence equation (3) entails simulating a hypothetical log of GDP per capita series for SSA that has the same initial value in 1960s as the true series but differs in terms of the forcing process for $RAIN$.[33]

We first calculate such a hypothetical GDP per capita series for SSA holding rainfall at its maximum mean annual anomaly over the entire twentieth century,[34] using the coefficient on rainfall from the sixth column and the coefficient on initial GDP per capita from the fourth column of table 3.[35] The resultant hypothetical GDP per capita series, along with the actual SSA and NSSA series, is depicted in figure 8. Accordingly, if rainfall had remained at the high level of the late 1950s, the difference in the mean growth rates between SSA and NSSA nations, which can be gauged from the relative slopes of the series, would have been roughly similar until the late 1970s, from which point onward, SSA countries would have even experienced a temporary slight superiority in economic growth. Using the underlying figures, one finds that if rainfall had remained at its 1955–1960 level, the gap in GDP per capita between SSA and NSSA would have been about 40% less than what was observed in actuality at the end of our sample period. Thus the gap would have been reduced by $1,418 per capita.

Given the high variability of African rainfall over time, perhaps a more realistic scenario to examine is the one

FIGURE 8.—GDP PER CAPITA IN SUB-SAHARAN AFRICAN COUNTRIES: ACTUAL VERSUS HYPOTHETICAL SERIES



under which rainfall would have remained at its previous long-term mean prior to the 1960s (1901–1959). This is shown, also in figure 7, relative to the true trends in SSA and NSSA countries. Accordingly, the divergence in growth rates between SSA and NSSA under this scenario would have actually been slightly greater in the earlier period due to the fact that the peak in the late 1950s was above the previous long-term mean. GDP per capita in SSA nations would thus have followed a roughly similar path to that observed in reality during the late 1970s and early 1980s. After 1985, however, GDP per capita growth rates in SSA nations would have risen to a level parallel to their NSSA counterparts. Overall, under this more moderate benchmark level of rainfall, the gap in GDP per capita between SSA and NSSA would have been about 15.6% less, reducing it by $550, than what was observed in actuality.

Finally, it is important to emphasize that our simple simulations should serve only as a fairly rough demonstration of the potential economic significance that rainfall trends have played in Africa, for several reasons. First, our choice of hypothetical rainfall series is not based on any criteria of what may be considered normal occurrences of precipitation, given that we observe its values only over the period in which our empirical analysis takes place. Second, we are assuming that rainfall has a direct effect only on economic growth and not through other control variables. Finally, our estimated impact compared to some hypothetical situation rests on accurately having measured the rate of convergence. In this regard, the inclusion of control variables other than the ones we have used here may result in differences in the convergence parameter. Moreover, one can easily rewrite equation (1) as a standard dynamic panel specification, so that, as shown by Nickell (1981), our estimate of the convergence rate may be biased. As a matter of fact Bond, Hoeffler, and Temple (2001) argue that the true estimate is likely to lie somewhere between the fixed effects and OLS estimates of it. In our case, this would mean that the absolute value of the coefficient on initial GDP per

[33] We did attempt to control for the importance of the two key sectors, agricultural and hydropower production, in our simulations since our econometric results in this regard used time-invariant measures of these.

[34] This occurred in 1955.

[35] We chose the former so as to allow an estimate from a less restricted error-generating process and the latter to measure convergence relative to all developing countries.

capita that we use for our simulations (the one from the fixed-effects specification) is above the true one, and hence that we are underestimating the impact of a more favorable precipitation situation in reducing the GDP per capita gap between SSA and NSSA. To examine this, we reestimated the pooled sample fixed-effects specification with the Kiviet (1995) correction. As can be seen from the last column in table 3, however, the estimated coefficient is not too different from the estimate that we use, hence suggesting that the bias is in our case likely to be minimal.

VII. Conclusion

Using a new cross-country panel climatic data set, we provide evidence that trends in rainfall have affected economic growth rates in sub-Saharan Africa but that no such relationship is apparent for other developing countries. This means that the general decline in rainfall that has been observed in Africa has had adverse effects on its growth rates and is likely to explain part of the puzzle of Africa's relatively poor performance. In fact, some simple simulations suggest that if rainfall had remained at previous levels, the current gap in GDP per capita relative to other developing countries could have been between 15% and 40% lower.

Our results arguably have important policy implications. In particular, economists and policy analysts studying African economies should pay closer attention to rainfall as an explanatory and conditioning factor of economic growth, not only for annual changes but also in terms of long-term trends. Including an indicator of rainfall anomalies, directly and potentially as an instrumental variable for other aspects (such as policy changes), may very well reverse some widely held views about the causes of low growth in the past and the effects of policy changes in the future.

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APPENDIX A

Selected Full Regression Results of Table 2, Columns 5–7 and of Table 3, Columns 4–6

Method	(1) OLS	(2) OLS	(3) OLS	(4) FE	(5) FE	(6) FE
RAIN	−0.007	−0.007	0.016**	−0.003	−0.003	0.022***
	(0.005)	(0.005)	(0.008)	(0.004)	(0.004)	(0.008)
RAIN × SSA	0.018***			0.014*		
	(0.007)			(0.007)		
SSA	−0.006					
	(0.008)					
log(Y)	−0.014***	−0.016**	−0.037***	−0.056***	−0.065***	−0.054***
	(0.004)	(0.007)	(0.009)	(0.009)	(0.012)	(0.015)
URB	−0.009	0.007		0.005	−0.042	0.092
	(0.019)	(0.026)		(0.053)	(0.068)	(0.091)
POP	−0.030	−0.054	−0.187*	−0.112*	−0.065	−0.250**
	(0.042)	(0.055)	(0.104)	(0.060)	(0.075)	(0.115)
OPEN	−0.000**	−0.000	−0.000	−0.000**	−0.000**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ED	0.004**	0.004**	0.004	0.002	0.002	−0.003
	(0.002)	(0.002)	(0.005)	(0.004)	(0.004)	(0.011)
CIVW	−0.014**	−0.010*	−0.013	−0.014**	−0.012*	−0.027*
	(0.005)	(0.006)	(0.012)	(0.006)	(0.007)	(0.014)
CIVW_S	−0.006	0.005	−0.003	−0.005	0.002	−0.048*
	(0.007)	(0.007)	(0.027)	(0.008)	(0.008)	(0.026)
INV/GDP	0.001***	0.001***	0.001	0.001***	0.002***	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
G/GDP	−0.000**	−0.000	−0.000	−0.001***	−0.001**	−0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
LANDLOCK	−0.009	0.001	−0.034***			
	(0.005)	(0.008)	(0.012)			
ETHNIC	−0.018**	−0.014	−0.014			
	(0.009)	(0.011)	(0.023)			
TROPICAL	0.000	0.003	0.501***			
	(0.007)	(0.007)	(0.171)			
AREA	−0.000	−0.000	−0.000			
	(0.000)	(0.000)	(0.000)			
Constant	0.137***	0.155***	−0.215			
	(0.034)	(0.051)	(0.177)			
Sample	ALL	NSSA	SSA	ALL	NSSA	SSA
No. of observations	393	254	139	393	254	139
F-test	4.63***	5.10***	3.05***	6.56***	6.21***	2.43***
R^2	0.21	0.30	0.39	0.26	0.33	0.28

Note: Standard errors in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels. See appendix B for a definition of the variables.

APPENDIX B

Data Source and Description

Country Samples

For the purposes of this paper, we generally use observations on developing countries, although as a robustness check, we also include developed countries in one of the specifications. We consider a country to be of developing status if it is either a low-, lower-middle-, or upper-middle-income nation according to the World Bank definition, which is based on GNP per capita cut-off points that are constant in real values over time and were first set 1987.[36] These cut-off points were based on the bank's operational lending categories (civil works preferences, IDA eligibility). In order to avoid potential sample selection bias where one excludes countries in our sample that at the beginning of our sample period, 1960, were developing but then became developed or vice versa, we used these cut-off points and data from the World Penn Tables to ensure that countries were classified as developing at the beginning of our sample period or at the earliest date at which data were available.[37] For those for which there was no information in the World Penn Tables, but which we did include in our graphical analysis in the paper, we used the 1987 definition of their status. Our classification of countries included in our analysis is as follows:

Developing: Sub-Saharan Africa: Angola, Burundi, Benin, Burkina, Botswana, Central Africa, Cote d'Ivoire, Cameroon, Congo, Comoros, Cape Verde, Ethiopia, Gabon, Ghana, Guinea, Gambia, Guinea-Bissau, Equatorial Guinea, Kenya, Lesotho, Madagascar, Mali, Mozambique, Mauritania, Mauritius, Malawi, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leon, Sao Tome, Seychelles, Chad, Togo, Tanzania, Uganda, South Africa, Zaire, Zambia, Zimbabwe

Developing: Non–Sub-Saharan Africa: Algeria, Albania, Argentina, Antigua, Bangladesh, Bulgaria, Belize, Bolivia, Brazil, Barbados, Chile, China, Colombia, Costa Rica, Cyprus, Cuba, Dominica, Dominican Republic, Ecuador, Egypt, Fiji, Grenada, Guatemala, Guyana, Honduras, Haiti, Hungary, Indonesia, India, Iran, Israel, Jamaica, Jordan, Cambodia, St. Kitts, Republic of Korea, Lebanon, St. Lucia, Sri Lanka, Morocco, Mexico, Malta, Malaysia, Nicaragua, Nepal, Pakistan, Panama, Peru, Philippines, Papua New Guinea, Poland, Puerto Rico, Portugal, Paraguay, Romania, Singapore, El Salvador, Syria, Thailand, Trinidad, Tunisia, Turkey, Uruguay, St. Vincent, Venezuela, Vietnam, Yemen

Gridded Climatic Data

The variable used to construct the gridded climatology was each available station's mean value of precipitation over the period 1961–1990, where these normals were calculated from a variety of sources.[38] In cases where published sources did not provide information on the chosen normal period, normals outside of this period were substituted. As noted by New et al. (1999), the improvement in accuracy gained by including additional station information outweighs any penalty associated with relaxing temporal fidelity. Moreover, means outside the 1961–1990 were generally assigned a low weighting during the interpolation. We then used a thin-plate spine-fitting technique to interpolate the climate surfaces into the 0.5×0.5 degree high-resolution climatology grid. Note that this technique is robust even in areas with sparse or irregularly spaced data points. Moreover, it maximizes the representation of the spatial variability of the mean climate given the available data.

For deriving the time series for each grid, first each station rainfall series from the beginning of the twentieth century was converted into monthly anomalies calculated as a percentage of its 1961–1990 mean, since the gridded climatology was calculated from the same measure. The individual series were then interpolated to obtain overall values for every grid using the angular distance-weighted method (ADW) on measurements of the eight nearest stations.[39] Since measurements from stations far away from the grid point were unlikely to provide useful information about that grid's climate, they were forced to 0 if they were beyond the correlation decay distance, thus relaxing their value toward the monthly 1961–1990 mean of that station measurement.[40] These series were then converted back into millimeters of precipitation, resulting in time series over the period 1901–1998. Annual measures are simply the sum of the monthly measures of each year.

Other Variables

All other variables used in the analysis are described according to their definition and source in the table below.

[36] http://www.worldbank.org/data/countryclass/countryclass.html.
[37] The only countries covered in the World Penn Tables that changed from developing to developed status were Singapore, Cyprus, and Puerto Rico.

[38] See New et al. (1999) for details.
[39] The ADW essentially "employs a distance weighting function so that stations closest to the grid point of interest carry greater weight" (New, Hulme, & Jones, 2000, p. 2221).
[40] The correlation decay distance is the distance at which zonally averaged interstation correlation is no longer significant at the 95% level.

Variable	Definition	Nature	Source
RAIN	Rainfall anomalies	Time varying (annual), 1901–2000	IPCC
RAIN_FAO	FAO rainfall measure	Time varying (annual), 1901–2000	IPCC
RAIN_POP	Population weight, rainfall anamolies	Time varying (annual), 1901–2000	IPCC; African Populations Database
TEMP	Annual temperature anamolies	Time varying (annual), 1901–2000	IPCC
SST_1, SST_2	CCA generated modes	Time varying (annual), 1901–2000	IPCC; COADS
SSA	1-0 dummy	Time invariant	
SAHEL	Sahel dummy		
NON_SAHEL	Non-Sahel dummy		
Log(GDP/Cap)	Log of initial year GDP per capita (constant value)	Time varying (annual), 1950–2000	World Penn Tables 6.1
OPEN	(Exports + imports)/GDP	Time varying (annual), 1950–2000	World Penn Tables 6.1
POP	Size of population	Time varying (annual), 1950–2000	World Penn Tables 6.1
ED	Average years of schooling	Time varying (quinquennial), 1960–1990	Barro and Lee (1993)
CIVWAR	Number of years of civil wars	Time varying (quinquennial), 1955–1990	Murdoch and Sandler (2002)
CIVWAR_S	Number of years of civil wars in surrounding years (weighted)	Time varying (quinquennial), 1955–1990	Murdoch and Sandler (2002)
INV/GDP	Investment share of real GDP per capita	Time varying (annual), 1950–2000	World Penn Tables 6.1

Variable	Definition	Nature	Source
G/GDP	Government spending share of real GDP per capita	Time varying (annual), 1950–2000	World Penn Tables 6.1
URB	Percentage of population living in urban areas	Time varying (five-year periods), 1960–1990	Davis and Henderson (2003)
HYDRO	Kilowatts per hour	Time varying (annual), 1960–1995	UN Energy Statistics Database
AGP	Aggregate price weighted volume of agricultural production compared with the base period 1999–2001	Time varying (annual)	FAOSTAT
LANDLOCK	1-0 dummy if country is landlocked	Time invariant	World Bank Global Network Development Growth Database
ETHNIC	Index of Ethnic Fractionalization	Time invariant	World Bank Global Network Development Growth Database
TROP	1-0 dummy for tropical climate	Time invariant	World Bank Global Network Development Growth Database
AREA	Land area	Time invariant	World Bank Global Network Development Growth Database
IRR	Percentage of land irrigated	Time invariant	FAO database
6 regional dummies	Dummies indicating whether country is in Asia, Latin America, Middle East, SSA, South Asia, and East Asia	Time invariant	